SPECIALIZATION PROCESS FOR THE BIOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT. ECOMED PROJECT

According to the EFIB (European Federation of Soil Bioengineering) soil bioengineering is a discipline that combines technology biology, and sociology making use of plants and plant communities to help protect and develop land uses and infrastructures, and contribute to landscape development, particular in the domain of slope stability and erosion control.

The promotion and greater adoption of soil bioengineering in the Mediterranean ecoregion is the main aim of the Erasmus + ECOMED project. This aim is being achieved by generating sector-specific theoretical and practical materials and tools essential for the specialization process and enhancement of this sector in the region of interest which is at the core of the ECOMED project strategy and approach. The lack of specialized training, a collection of analysed case studies and shortage of specialized staff in soil bioengineering in most of the Mediterranean countries makes it a necessity to develop training courses and a handbook on soil and fluvial soil bioengineering implementation, along with hazard assessment methods and effective selection of soil bioengineering methods specific to the Mediterranean environment.

Book Topics:

Part I

- Introduction to soil and water bioengineering.
- Soil and water bioengineering and geological engineering.
- Hydrology, Hydraulics and water bioengineering techniques.
- Geographic Information Systems (GIS) for soil and water.
- Environmental Impact Assessment and Planning.
- E-Learning, Data Management and Technical Drawing.

Part II

- Protocols and Case Studies.

ECOMED
Co-funded by the Erasmus+ Programme of the European Union

SPECIALIZATION PROCESS FOR THE BIOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

SPECIALIZATION PROCESS FOR THE BIOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT. ECOMED PROJECT

PART I. TRAINING MODULES

Editors

García Rodríguez, José L.; Sangalli, Paola; Tardío, Guillermo; Mickovski, Slobodan; Fernandes, Joao; Giménez, Martín

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Fernandes, Joao Paulo

Giménez, Martín C.

Authors

Paola Sangalli
Guillermo Tardío
Klaus Peklo
Alexia Stokes
João P. Fernandes
Aldo Freitas
Ana Oliveira
Sílvia Faria
Ettore Marrone
Angela Salustri
Giuseppe Burricco
Vincenzo Astarita
Betül Uygur Erdogan
Mehmet S. Özçelik
Hüseyin Emrullah Çelik
José L.García
Martín C. Giménez
José C. Robredo
Rafael Escribano
Clara Cordón
George N. Zaimes
Valasia Iakovoglou
Slobodan Mickovski
Craig Thomson
Gloria Monterrubio
Caroline Gallagher
Albert Sorolla
Dragan Dimitrievski
Darko Ilievski
Ferhat Gökbulak

SPECIALIZATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT. ECOMED PROJECT. PART I. TRAINING MODULES.

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E.T.S.I. de Montes, Forestal y del Medio Natural. UPM.
Ciudad Universitaria s/n.
28040 Madrid
Phone +34 91 336 64 03
publicaciones.montes@upm.es

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Designed by
Clara Cordón & Martín C. Giménez Suárez

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This book is intended for educational and scientific purposes only

PART I.
TRAINING MODULES

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PROLOGUE

Soil and water bioengineering techniques rely on biological knowledge to build geotechnical and hydraulic structures and to secure unstable slopes and banks. Whole plants or their parts are used as construction materials to secure unstable sites, in combination with other (dead) construction material. Thus, soil bioengineering does not replace traditional hydraulic or geotechnical engineering (e.g. geotextiles, or concrete blocks), but complements and improves other technical engineering methods. Unlike traditional engineering methods and approaches, soil and water bioengineering make allowance for the environmental and ecological approach at the design and construction stages.

According to the EFIB (European Federation of Soil Bioengineering) soil bioengineering is a discipline that combines technology biology, and sociology making use of plants and plant communities to help protect and develop land uses and infrastructures, and contribute to landscape development, particular in the domain of slope stability and erosion control.

The promotion and greater adoption of soil bioengineering in the Mediterranean ecoregion is the main aim of the Erasmus + ECOMED project. This aim is being achieved by generating sector-specific theoretical and practical materials and tools essential for the specialization process and enhancement of this sector in the region of interest which is at the core of the ECOMED project strategy and approach. The lack of specialized training, a collection of analysed case studies and shortage of specialized staff in Mediterranean countries makes it a necessity to develop training courses and a handbook on soil and bioengineering implementation, along with hazard assessment methods and effective selection of methods specific to the Mediterranean environment.

The sector needs analyses made throughout the Ecomed project clearly showed the need for an improved training offer as well as the need for case studies analyses and benchmark on examples.
This situation is well reflected within this handbook structure. Giving answer to the detected needs will effectively support the specialization level of the bioengineering sector within the Mediterranean ecoregion.

In soil and water bioengineering, the use of organic materials is preferred, because parallel to the development of the vegetation and its increasing stabilisation ability, these materials will rot and be reincorporated in the natural biogeochemical cycles. Also preferred are (autochthonous) and site-specific plants, as they promote a biodiversity suited to the landscape. Until the plant communities take over the stabilization role within the intervention area, the inert materials must provide the necessary reinforcement. The stress transfer process between the inert and living material is eventually achieved throughout the bioengineering work service life. In order to successfully attain the preceding objective, the following analysis must be made:

- Analysis of the intervention area from an engineering point of view. For this purpose, traditional

- Botanical analysis of the intervention area. Analysis of the autochthonous vegetation and the

-

-

- Selection of an effective strategy and approach for stabilising and improving the intervention area. At this stage, the selection of appropriate soil and water bioengineering techniques is included. A suitable and justified localisation of the different techniques is also very important.

In order to support the before mentioned tasks, this handbook is structured in different sections. Each one offers useful contents for supporting the project and work decision making process. Hence, the general framework and the processes analysis is shown in the module 1 'Introduction to soil and water bioengineering'. In modules 2 and 3, the necessary training for analysing the study area from both geotechnical and hydraulic points of view is given. In the subsequent modules other important tools are also included such as GIS, technical drawing, environmental assessment and landscape architecture.

The selection of the topics and the structure of this handbook reflect the disciplines necessary for designing a successful soil and water bioengineering intervention.

Given the semi-empirical nature of soil bioengineering, the analysis of existing works and projects, the know transfer and sharing the lessons learned are essential tools for improving the specialization level of the project. This idea is also well represented within this handbook.

In general terms, this handbook could be seen as a good first step in the process of giving answer to the Mediterranean bioengineering sector needs.

MODULE 1.

INTRODUCTION TO SOIL AND WATER BIOENGINEERING

Module 1

ECOMED

SPECIALIZATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

23m high steep cliff rehabilitation in the South of France

10m high steep bank riparian rehabilitation in the South of France

Module 1 Introduction to Soil and Water Bioengineering

SPECIALIZATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

MODULE 1. INTRODUCTION TO SOIL AND WATER BIOENGINEERING

Authors:

Paola Sangalli, Guillermo Tardío, Klaus Peklo, Alexia Stokes, João Paulo Fernandes , Aldo Freitas , Ana Oliveira, Sílvia Faria , Ettore Marrone, Angela Salustri, Giuseppe Burricco, Vincenzo Astarita

Department of Forest and Environmental Engineering and Management Institution.
Universidad Politécnica de Madrid

September, 2018

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Module 1 **Introduction to soil and water bioengineering**

1. MODULE DESCRIPTOR

Status: core

Credit Points (ECTS): 6

Pre-requisite knowledge: None

Module structure:

Activity	**Total Hours**
Lectures	50
Tutorials	20
Seminars	20
Practical	28
Independent learning	30
Assessment	2
Total	150 hours (1ECTS=25 h)

Summary of module content:

This module will present the basic issues related to the instability of slopes and soil erosion.
The main models will be presented and applied both for structural stability (mass movement) as for soil erosion.
The main Soil Bioengineering approaches to these problems will be presented and its efficiency evaluated according to the existing models.

Learning outcomes:

On successful completion of this module students should be able to:

- Identify the main instability processes occurring in slopes and relating them to the slope geology, soil and drainage.
- Handle the main models characterizing both erosion and mass movement processes
- Identifying the critical issues to be controlled and the necessary technical approaches
- Identify the viability of soil bioengineering interventions and assess their typology and limits of applicability
- Identify and conceive the adequate soil bioengineering techniques for each situation
- Evaluate their efficiency using the existing models

Teaching/Learning strategy:

Teaching will follow novel methods derived through the ECOMED project: lectures for imparting fundamentals of module and tutorials and practicals for application of the fundamentals. These will be supplemented with virtual learning content, case study analysis, site visits and work placements.

Other learning and teaching strategies will be developed and implemented, appropriate to student needs, to enable all students to participate fully in the module.

Indicative reading:

Bloemer, S. et al 2015. European Guidelines for Soil and Water bioengineering. EFIB

Bromhead, E. N. (1992) – The Stability of Slopes. 2nd. Ed. Blackie Academic & Professional. Chapman & Hall.

Ortigao, J.A.R. & Sayao, A.S.F.J. (Ed.)(2004) – Handbook of slope Stabilization. Springer. Heidelberg.

Coppin, N.J. y I.G. Richards (Eds.) 1990. Use of Vegetation in Civil Engineering. Construction Industry Research and Information Association (CIRIA). Butterworths, London

Cornelini, P., y G. Sauli. 2005. Manuale di Indririzzo delle scelte progettuali per interventi di Ingegnieria Naturalistica. Ministero dell'Ambiente y della Tutela del Territorio, Roma

EFIB. European Guidelines for Soil and Water bioengineering. 2015. Edited by the European Federation for Soil and Water bioengineering (EFIB).

Fernandes, J.P. e A. Freitas, 2011 - *Introdução à Engenharia Natural* - Colecção Nascentes para a Vida, EPAL, Lisboa

GRAY, D.H.; Leiser, A.T. (1982) *Biotechnical Slope Protection and Erosion Control*. Van Nostrand Reinhold Company, New York

Gray, D. H., Sotir, Robbin B. 1996. Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. Wiley-Interscience, ISBN 10: 0471049786 ISBN 13: 9780471049784.

Menegazzi, G., & Palmeri, F. (2013). Il dimensionamento delle opere di Ingegneria Naturalistica. *Direzione Infrastrutture, Ambiente e Politiche Abitative. Regione Lazio.*

Norris, J.E.; Stokes, A.; Mickovski, S.B.; Cammeraat, E.; van Beek, R.; Nicoll, B.C.; Achim, A. (Eds.) Slope Stability and Erosion Control: Ecotechnological Solutions. 2008, VI, 290 p., Hardcover. Springer.

Peklo, Klaus Dipl.-Ing., 2013 «Planung einer ingenieurbiologischen Ufersicherung mit Unterstützung durch 2D Hochwassersimulation». Mitteilungen der Gesellschaft für Ingenieurbiologie e.V. n°40 Festschrift Pflug, Aachen Germany, en allemand.

Peklo, Klaus Dipl.-Ing., 2015 «L'apport d'un programme de modélisation hydrodynamique bidimensionnelle au travail de l'ingénieur spécialisé dans les techniques de l'ingénierie végétale pour le contrôle de l'érosion fluviale ». Ingenieurbiologie/Génie Biologique n°3/2015, ILF-Institut für Landschaft und Freiraum, Rapperswil Switzerland, en français.

Peklo, Klaus Dipl.-Ing. avec Rey F. et all. 2015« Génie végétal et ingénierie végétale: des compétences et une réglementation aux bénéfices de la nature et de l'homme » Ingenieurbiologie/Génie Biologique n°3/2015, ILF-Institut für Landschaft und Freiraum, Rapperswil Switzerland, en français.

Peklo, Klaus Dipl.-Ing. 2017 «Travaux fluviaux - Études de cas des constructions en techniques de l'ingénierie végétale et mixte de 1993 à 2016 en France ». Compte d'auteur, Parisot France (PPT en français).

Peklo, Klaus Dipl.-Ing. et Fernandes, J.P. Universidade de Evora 2018 «Fachgutachten zum Erdrutsch nach dem Waldbrand 2017 im Mata da Margaraça Naturpark, Arganil Mittelportugal – Standortgutachten zum Konzept einer Naturwaldrehabilitation…" „RELATÓRIO PERICIAL SOBRE OS ALUIMENTOS POSTERIORES AO INCÊNDIO DE 2017 NA MATA DA MARGARAÇA (ÁREA DE PAISAGEM PROTEGIDA DA SERRA DO AÇOR)". Parisot France et Universiade de Evora, Portugal,in german and portuguese.

Sauli, G.; Cornelini, R.; Preti, F., (2006) Manuale di Ingegnieria Naturalística, Sistemazione dei versanti. Regione Lazio, Roma

Schiechtl, H.M. 1980. Bioengineering for land reclamation and conservation. Univ. of Alberta Press. Edmonton/Alberta

Schiechtl, H. M., Stern, R. 1996. Ground Bioengineering Techniques: For Slope Protection and Erosion Control. Wiley-Blackwell, ISBN 10: 0632040610, ISBN 13: 9780632040612.

Studer, R, Zeh, H., De Cesare, G. 2014. Soil bioengineering – construction type manual. vdf Hochschulverlag AG der ETH Zürich, ISBN: 978-3-7281-3642-8

Transferable skills development:

Setting personal targets and time management.

Learning skills will be enhanced by use of open-source information and IT skills to research and collate information for case studies.

Communication skills will be enhanced by requiring the use of appropriate language when writing and speaking to fulfil assignments and when making presentations in seminars.

Group-work skills will be developed to address case study problems including the taking of initiative and assuming responsiblity in carrying out agreed tasks.

Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Class test	10	20	50	Project elaboration
Practical	18	40	50	Field characterization and construction practice
Exam	2	40	50	Unseen exam
Total	30			

Table 1 Assessment methods

Module contacts:

Module leaders: Mr Klaus Peklo, Mrs Paola Sangalli

Module tutor (academic): Dr Alexia Stokes, Dr Joao Paulo Fernandes

Module tutor (industry): Mr. Klaus Peklo, Dr Guillermo Tardio

2. INTRODUCTION TO SOIL AND WATER BIOENGINEERING

2.1 Basic principles of soil and water bioengineering natural based solutions (adapted from the EFIB European Guidelines for Soil and Water Bioengineering)

Soil bioengineering is a discipline that combines technology biology, and sociology making use of plants and plant communities to help protect and develop land uses and infrastructures, and contribute to landscape development, particular in the domain of slope stability and erosion control.

Typically, plants and parts of plants are used as living building materials, in such a way that, through their development in combination with soil and rock, they ensure a significant contribution to the long-term protection against all forms of erosion. In the initial phase, they often have to be combined with non-living building materials (also called 'grey material'), which may, in some cases, ensure more or less temporarily, most of the supporting functions by increasing immediately the necessary soil stability.

The use of organic materials is preferred, because parallel to the development of the vegetation and its increasing stabilisation ability, these materials will rot and be reincorporated in the natural biogeochemical cycles. Also preferred are indigenous (autochthonous) and site-specific plants, as they promote a biodiversity suited to the landscape. The planning and construction objectives are the protection and stabilisation of land uses and infrastructures as well as the development of landscape elements.

2.1.1 Soil and water bioengineering history

…"*The roots of the willows do not allow the escarpments to break and the branches of the willows along the slopes are pruned so that they become more robust every year. And so it becomes a compact living sideboard*"... These simple and effective words that are not of a contemporary scholar, but have more than five centuries, having been written by Leonardo da Vinci (1452-1519), show how the basic concepts of naturalistic engineering are far from being recent, but rooted in historical experience of the agricultural and forestry world, up to the time of the ancient Romans and Celtic communities.

The ancient Romans, pragmatic and with eminently applicative purposes, possessed profound knowledge in the agronomic sector, as evidenced by various works by Cato , Virgilio and Columella, in whose treatises the vast problems of the exploitation of land for agricultural purposes are dealt with in a scientific way. Compared to the foundations of naturalistic engineering, in classical literature, particularly in Columella, Cesare and Cato, there are numerous references both to the living part and to the structural part of the works, which show how the basic principles for the realization of such interventions were known in the Latin World.

In particular, the Romans knew well the reproductive capacities of the willow cuttings (from which they derived the bonds for the cultivation of the vineyard) and in the text of Columella the dimensions of the length for the insertion into the ground are provided. According to that author, the buried part of the cutting should be equal to one and a half feet (about 45 cm): …"*Taleae sesquipedales terrain inmersae paulum obruuntur*"… (the cuttings of a foot and a half in length, are planted in the ground covering them a little; Columella: De Re Rustica fourth book, 30.1-5). In more recent times the army engineers have had the need to use in the works on the battlefield the materials found on site for the construction of trenches, shelters, posts, etc. with use, in addition to dead materials (wood, stone, earth, etc.), also of living plants (shrubs, turf, etc.) for the stabilization of slopes and for the camouflage of works, with functions similar to those of Bioengineering for the landscape insertion of the infrastructures.

It is therefore possible to affirm that soil and water bioengineering techniques, as understood today, come from far away and, in particular, for interventions in watersheds, they find their historical roots as a discipline in the forest plumbing arrangements, with the contribution of plant ecology for the selection of live plants to be included in the works.

2.1.2 Possibilities and limits

The **areas of application of soil bioengineering** in the context of these proposals are the stabilisation of slopes, forelands, dykes, dams, as well as areas surrounding infrastructures like roads, bridges and facilities.

- In slopes and embankments soil bioengineering techniques contributes to the prevention of the different types of erosion, the revegetation and stabilisation of areas affected by landslides as well as to the immediate and long-term protection of slopes against slope failures and landslides trough the anchoring and buttressing effects of plant roots as well as the contribution of plant transpiration to the soil drainage of soil and consequent increase of particle cohesion.
- In the improvement of the local and regional water regime through suitable soil and water bioengineering measures, forestation and restoration of the vegetation cover on slopes inclusively above the timberline.

The use of plants is possible wherever there is a potential habitat for vegetation. **A protective and stabilising vegetation cover to prevent erosion can be used as an alternative or useful addition to conventional engineering methods as long as the plants ensure adequate biotechnical properties.**

Long-term experience in riparian restoration works proves evidence that these properties are well existing up to 15 years after achievement date by low maintenance activities. Thereafter, if there is no maintenance by rejuvenation, these properties are very quickly lost forever.

The development of bioengineering solution involves the combination of the technical expertise of the engineering disciplines, combined with knowledge from the fields of biology and landscape ecology in order to develop a sustainable vegetation cover using site-specific plants able to perform the necessary technical and structural functions. Along with their ability to prevent erosion and contribute to the regulation of the water regime, soil and water bioengineering measures also have a positive effect on microclimate, biotope structure and landscape.

Advantages of soil bioengineering measures compared to conventional engineering methods include:

- Longer and sustained functional development due to the development and regeneration ability of plants and plant communities
- Establishment of an more developed plant community in the frame of the natural vegetation succession
- Increase in stability as the plants develop

- Favourable response to disturbance through the natural ability of plants to adapt
- Adaptation of plants to the forces to which they are subjected through their elasticity, resistance to pull-out and new succession lines
- Structuring function of plants
- Increase in biodiversity and habitat functionality (ecology)
- Enhancement of landscape (landscape aesthetics)
- Support of socio-economic factors (tourism, local recreation)
- Measures that are low-impact, use little energy and promote the self-development of nature (no regret measures)
- Colours and shapes of wooden layers affecting in a positive way the wellbeing of human activities.

The **preferential use of indigenous plant material** preferably from natural origins instead of cultivated and not site-specific plant species has a number of additional positive effects:

- successful and long-term stabilisation due to optimum integration in the local ecosystem, better adaptation to extreme local conditions and local and regional climate and geology,
- greater potential for the development of site-specific plant communities ,
- better and more sustainable integration into the ecosystem and landscape processes,
- better cost-benefit ratio and greater cost-efficiency.

In urban areas with particular demands on safety and in the frame of the landscaping and the design of green areas it is also possible to use non-native species as long as they are suited to local conditions and have the necessary biotechnical properties.

The limits of soil bioengineering are the limits of the abilities of plants and plant communities to fulfil the technical objectives of the intervention in domains such as when:

- mechanical forces exceed the resistance of plants and plant communities,
- plant roots are not deep and strong enough to prevent slope failures,
- environmental conditions for plant germination and development are too poor or extreme to enable adequate growth even with the aid of growth-promoting substances (bad lands),
- maintenance inappropriate to the particular local conditions, leads to an inadequate development of the vegetation and adverse effects on stabilisation and drainage.

When deciding in favour of soil bioengineering solutions, it is necessary to be aware of the **disadvantages of soil and water bioengineering solutions in comparison to conventional engineering methods**:

- The timing of soil bioengineering works is constrained by the rhythm of plant establishment and development as well as disturbance factors affecting the vegetation.
- In many cases, more space and more soil volume is required to allow the adequate development of the vegetation.
- Root and stem development, can affect the integrity of conventional light mass engineering structures when growing in cracks or fissures but not so when heavy mass structures in close proximity.
- Because of their increasing thickness, roots can lead to the deformation of structures.
- Large woody plants when subject to external forces transmit those forces through the root system to the soil reducing its stability and increasing for example the risk of slope failure.
- The development of roots can cause changes in the soil structure affecting its stability and the stability of existing structures. Geotechnical limits may be reached (e.g. effective rooting depth).
- The limited calculation possibilities of bioengineering interventions cause considerable degrees of uncertainty.

These 'apparent' disadvantages can often be compensated by systematic management along space and time. In many cases, it is possible to identify more advanced bioengineering solutions better adapted to the particular local conditions and stress factors.

2.1.3 The functions of plants and plant communities in soil bioengineering

The use of plants in structural and civil engineering is based on knowledge and observations of their properties, which often date back centuries.

Thanks to their different **properties**, plants can respond flexibly to their environment and are therefore employed to perform engineering functions. They can:

- Reproduce and develop in different ways – trough seeds and/or trough vegetative forms,
- regenerate following damage and adverse environmental changes,
- extract water from the soil and release it to the atmosphere (evapotranspiration),
- connect and interlink different materials and structures,
- cover surfaces,
- intercept /retain / moving solid materials, dissolved substances and water,
- tolerate burying or submersion by developing sprouting roots,
- ability to adapt to changes in local conditions like the variation on the speed of the water flow in a natural river bed or a channel.

These properties enable plants to perform complex functions, which can be roughly divided into four categories: technical (1), ecological (2), aesthetic (3) and economic (4).

The result of soil bioengineering interventions are living systems, which develop and maintain their balance by means of natural succession, i.e. by undergoing a process of dynamic self-regulation without artificial energy input. The correct choice of living as well as non-living building materials and types of construction ensures an exceptionally high level of sustainability whilst requiring minimum maintenance. It is important to note, however, that in urban spaces such as towns or cities, which have been subject to major changes, these goals require specialised maintenance.

2.1.3.1 Technical functions

Technical functions of primary importance in terms of the stabilisation properties of plants in the frame of soil bioengineering interventions are:

- Covering of the ground using plant communities as protection against heavy precipitation, soil erosion by water and wind, snow abrasion and rock fall.
- Mechanical anchoring and buttressing of the soil by the roots.
- Cohesion and stabilisation of the soil trough the aggregation of soil particles by plant roots, humus, mycorrhizae and microfauna as well as interlocking or anchoring of topsoil and subsoil and prevention of the washout of fine material through their retention and filtering bi the network of fine roots.
- Roughening of the ground by shoots, twigs and leaves promoting the interception and retention of debris, boulders and snow.
- Slowing down and diverting air and water flow.
- Effects in the area of the root, in particular compression through the increase in root thickness, soil loosening due to movement of the root system induced by the movement of the stem and branches and soil compaction due to the weight of the vegetation.
- Increase in overall soil cohesion through the extraction of water by evapotranspiration
- Positive management of the local and regional water balance trough the retention of precipitation water, retention of soil water and balanced water infiltration.

2.1.3.2 Ecological functions

Soil bioengineering measures can lead to the following improvements in environmental quality:

- Positive effects on soil properties such as increase in pore volume as well as improvement of living conditions for microorganisms and formation of humus and plant nutrients.
- Development of plant communities (succession) and improvement of biotope structures.
- Habitat for fauna.
- Absorption and retention of eventually toxic or eutrophication inducing substances.
- Beneficial change of microclimate.
- Absorption of noise to a low extent.
- Filtering of dust or exhaust gas from the air, and their deposition on parts of plants.

2.1.3.3 Aesthetic and wellbeing functions

Damaged landscapes can be recovered and aesthetically rehabilitated in a natural way using soil and water bioengineering methods.

- Plants and groups of plants diversify the landscape perspectives.
- Replacement of conventional engineering structures with vegetation ones provide that they are able to ensure similar stability and safety levels.
- Fast integration of earth structures into the surrounding vegetation and therefore into the landscape.
- Visual integration of engineering structures through the use of vegetation formations adapted to the landscape nature and structure increasing the quality of our living/human environment.
- Integration and emphasising of constructed structures.
- Screening of conventional engineering structures which would otherwise seem massive.

The application of soil bioengineering therefore helps to reduce any visual disturbance of the landscape, whilst allowing engineering structures to naturally blend into the environment.

2.1.3.4 Economic functions

Based on its knowledge and use of natural elements and processes, soil bioengineering helps to recover disturbed areas with a reduced use of materials and energy.

Soil bioengineering ensures, therefore, a significant contribution to the sustainability of structural and civil engineering interventions:

- By using proven living construction methods based on the ability of plants to install, reproduce and develop vegetatively more cost-efficient solutions than traditional civil engineering ones can be implemented, Additionally the fact that nowadays bioengineering works can largely by performed by machines increase its comparative cost efficiency.
- Through the use of building materials able to regenerate, thereby reducing the amount of material required, even if this results in higher wage costs.
- Through sensible reutilisation of site-specific and site obtained plant material, soil and stones transportation costs and construction material costs can be strongly reduced in may cases.
- Thanks to the special properties of living plants, it is also possible to keep the maintenance costs of bioengineering structures to a minimum.
- In the event of damage of bioengineering structures, renovation costs are often lower due to the ability of the vegetation to self-regenerate.
- Socio-economic factors (e.g. tourism in high mountain regions, local recreation)

2.1.4 Requirements for successful soil and water bioengineering work

Successful soil and water bioengineering work has always relied on the involvement of other disciplines necessary for the achievement of a project and their close interdisciplinary cooperation. Therefore, and this is a mandatory field, the following points must be taken into account during the preliminary studies stage:

- Assessment of required stabilisation work: is it technically feasible to use soil and water bioengineering methods?
- Careful examination of the conditions of the site and natural landscape such as the microclimate of the working area, analysis of the soil conditions taking into account its chemical, physical and hydrological properties,
- Assessment of light and shadow conditions,
- Application of basic knowledge on flora and phytosociology,
- Presentation of the basis for evaluation and review of the hydrological, hydraulic, geomechanical and geotechnical data in view of the project target,
- Evaluation of potential interaction with existing infrastructures,
- Consideration of possibilities for site improvement,
- Determination of target vegetation as well as pioneer plants, further succession phases and maintenance measures with which this can be achieved,
- Consideration of similar reference lines in comparable natural environments,
- Compliance with codes of practice (standards, guidelines, manuals of the relevant disciplines),
- Determination of the conditions of professional maintenance at regular intervals (lifetime maintenance),
- Determination of maintenance and efficiency review.

When performing soil bioengineering work the legal requirements and codes of practice of the respective country must be complied with (e.g. accident prevention regulations). In addition, the respective project promoter requires compliance with its specific regulations. This may lead to different solutions in different countries even if the issues and site conditions are the same.

2.1.5 Basic considerations on the use of site-specific plants and the evaluation of site-specific factors

Sites which need bioengineering soil protection are very often very difficult sites namely because of the difficulties to the establishment of vegetation. The successful design and construction of stabilising measure implies a careful characterisation of the construction site and adjacent region in order to accurately assess its conditions for the establishment of a successful plant community. Following aspects must be taken into consideration during the site assessment process:

- Natural landscape unit
- Location, height above sea level
- Morphology, slope length and angle, slope height , exposition, form of the bank and the water body
- Geology, soil, substrate, soil horizon sequence
- Macro- and microclimate, temperature, precipitation, heavy rainfall events, snow

- Natural flora of the area, potential natural vegetation (PNV), corresponding pioneer vegetation and early phase of succession, neighbouring vegetation of the construction field, competition and support (effect of synergy)
- Information about the fauna relevant for the design
- Land use and its requirements
- Nature and environmental protection conditions

Only on the basis of a sufficiently analysed location is a judgement possible, whether a soil and water bioengineering stabilising measure can be successful, which plants, which methods and which auxiliary material for plantation or stabilisations can be used.

3. INTEGRATION OF SOIL BIOENGINEERING CALCULATIONS INTO THE PLANNING AND DESIGN PROCESSES

The whole process of planning, conducting and development of a bioengineering measure is organised in the following way:

- Definition and characterisation of the causes of the problems
- Preliminary assessment stage with the aim of setting spatial, ecological, social and economic limits to the following design, construction, maintenance stages
- Preliminary design stage
- Design according to existing regulations and conditions of construction permit
- Detailed design and preparation of documents for contracting and call for bids.
- Construction stage and site supervision
- Maintenance stage (regular service life time maintenance works)
- Control of growth- and development during the maintenance period
- Development maintenance up to the intended vegetation
- Maintenance and care of the intended vegetation

3.1 Characterization of the problem and preliminary design

The designer should look into the problem in such a way, that no solution is excluded or pre-defined. He has to find the best suitable solution for the client under the local conditions and other constraints.

This means in case of problems with erosion protection, that a wide range of possibilities should be considered and discussed at the stage of preliminary design. The following example concerns the problem of bank stabilisation:

1. Natural development should be allowed and incompatible land uses close to the bank should be excluded.
2. Steel, masonry or concrete walls, as an adequate solution in technical solution able to preserve existing land uses without further disruption.
3. Water bioengineering stabilising measures like planted river bank slopes and exclusion of some land uses or used areas in the direct vicinity of the watercourse.

If the preliminary design suggests bioengineering stabilising measures, it has to be checked whether it is viable in that concrete location. The intended target vegetation has to have sufficient resistance against foreseeable acting forces.

Design according to existing regulations and conditions of construction permit the project design, able to be submitted to obtain the necessary licensing includes the types of vegetation and biotope to be installed as well as the identification of the main species to be used. The necessary maintenance will also be described and characterised.

The steps necessary to initiate the development of target vegetation community in the frame of the selected bioengineering building technique must be described together with the complementary growth- and development maintenance activities. The resistance of the target vegetation and eventual complementary structures to the foreseeable acting forces must be evaluated and proven suited. The entire soil and water bioengineering technique solution has to ensure the security demands including in the more exposed situation (e.g. during the construction).

In the case of intervention on watercourses, the influence of the vegetation on the hydraulic conditions must be evaluated and characterised along the entire development process. . Damage that might occur from higher water levels or flooding must be assessed and preventive measures taken.

In the frame of the processes of licensing and administrative approval all environmental regulations as well as nature conservation demands must be taken into account with particular attention to the selection of plant species (preferably if not exclusively site specific) as well as the other construction materials. The project must ensure that the final system integrates in the natural environment and natural processes help the development of the water body and improves the recreation value of the landscape.

The design, suitable for approval takes into consideration the available areas and expresses adequately the selected solution.

3.2 Detailed design and preparation for contracting

In this project phase detailed designs, quantity determinations and table of quantities are developed. Cooperation with the different stakeholders is necessary. The detailed design must include technical preparation concerning all details of the bioengineering building method and stabilising measures as well as the planting procedures with particular attention to the areas more susceptible to any type of risk or disturbance. This design phase must include the detailed evaluation of all relevant soil and other site factors.

Quantities and quality of the living building material such as seeds, seedlings and plants have to be precisely defined as well as type, quality and dimension of the other building material such as mats, fascines, pickets and stones. The focus of this project phase must be set on the development of clear reproducible scopes of work. The design have to match accident prevention regulation, regulations by the client and generally accepted codes of practice in order to clear the liability a case of damage, accident of design failure.

3.3 Construction and site supervision

Normally the construction is performed by qualified enterprises selected according to open competition and well defined selection criteria.

The site supervision is performed by qualified consulting engineers. They supervise the construction work in terms of its accordance with the plans as well as generally accepted codes of practise and acts on the behalf of the client. The consulting engineers assist the client in finding solutions for unexpected situation or natural disasters occurred during the construction stage.

3.4 Control of growth- and development

The project must include and clearly describe a period of maintenance which lasts a given number of years according to the specificity of each problem site and technical solution, in which growth- and development maintenance has to be performed. It is commonly done by the construction company.

3.5 Development, preservation and long term maintenance

When the arranged maintenance stage is finished, the whole work will be verified and accepted formally by the bioengineer and by client. The care is now up to the client or he transfers the task to another company. Tree and brush formations have to be maintained for a long time period (several years) up until the target vegetation is perfectly installed. The maintenance work must be performed by a competent professional in order to ensure the success of bioengineering intervention.

3.6 Management of the process of design, construction and maintenance of bioengineering interventions

The process planning and construction of bioengineering interventions must be throughout conducted as an integrated single process and supervised bya single entity. Otherwise it is possible that important information is lost when changing from one phase to another. It is often necessary to clarify at each state of detailed design which aspects of environment and nature protection have to be looked at closely. The focus has to be set on the target vegetation. It must not be subordinated by other aspects such as species conservation, aesthetic aspects or economy of maintenance.

4. RECOMMENDATIONS FOR COMMON AREAS OF APPLICATIONS

The following recommendations are taken from the EFIB (European Federation of Soil Bioengineering) European Guidelines for Soil and Water Bioengineering (EFIB, 2015).

4.1 Erosion of earth slopes

Problem

Erosion on unprotected, free of vegetation slopes can lead to significant damage on new built earth works in the field of road transport infrastructure, hydraulic construction, mining and disposal site construction. Secondary damage can occur at the road transport infrastructure itself or at its drainage structure.

Action

The most common impact on earth slopes is originated by rainstorm, hailstorm, local surface run off, snow, strong wind as well as the impacts of humans and animals.

Resistance

The impact of humans and animals can be reduced by safety measures and use restrictions. Grass and herbs with a high cover ratio have been proven adequate in case of rainstorm and local surface run off. The overall coverage includes buds and other above ground vegetative organs, leaves, dead leaves – as long as they are still attached to the plant, superficial and sub superficial root systems as well as erosion resistant substrates like stones, rock and wood. Bushes and tree formation with a sufficient density complemented by adequate herb vegetation provides good protection against snow and wind action.

Limiting factors

Extreme site conditions are limiting factors: slope gradient, light exposure (solarisation), local climate, type of soil, type of compaction, lack of nutrients and presence of toxic elements or compounds.

Directions for dimensioning and design

The target vegetation is defined according to the evaluation of the location and the existing natural vegetation. The method of erosion control and planting is chosen according to experience gathered in similar situations.

It is recommended to run a comprehensible risk and cost assessment as stated in DIN 18918. A more effective risks assessment must be performed in situations where extreme events such as heavy rain, heavy wind, depth of snow occur (1/ n years). The liability in the case of events with a frequency under the defined value lies with the constructing company and, in case of rare events with the client.

4.2 Shallow landslides at slopes

Problem

Vegetation and soil bioengineering stabilisation measures only have an impact on shallow landslides which are parallel to the slope as well as small slopes of non-cohesive soil with a high gradient. High and heavy trees act disadvantageously on steep slopes, especially on cohesive soil. The problem of sliding is handled by soil bioengineering in the same way as is the field of soil mechanics, with the model of solid state bodies. Loads and resistance act on the solid state body.

Action

A slope failure is originated by factors such as the weight of the moist soil (including loads such as vegetation, snow), hydrostatic pressure, groundwater flow and ascending force.

4.2.1 Resistance given by vegetation

A shear stress τ_f (kN/m²) exists between the sliding layer of soil and the underground. The shear stress can be estimated from data referred to similar soil layers. It is the combination of parameters like friction and cohesion, both known from soil mechanics as well as from biological influences from roots, mycorrhiza, and natural alginates and other gluing gels. These influences are often described as biological cohesion. The biological shear parameters vary strongly with the depth, compaction and soil moisture, which makes it hard to predict.

Limiting factors

Following factors limit or eliminate the impact of roots in case of slope stabilization measure:

- Highly compacted silt or clay and rock
- Influence of groundwater or water layers at root depth
- Toxic substrates and
- Wide number of other site factors, which prevent vital growth of plants

4.2.2 Advises for dimensioning and design of a non-slipping base layer of vegetation on earth slopes

Conditions to build a stable non slipping vegetated layer on earth slopes are:

- The underground is stable.
- The underground is more permeable for water than the top soil.
- There is no hydrostatic pressure on the top soil due to ground- or seepage water.
- rooting is possible in the underground in terms of factors like void volume, soil substances, pH, etc.
- The top soil (vegetated layer) is either thin or poor, so the plants will develop roots in the under layers in a foreseeable future.

These are conditions under which the evaluation of slope failure can be performed trough analysis at a reference site or compared with a block model. The action of the vegetation can be determined as corresponding to the shear resistance necessary to stabilise both layers as provided by the specific area of root crossing the discontinuity between the layers.

4.2.3 Very steep slopes of non-cohesive soil

Several experiments showed that it is possible to consolidate slopes of low or medium high with angles just underneath the angle of inner friction of the soil by using deep rooted plants combined, during the plant development period with complementary bioengineering stabilisation methods such as bush layers..

Lower slopes can be stabilised to a maximum angle of 45° if they are secured by deep rooting vegetation systems and the surface is covered completely with grass and herb vegetation. Complementary stabilising structures made of wood are used during growth- and development period like, for example, a log cribwall which can also resist small active earth pressures. The dimensioning of such a cribwall is similar to those of a gravity wall, it is also partly based on the method reinforced earth.

4.3 Gully erosion at slopes and hillsides

Problem

As a result of the concentration of runoff on long and steep slopes along prevalent lines, the creation of erosion gullies can occur. Further sources of gully erosion are: sealed ground, forest clearance in the catchment area and a higher concentration of runoff because of road building and other morphological interventions.

The process of erosion works his way up against the direction of the flow. Mudslides, resulting from slope failures have an unpredictable increasing effect.

Action

Design drainage and rainfall-discharge systems for a peak flow Q (m^3/s) defined accordingly to an adequate and predefined frequency of repetition (1/n years) and the calculation must include the definition of average flow velocity v (m/s) and shear stress of the river bed τ_0 (N/m^2).

Resistance

Low and dense formations of bush, herbaceous or grass vegetation should be planted in the gully slopes and flow bed. The vegetation must be able to resist overflow, erosion and silting. The critical shear resistance τ_{crit} determining thebeginning of the erosion process has already been mentioned before.

Limits of application

High flow velocity and shear stress together with the load of carried sediments limit the applicability of bioengineering methods. Furthermore the exposure to light and the usual site factors as well as damages caused by livestock and game are also limiting factors.

Directions for dimensioning and design

The impact of sealed grounds within the catchment should be compensated by rainwater retention measures. Head waters of neighboring creeks can be analyzed as objects of reference. Results from reference sites should be compared with results from hydro technical, theoretical design parameters. In this way a sounder characterization can be achieved.

Structures whose conception took into consideration comparable near to natural reference watercourses and its corresponding vegetation as well as natural stone and wood are well integrated in the surrounding environment.. Weirs and steps of weirs do not exist in nature. They disturb the natural landscape, constrain and interrupt biotopes and are incompatible with the aims of the European Water Framework Directive. Therefore, near to natural stabilization measures should be applied whenever possible. Nevertheless in some regions weirs are the only way to restore gully erosion and wild creeks, e.g. in densely populated high mountains.

4.4 Riverbanks and adjacent areas

Problem

Wash-outs, potholes and other forms of erosion occur due to the natural dynamic of the on riverbanks and adjacent areas including floodplains. These processes are welcomed on one hand, because they lead to a natural structure and dynamical of the water body. However when infrastructures, other constructions or sensitive land uses are located near the water course it is necessary to ensure their safety and protection against damages. In both cases in more or less intensively used landscapes, and particularly in the vicinity or within human settlements the discharge capacity as well as maximal water level by flood and average water flow must be controlled in order to ensure the safety of buildings, infrastructures and other land uses.

Action

Flow forces, quantified as flow velocity v (m/s) and shear stress τ (N/m^2) as well as impelling forces from drift wood and drift ice must be taken into consideration in bioengineering stream bank stabilization measures.

Additional impacts from human and animals are also possible and must be controlled by special measures or constructive interventions. In the aftermath of a flood event when the water levels decrease rapidly the difference between the ground water level and a river water level determine hydrostatic pressure on the river banks that determine additional risks of slope failure.

Resistance

The different vegetation structures offer different resistances to the flow of water. Low grass provides a very effective protection against erosion and creates little resistance to water flow. Reeds have a similar effect because they bend over in case of over flow. Wood structures (bushes or trees) decelerate the average water flow as well as the flow near the river bed and margins.

According to their hydraulic effective density, most willow species build a dense root system that protects the surface of the soil of the riverbanks. Therefore riverbanks and floodplains can be protected against erosion within the limits of the critical flow velocity vcrit and shear stress critical values.

Limits of application

Along with the natural site limitations and the highest acceptable flow velocity and shear stress other limiting factors must be taken into consideration Every plant species as a given limit of application according to their capacity of resistance to overflow, flow velocity, flooding, shear strength in terms of intensity duration and frequency of occurrence. Other factors set also limits such as the ones associated with ice drift or nature of carried materials. It is recommended to investigate the limits of appliance in comparable reference sites.

The overall stability of a bank slope has to be determined for the extreme situation of a high groundwater level and a low water level determining a maximum of the hydrostatic pressure acting on the bank. Due to their influence on the reduction of the flow velocity and consequently of the flow volume, wooden formation must be used with the utmost care in urban areas in order to avoid problems in narrow channels.

Directions for dimensioning and design

Design and construction of near to natural stabilization measures have to be done according to the European Water Framework Directive. This includes: no degradation of the present situation and a development towards good ecological balance. Bioengineering presents a particular positive contribution in this domain because its interventions favor the natural structure and processes of the water body, the use of natural building material from the area and site-specific plant species in suitable variations according to the nature of the problems and the intervention goals. Information about vegetation structures and limits of appliance can be taken from reference sites. When intervening in watercourses one has always to consider the hypothesis of restoring the natural structure and dynamics of the water body and the entire river structure, by removing the disturbing or conflicting land uses. Such an alternative will lead to a near to natural development of the water body.

Stabilization measures on the base of the river bank as well as on very steep banks must be complemented with natural rocks, wood structures or trunks and branches obtained on location. In this way, a diverse structure will be created along the river, the cross section and the longitudinal profile. It should be paid particular attention to connectivity and complementarity between biotopes and to avoid monotone cross sections.

Near to natural stabilization measures and the restoration of a sustainable functional riparian vegetation determines normally a reduction of the hydraulic efficiency of the watercourse. Therefore, an extensive hydraulic analysis must be performed in all hydraulic engineering projects in order to determine the way in which the water levels, flow velocity and other dynamic processes associated with the watercourse will affect the surrounding land uses and existing infrastructures. The stability of the bank slope in all hydrodynamic and hydrostatic conditions must also be taken in consideration and evaluated in all detail.

This process of planning and design of water courses involve important and complex processes of coordination between technical authorities, residents, politicians and environment protection groups. All involved parties must cooperate in order to develop a concept and a project that fulfill every condition for approval and respond to the needs of the different stakeholders.

4.5 Banks at standing waters

Problem

Along the banks of standing waters occur different types of erosion similar to the ones originating cliffs on the seashore. These natural phenomena can be increase due to the action of land uses.

Action

Natural waves and waves originated by ships, together with driftwood, drift waste and drift ice are the main problems faced by bioengineering interventions on standing waters. Appealing shores and banks are often damaged by trespassing, boats and other recreation activities. Animals can also have a negative impact on shore stability.

Resistance

The soil can be protected by a dense grass cover. Wide zones of reeds reduce the effect of waves and protect the soil through rooting. Flood tolerating bush and tree formations with well developed stems and branches have also a similar effect.

Limits of application

Along with the general site constraints there are, for each plant species a given limit of application. It is determined by height, frequency and duration of flooding. The frequency of wave impact is also of importance determining that regular waves originated by ship traffic can destroy a reed formation that otherwise would resist similar waves originated during a storm event.

Directions for dimensioning and design

Agricultural, touristic and landscape planning work must be taken into particular consideration in the process of design bioengineering stabilisation measures for banks and shores of standing waters. Conflicting land uses must be kept away from the bank. It is generally useful to offer appealing recreation facilities at nearby adequate locations. Carrying capacity and limits of application of the vegetation must be determined by analyzing comparable natural sites. To ensure a successful establishment of the initial vegetation long term protection measures are necessary against trespassing, driftwood, grazing livestock and water birds.

4.6 Dykes and dams

Problem

Dykes protect from flooding land uses, building and infrastructures in the hinterland when high water levels occur in river and forelands. Dams are built to conserve a permanent high water level in a channel of flowing or standing water. The problem of erosion is the same as those of earth slopes and embankments. At water side of the dam the same problems occur as on banks of flowing or standing waters. Due to high damage potential of associated to dyke or dam failure, caused for example by floods, heavy storms, rain etc., measures of controlling, restoration and reinforcement have to be ensured at any time. It is especially important to react fast and at an early stage when it comes to an outlet of seepage water and erosion ground break.

Action

The main actions are caused by self weight, wind, rainstorm and surface run off. Additional actions occur on the waterside due to water flow, shear stress, crush of driftwood and waves. The differences in water levels may lead to slope sliding after a flood on the water side of the dyke. After flood events, because of hydrostatic pressure or overflow of the dyke crone, slope failure, hydraulic ground break and erosion ground break can occur on the landside. Grazing livestock (except sheep), as well as riders and cars can damage the vegetation. Further damage is often caused by digging animals.

Resistance

It is common to use a dense grass cover in places where shear stress and flow velocity will cause no damage on the vegetation. It is furthermore a protection for wave effects and wind erosion. There is, nevertheless the possibility it can be damaged by drift ice and driftwood. The damage risk can be reduced by reinforcing the top soil (combination of stones and grassed top soil) or by creating a zone of willow shrubs on the forelands of erosion-prone banks.

On the landside species of grass and herbs are used to protect the slope against wind and rainstorm. This vegetation cover allows a better detection off seepage water. The use of a diversified choice of autochthon species of grass and herbs eventually combined with the application of threshed hay ensures the development of a dense, diversified and very effective root system ensuring, therefore a high level of protection against erosion.

Limits of application

Limits of application are associated, in the water side with the level and duration of flood submersion. Another limiting factor is the is the height of the individual plants and their carrying capacity against overflow, the action of waves and the effect of driftwood and drift ice on the waterside.

Directions for dimensioning and design

Dykes and damns are primarily technical constructions. In most cases bioengineering stabilisation measures with grass is the cheapest way to protect dykes against erosion.

If the limit of application is surpassed, a combination with stones is necessary. The possibilities of maintenance, defence and reinforcement have to be taken into account during the process of planning. Different wet zones of the slope and different frequencies and duration of flooding have to be considered when choosing the plants to be applied.

4.7 Coastal protection

Problem

There are several ways bioengineering measures can be used to stabilise and shaping the coast. They include measures of protection and development of dunes as well as dyke stabilisation. This is done by building and maintaining forelands on tidelands. Bioengineering methods in tidelands such as “biogenic land reclamation” were common in the past and are rarely applied today.

Action

Wind and water in combination.

Bioengineering measures are most commonly used in retrogressive areas along beaches. These are areas where the erosion force is stronger and beach and white dunes are eroded. The action of wind can cause the breach of interior dunes eventually causing the destruction of the entire dune. In progressive areas along the coast, meaning areas where beeches, sandy tidelands and dunes are growing due to a positive sand supply, plant growth and fore dunes can also be supported by bioengineering measures.

In the forelands the main problem are the ways of reducing the energy of the water, which, in the absence of stable forelands acts on the dyke during storm flood events endangering their safety. A heightened foreland will reduce and disperse the energy of the water diminishing therefore the disruptive forces acting on the bottom of the dyke.

Resistance

Morphodynamic of dune development and the corresponding biology of the site adapted species are the best indicators on the possibilities of their application in coastal protection. In retrogressive areas the resistance against the action of the wind and the associated sand deposition can be effectively ensured by vegetation with a high roughness coefficient, such as it is created by brushwood combs or planted culms grass species. The rooting system from dune grass and bushes stabilises the dunes.

In forelands Bioengineering measures are of particular significance in the prevention and control of wave impact through its influence on the period and height of a storm surge wave, reduce therefore the energy of the wave.

Rough texture of the foreland increases bed friction and reduces velocity of the water flow. The site specific plant species and communities stabilise the soil structure and reduce erosion trough decreased flow energy. The root system is of importance because. it bonds with soil particles and consists of flexible and inflexible elements creating a very effective stabilising structure. The soil particles are highly stable against external forces and the root structure supports drag and shear forces created by the flow. This stabilisation capacity depends from the vegetation density, horizontal as well as vertical. The rate of sedimentation depends from the intensity of flooding, which is determined by the average water height of the tide. The transmission of energy depends on height, flexibility and mechanical resistivity of the plants. The reduction of flow velocity increases with increasing height of the plant and leads to an improved soil protection.

Limits of application

Abrasion forces are higher than grass, bushes, culms and plants can support.

Directions for dimensioning and design

The principle of sand retention trough the roughness of the vegetation and of sand and silt stabilization of trough the structuring and stabilizing action of roots applies along every coastal area. Suitable plant species are those with a stem and root system able to regenerate after being covered by sand. These species, such as strand grasses and coast bushes, can stabilize blown and drifted material.

4.8 Planting for wind and erosion protection

Problem

Hedges of trees and bushes are very effective protection systems against damages to land uses and infrastructures caused by wind and associated effects of desiccation, sand-, silt- and snow drifting. Hedges and woods can also be used at excavation-, deposition-, mining- and other industrial areas to reduce dust emission or dispersion. The use of a dense grass cover is also very effective in the prevention of dust dispersion by wind of landfills and other waste disposal sites.

Action

Wind as the main acting factor must be extensively characterised in terms of its strength, duration, frequency and direction.

Resistance

Critical values for the wind transport of materials according to their grain size, weight and moisture must be identified.

Species of grass, herbs and shrubs of dry and semi dry sites have proven of value when it comes to wide area erosion protection on surfaces endangered by wind erosion. Hedges made out of trees and bushes can affect the wind flow up to a distance of 10 fold the height of the hedge. The hedges should be designed permeable in order to reduce turbulences on the lee side of the fence. Hedges for protection against emission must be made by several multi layered plant rows.

Limits of application

Zones of excessive moisture and drought must be taken when choosing species of trees to be applied. In the case of Hedges to protect from emission at mining or industrial areas, species should be used which are tolerant to the specific emissions in addition to the other site conditions and constraints.

Directions for dimensioning and design

The aerodynamic impact can be prognosticated based on specific literature such as KOVALEV 2003. The development of a hedge height requires yearlong or even decade long planning, planting and maintenance. It is especially important to pay attention to irrigation and the protection from competing vegetation as well as from grazing by cattle or game.

Revegetation and recultivation on mining and industrial areas often requires investigation of soil concerning environmental impact. When dealing with brown fields and contaminated soil particular attention must be paid to maximal acceptable concentrations of pollutants in the soil and all dispersion and exposure pathways. A decision, whether a direct plantation is acceptable or if a cover layer of top soil or even a surface sealing is necessary must made based on expert evaluation and existing regulations and guidelines. Planning and design of the vegetation cover should only start after a clear decision concerning the measures of environmental impact control and minimisation.

4.9 Water regime regulation

Problem

Intensive rainfall events may cause, particularly in areas with no or only little vegetation in gullies and other drainage channels, strong surface run off with a short time of concentration and causing intense erosion. This leads to sediment and mud loads with a negative impact on water quality. The accelerated run off reduces groundwater enrichment. A suitable coverage with vegetation such as wood, bushes and hedges can be used to regulate the water regime particular in extreme or very disturb sites like gullies, steep slopes or other erosion prone areas. The impact of these bioengineering measures can be especially important in catchments which sit above an area of flood risk as well as a catchment belonging to hydro damn and other constructions of water supply.

Action

The main acting factors are precipitation, described in terms of intensity, duration and frequency as well as drought, described as the duration of a period without precipitation.

Resistance

Slopes and other areas should be covered by vegetation that potentiate percolation and decelerate surface run off.

That is why a dense vegetation cover is needed as associated with complementary measures to increase the roughness of the surface. Slopes and gullies should be structured in a way that reduces flow velocity, increases the time of concentration, reduces the peak flow and improves infiltration. An improved infiltration can be achieved by enhance permeability and extending the surface retention. Bioengineering measures such as the plantation of a dense bush cover determining a clear increase of the surface roughness together with measures increasing the hydraulic roughness of channels (rock channels, planted gullies, torrents and creeks) are very effective in terms of these general goals. .

Limiting factors

Limiting factors are extreme conditions of the site such as slope gradient, exposure to light, site climate, type of soil, compaction, lack of nutrients and presence of toxic substances. Further limits in gullies and creeks are high flow velocity, shear stress and the impact of bed load.

Infiltration might potentiate the risk of slope failure at endangered slopes. These different risks must be evaluated by geotechnical engineers.

Directions for dimensioning and design

The impact of infiltration and the velocity of surface run off can be predicted based on specific literature such as MARKART et al. 2004. The development of the target vegetation density and structure requires consistent planning, planting and caring over a period of years and decades to achieve and maintain the intended effects.

The regulation of infiltration and surface run off requires vegetation maintenance. The choice of the target vegetation must be based on the natural vegetation of the site to gain ecological stability and ensure an higher resistance to environmental stress and diseases and reducing therefore the maintenance demands and costs.

4.10 Areas destroyed by fire

Problem

Forest fire and other wild fire destroy vegetation as well as part or the totality of the litter and humus layers. The resulting effects are a higher risk of erosion and increased runoff which has to be immediately controlled by adequate measures. This is necessary in order to reduce the loss of soil and nutrients and facilitate a faster and easier revegetation. The importance of preventing nutrient leaching derives from the need to prevent eutrophication and the contamination of drink water reserves.

Action

The main actions are associated with the mass of dead plant material or the stock of flammable materials in combination with climatic impacts such as drought, heat and wind (intensity, duration, frequency and direction).

Resistance

Wild fires are linked to dry weather conditions and dry locations. Large, monotone woods and forests favor the spread of the fire. Wide bands free of flammable materials (e.g. grass cover instead of bushes or trees) retard the progression of fire. These open space zones can also promote biodiversity and can be used for grazing.

The natural development of vegetation after a fire due is normally very limited due to intensity of disturbance of the ecological conditions, the lack of water and nutrients. .

The first measures have to be aimed at preventing soil erosion. This can be done with temporary structures made out of available material. It is sensible to use charred trunks of trees on creeks, gullies and steep slopes to create pile walls able to retain soil. Cribwalls and other type of catch dams can also be used in gullies and creeks. It is also important to sow grass and herbs in order to create a dense grass and herbaceous cover of the soil in a short time. The seed mix should consist of a variety of species which are suitable for the extreme site conditions as well as fast growing species and species which belong to a later level of succession.

Limits of appliance

Methods of revegetating depend on the level of soil destruction. Rapid planting is essential to prevent the erosion fine and organic soil material.

Directions for dimensioning and design

The impact of linear erosion protection measures can be evaluated using erosion models. Vegetation of the retarding fire bands must site-specific and f correspond to the natural vegetation. The target vegetation should evolve in such a way that the risk of fire is reduced and that the vegetation is able to recover in a short period of time. Maintenance should include removal of biomass; grazing is a particularly good solution.

4.11 Bioengineering avalanche protection

Problem

Avalanches are natural hazards, which endanger human life and infrastructure in alpine and other high mountain regions. The breaking of avalanches can be avoided by a suitable and well maintained protection forest. This effect is achieved by the retaining action of stable and strong tree trunks that are able to retain the snow pressure that builds a force parallel to the slope. The forest acts also positively by promoting a more even distribution of the snow and its associated mechanic tensions. Vegetation can hardly stop an avalanche once it is broken off. The maintenance of a protection forest should therefore prevent this case from happening.

Action

Mechanical actions before the break off of an avalanche are created by the longitudinal component of snow weight parallel to the slope. The layer of snow holds different specific weights depending on the ratio of compaction; 1 KN/m^3 in a loose state and compressed as ice 10 KN/m^3.

The layer of snow can present a thickness of several meters by the end of the winter.

A permanent pressure due to the slow movement (no break off) of the snow layer acts on vegetation. The so called snow creep / glide downwards leads to snow pressure in areas of 1-3.5 kN/m^2. The forces are strong enough to unroot small trees. When an avalanche breaks of it generates forces capable of breaking trees only after a fall of 50m. After 150m trees are generally broken or unrooted. The forces acting on the trees depend on type of avalanches: 3-5 kN/m2 in case of powder avalanches and 10 - 50 kN/m^2 in case of flow avalanches.

4.11.1 Effect of vegetation in reducing avalanche impacts

The effect of vegetation in reducing avalanche impacts is determined by the different characteristics of the forest, and do not exist in areas without adequate forest cover.

The most important affects are:

Snow interception

A part of the falling snow will be captured at the tree crown. A small part of it will evaporate. This leads to a thinner layer of snow which is more structured in the woods, than in open space. Wintergreen species have a higher ratio of interception than species without leafs in winter.

Radiation balance

Microclimate is more balanced in a dense wintergreen forest. Rise of temperature at day and fall at night is minor compared to open space. This leads to a reduced risk of formation of a a weaker layer within the accumulated snow layers.

Wind

The impact of wind and aeolian transport of snow is less of a problem in compact tree formations.The mass of snow deposited on dense forested areas is higher than in clearings or areas without trees.

Resistance of vegetation against avalanches

The protection function of forest vegetation is to stop the avalanche from breaking off. If an avalanche brakes off, no forest will be able to stop this mass of snow. In order to prevent avalanches from breaking off it is important that forest vegetation is is high enough (roughness of surface) to pierce through the layer of snow. No protection function exists if the layer of snow surmounts the roughness of surface (SAEKI u. MATSUOKA 1969).

It is necessary to take particularly into consideration that small plant species, when completely covered by snow bend to the soil and facilitate the flow of snow by reducing friction and promoting the break down or the flow of avalanches. Small trees ensure, therefore only a given protection when they are not completely covered by snow and can even promote the occurrence of avalanches in mountain areas where the snow can accumulate to several meter thickness. Only continuous homogeneous forests can protect from this danger. Forest is an effective and economic protection against avalanches. The trunks of trees support and stabilise the layers of snow.

Nevertheless this protection action cannot be overrated.

Only a dense forest gives protection because it depends on the direct interaction between the snow layers and the individual trunk.

Limiting factors

The natural timberline, determined by altitude and climate, defines the limits of bioengineering appliance in the field of avalanche prevention. Local differences can occur according to the period of snow coverage, exposure to wind, cold temperature, soil types and level of humus.

If particular attention is given to microclimatic and local topography is given there is the possibility that forest formations can occur or be installed above the average timberline. Young trees often die of fungal/ mould infection due to long coverage with snow. For example Herpotrichia juniper appears in areas stretching from the foothills of the Alps to the high mountains and affects the needles of spruces, pines, fir trees and juniper. The distribution area is from 900 up to 2000 meter above sea level. This fungus causes especially in the snow-prone area of foothills of the Alps a strong damage in regeneration forest formations. It affects trees in nature regenerations as well as in alpine reforestations and can also infect and destroy well developed and established trees.

Damage caused by game animals is a further threat to young trees. One must, nevertheless take into consideration that young trees are more flexible than older ones. therefore only trees with a diameter larger than 10 cm will crack due to the pressure of snow Causing the failure of reforestation projects of reforestation after 30 to 50 years due to lack of adequate maintenance.

Directions for dimensioning and design

The required forest profile depends strongly from the defined protection targets and the damage probability and intensity. For example, small glides of snow, which endanger people on ski slopes, can, if any, only be prevented by a very large ratio of wintergreen tree formation (crown ratio > 50%). The prevention of large avalanches in less susceptible areas is tendentialy less demanding. Less dense tree formation as often occur around the timberline must, nevertheless be carefully evaluated. The crown ratio and eventual clearings in the tree formations in combination with the slope gradient are important criteria to take into consideration when evaluating protection functions (FREHNER 2005). Target value are 500 trunks per hectare for slopes with a gradient of ~35° and 1000 trunks per hectare for steeper slopes in order to prevent avalanches from breaking off. This trunk density is often not achieved in many subalpine areas. It is therefore important that clearances are no bigger than 15 to 25 m and a crown ratio of of 30 to 50 % is ensured. The break off of avalanches is unlikely at a crown ratio of 50%, a slope gradient of 35° and with clearances not larger then15m. The forest should consist of different age groups and species. Overthrown trees are an additional protection and if possible should not be removed.

Complementary the particular silvicultural management of avalanche prone areas additional structures can be indispensible to prevent the break out of avalanches..

Examples of such complementary structures are, snow barriers, pilings, terraces and stone and soil piles.

5. SOIL AND WATER BIOENGINEERING TECHNIQUES CLASSIFICATION

In this epigraph the traditional classification of soil and water bioengineering techniques is presented.

Some examples of soil and water bioengineering techniques are given. A detailed description and a more comprehensive list of the soil and water bioengineering techniques are presented in modules 2 and 3.

5.1 Soil protection techniques

5.1.1 Sowing

Description

Manual spreading of seed mixtures:

a) with commercial mixtures of certified origin (species origin, blend composition, degree of purity, degree of germination);

b) with flowers harvested directly in the field from stations of conditions similar to those in which it must operate.

The covering is immediate, with an anti-erosion surface effect determined by the radical reticule deepened in the ground (10 - 30 cm).

5.1.2 Hydroseeding

The spreading is made by a hydroseeding machine, equipped with barrel, of a mixture composed mainly of seeds, adhesives, fertilizers and water. The various components of the mixture are mixed in the mechanical ways, which is then sprayed onto the surfaces to be grassed by means of pumps and nozzles with adequate pressure, which does not damage the seeds. The presence of adhesives guarantees the protection of seeds during the first phase of germination.

The anti-erosion effect is immediate thanks to the presence of the film due to the adhesive and then the radical reticule deepened in the ground (10 - 30 cm). In a short time an environment suitable for the microfauna is developed.

5.1.3 Biomats

Description

Vegetable fiber mats (straw, coconut, mixed) or woven in jute or coconut yarn (of remarkable resistance), used in the anti-erosion treatments of slopes that are poor in organic matter and subject to meteoric erosion. The meshes of the biodegradable mat allow the plants to grow, thus ensuring the protection of the surface once the mat has undergone complete degradation.

The mat durability is variable, the coconut fiber in particular lasts up to 5 - 6 years, but the final degradation is complete.

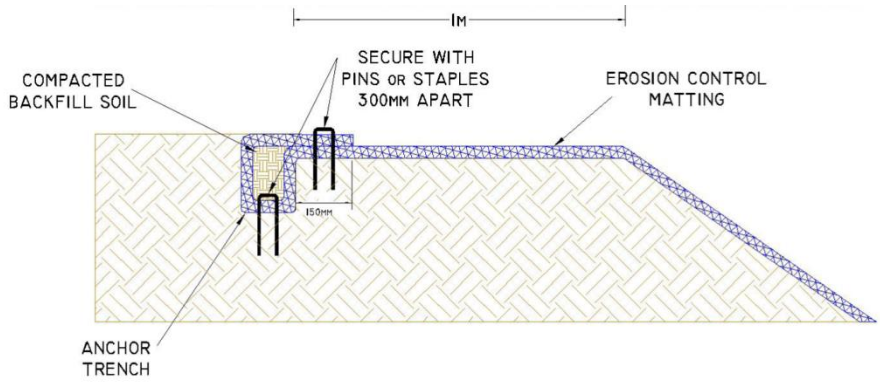


Figure 1Detail of erosion control matting. Source: ECTC, 2008.

5.2 Ground stabilising techniques

5.2.1 Live stakes

Live stakes consist of driven woody cuttings and / or branches of plant species with capacity of vegetative propagation in the soil or in the fissures between boulders, insertion in live palisades, gabions and reinforced earths. The use of willows is classic, as well as other species such as privet and tamarisks (the latter resistant to alternate conditions of strong aridity and the presence of salts in the soil). The stability of the slope and the superficial consolidation of the ground are limited to the development of an adequate root system.

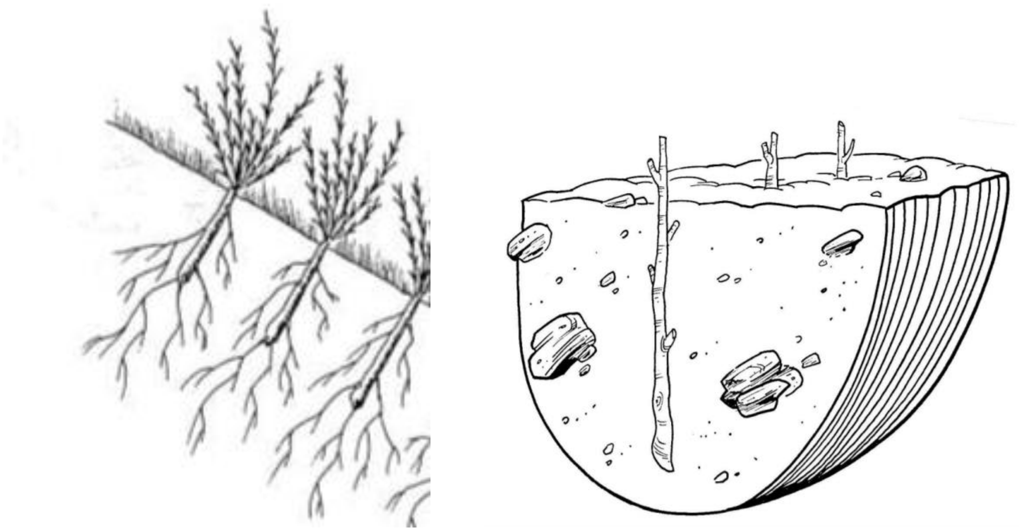


Figure 2 Source: Polster, 2001

5.2.2 Shrubs plantation

This technique consists in planting of young indigenous shrubs in clods in pots or phytocells (of nursery production) in specially prepared holes of appropriate size to accommodate the entire root or the entire root volume of the plant. The stabilization of the soil is limited to the development of an adequate root system and therefore this condition must initially be guaranteed by other material.

5.2.3 Wattle fence

Wattle fences are short retaining walls built of living cuttings. Wattle fences are used on sites where oversteepened slopes are preventing growth of vegetation. This technique can also be used to protect the toe of fluvial slopes from the river drag forces (protection from undercutting processes).

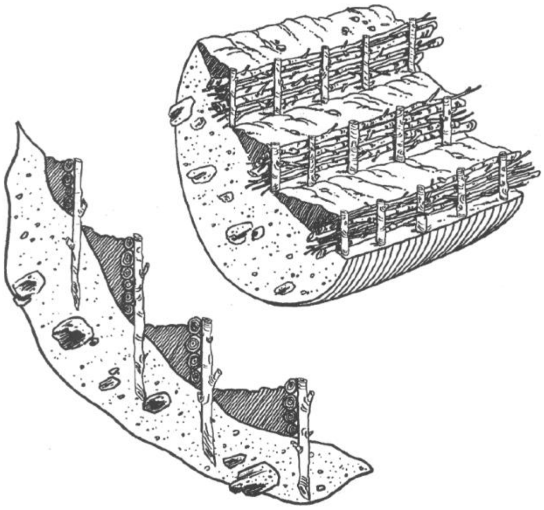


Figure 3 Wattle fence (source: Dave Polster, 2002)

In the following figure an example of the use of Wattle fences as a water bioengineering technique is shown. In this case, the wattle fences are placed along the bank of the stream to create a woody buffer against further erosion.

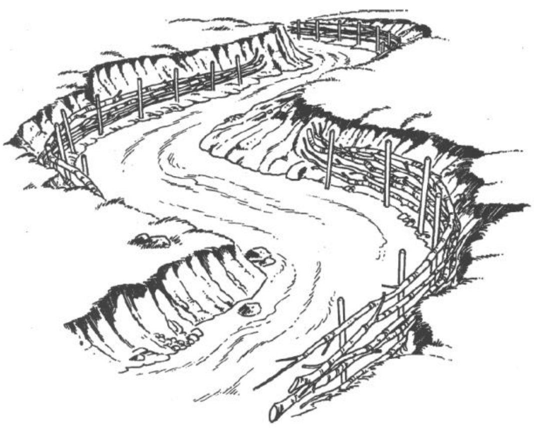
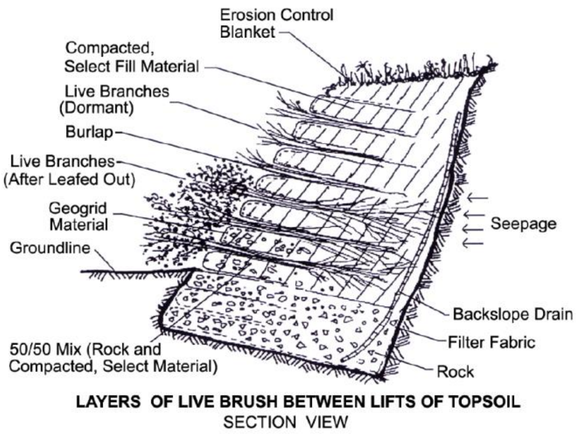


Figure 4 The water fences are placed to protect areas where the current is actively eroding the banks. Source: Dave Polster, 2002.

5.2.4 Brush layers

Brush layers are horizontal alternating layers of soil and live branches that create a continuous reinforced bench within the bank. The vegetated end of the brush layers acts as 'live fences' that can catch material moving down the slope. As the root system develops, the roots bind the soil together which strengthens the bank. It can be used combined with other toe protection techniques (such as, wattle fences or rock revetments)



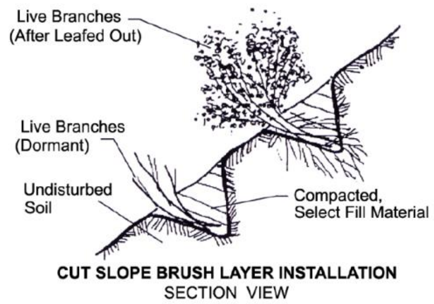


Figure 5 Brush layers details (Water Science Institute, NRCS)

5.2.5 Live fascines

A live fascine consists of planting of live bundles of wood species with propagation capacity vegetative (rods tied together with iron wire) inside a furrow:

a) on the slope: secured with pegs struck through the bundles or in front of them;

b) on the bank: infixing wooden stakes with alternating orientation, for thus making the structure more elastic and supportive in the event of full realization of bank spines causes a narrowing of the riverbed;

c) dead: along banks of water courses at low water speed and limited solid transport, dead bundles of wood species are placed, arranged longitudinally on the bank below the average water level.

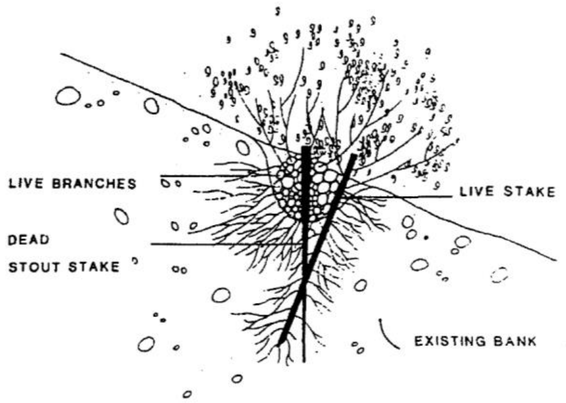


Figure 6 Detail of a live fascine. Source: Robbin B. Sotir and Associates)

5.3 Water bioengineering techniques in lakes

5.3.1 Vegetated rolls

Vegetated rolls are usually made of coconut fiber bound together with twine. However, these rolls may also be made of other materials that provide the same effect. Other bio-engineering techniques, such as brush mattresses may be necessary to reinforce the upper bank above the roll.

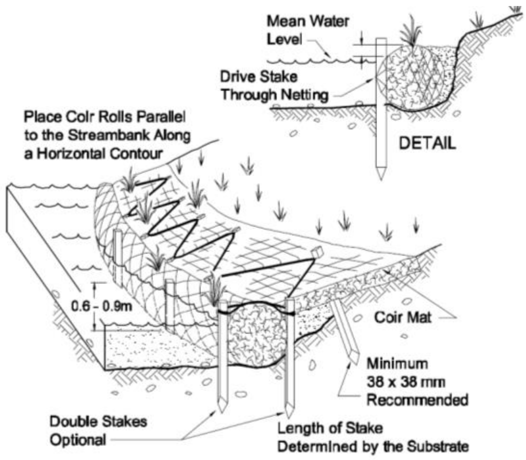


Figure 7 Detail of the vegetated roll. Source: ErosionDraw 4.0

5.3.2 Reinforced fascines (fascines with double poles)

Fascines with double willow (or balsam poplar) poles are used to protect the toe of an eroding streambank. This is a useful wave break technique.

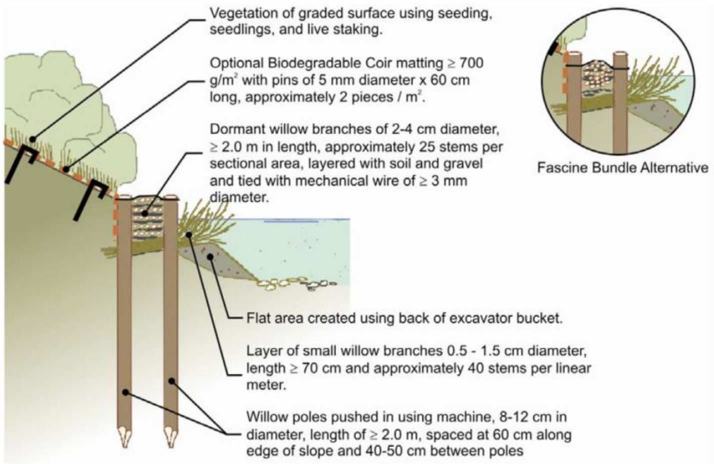


Figure 8 Detail of fascine with double pole. Source: adapted from Bernard Lachat, 2010, BIOTEC.

5.4 Soil bioengineering techniques for sand dune stabilization

5.4.1 Natural fiber blancket

This technique combines the use of fiber blanckets (a runoff control measure) with revegetation.

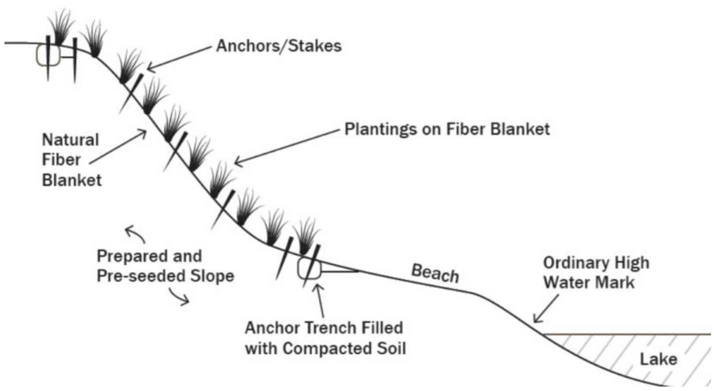


Figure 9 Natural fiber blanket installation using anchor trenches and planted with native grasses. Source: adapted from Massachusetts, 2016

5.4.2 Sand fixation using coir rolls

Coir rolls can be used to protect and stabilize the toe of a bank or bluff by providing a physical barrier that buffers waves and reduces erosion of exposed sediment.

Coir rolls provide stability and protection to the site while the vegetation planted in and above the rolls becomes established. As the coir rolls disintegrate, typically over 5 to seven 7 years, the plants take over the job of site stabilization.

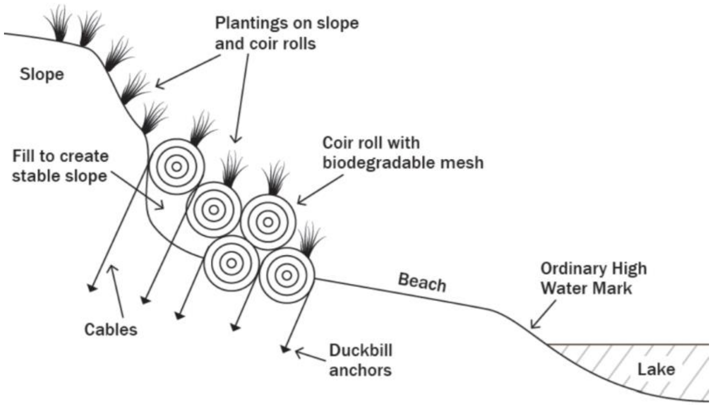


Figure 10 Cross-section of sand fixation using coir rolls. Source: adapted from Massachusetts, 2016.

5.5 Mixed construction techniques: consolidation techniques

5.5.1 Live slope grid

Vegetated slope gratings are large wooden structures that are constructed where slopes have failed. The wooden elements provide a structure to support the slope while the vegetation becomes established. The stabilization is immediate thanks to the wood reinforcement and the effect increases with the rooting of the plant species, which also perform a draining action. The wood rotates over time, so that in addition to good nailing, it is necessary that the plants inserted in the structure are vital and deeply rooted, thus replacing the function of support and consolidation of the slope once the wood has lost its functions.

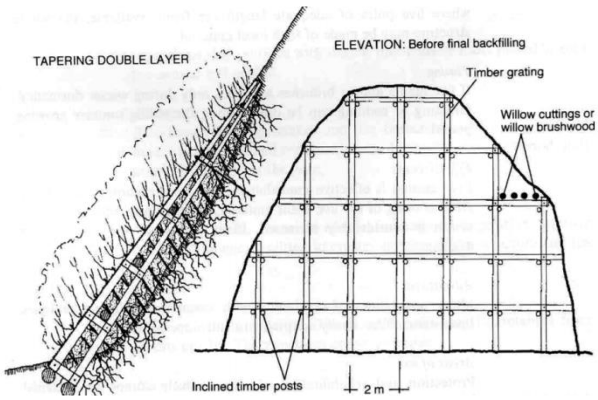


Figure 11 Detail of a live slope grid. Source: Schiechtl and Stern, 1996

5.5.2 Live log crib wall

Timber structure consisting of a frame of logs to form chambers in which cuttings and / or fascines of species with vegetative propagation capacity are inserted.

Vegetation is planted between the logs used to build the wall. The vegetation reduces stream velocities as well as providing cover and shelter for fish. The root structure of the vegetation strengthens the material and soil within the crib.

This technique is useful when slopes are too steep for other techniques of stabilization and there is no room to cut back the slope.

The wood with time decays, so besides good nailing, it is necessary that the plants inserted in the structure have a good development in order to, over time, fulfill the support and consolidation function on the slope. The stabilizing role transfer between the logs and the vegetation must be ensured by means of a good design of the technique.

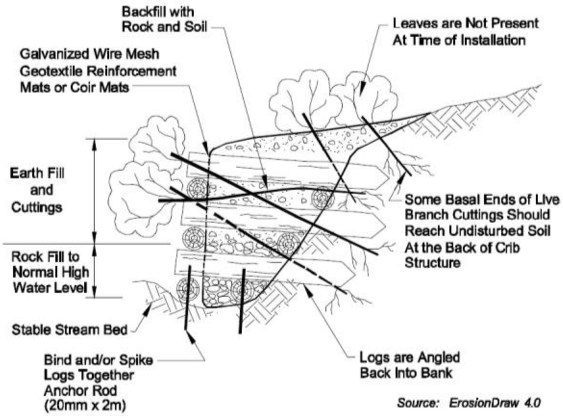


Figure 12 Log crib wall detail (source: ErosionDraw 4.0)

5.5.3 Live gabion wall

Technique suitable for both linear arrangements and point-like arrangements, consisting of gabions in double-twisted galvanized wire mesh and hexagonal mesh, filled on the spot with small stones of a minimum size of 15 cm, arranged in parallel overlapping rows. Inside the gabions are inserted willow or tamarisk cuttings with irregular or row arrangement in the first mesh of the upper gabion (not between one gabion and the other).

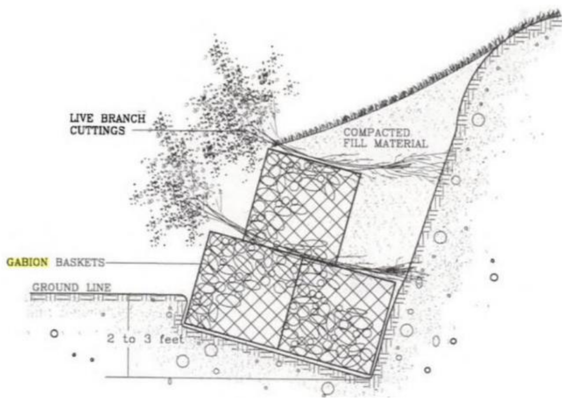


Figure 13 Source: Gray and Sotir, 1996

5.5.4 Vegetated geogrids

Vegetated geogrids are similar to brush layers except natural or synthetic geotextiles are wrapped around the exposed soil between the layers, anchoring the ends of the geotextile in the fill material. The geotextile material protects the exposed soil. This technique is used instead of brush layering in areas where the water velocities are relatively high. Vegetated geogrids can be used on steep slopes that have limited room for bank shaping.

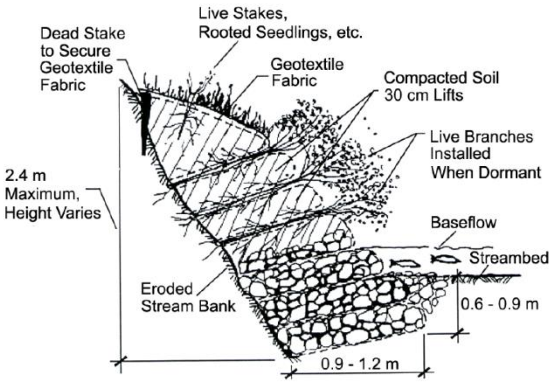


Figure 14 Detail of a vegetated geogrid with rock toe key (Watershed Science Institute, NRCS)

An alternative classification of soil and water bioengineering techniques is the following:

5.6 Techniques using only vegetation

Technique	**Soil cover**	**Stabilisation**
Manual seeding	X	
Hydroseeding	X	
Cover seeding (with geotextiles)	X	
Hay seeding	X	
Dry mulching	X	
Cuttings		X
Living brushes and combs		X
Plantation of rooted branches		X
Living bush matress	X	X
Fascines		X
Wattle fence		X
Bush layer		X
Planting of rhizomes		X
Plantation of woody plants		X
Hedge layer		X
Sod		X
Log branch cutting		X

Sod rolls	X	
Transplantation of live soil	X	

Table 2 Techniques using only vegetation

5.7 Combined techniques (mixed techniques)

Technique	Soil cover	Stabilisation
Rock fill and pavement	X	
Reno matresses	X	
Dry stone walls	X	X
Living or inert Rip-Rap (EN 13383 1 and 2)		
Use of soil aggregating substances	X	
Geotextiles	X	
Mulching	X	
Anchors		X
Wire mesh	X	
Gabions		X
Reinforced earth with geotextiles	X	X
Log crib wall and other support log structures		X
Slope grid	X	X
Cuttings		X
Fascines		X

Table 3 Combined techniques (mixed techniques)

6. SOIL AND WATER BIOENGINEERING BUILDING MATERIALS

As explained before, one of the main features of soil bioengineering is the use of plants or parts of plants as building material. Initially, the stabilising functions are often developed by inert material and, eventually, plants take over the reinforcing effects. This strategy has both advantages and limitations that must be taken into consideration in the intervention design.

According to the NTJ 12-5 (Spanish technological norms for gardening and landscaping), the material utilised in soil and water bioengineering works can be classified into four groups:

- Live plant material
- Inert plant material
- Inert natural material
  Manufactured material: The French technological norms for gardening and landscaping ("CCTG fascicule n°35 - Aménagement paysagers ...) is distinguishing between new works and maintenance works offering many indications for the tendering procedure.

6.1.1 Live plant material

This group comprises the typical and particular material used in soil bioengineering works. This group includes the woody and herbaceous plants or plant fragments matching good biotechnical traits. An adequate choice of the living material to be used in a particular intervention area is one of the critical points for ensuring a successful soil bioengineering strategy and performance. In this framework, the following criteria must be considered:

- The plant material must be chosen after a particular assessment of the intervention area characteristics and incorporating a phytosociological approach.
- The final choice must include suitable plant species not only from the ecological approach but also from the functional one. This is especially relevant in those cases where the reorganization and the hydrogeological balance are aims of the intervention.
- Autochthonous plants must be prioritised because of their suitable adaptation to the local conditions.
- The final selected set of plant species must be varied from both the plant size and typology in order to achieve a suitable plant composition and structure.

According to the morphological traits and size, the following groups can be distinguished:

- Non rooted plant fragments with good vegetative reproduction capacities.
- Seedlings and rooted stakes

- Seeds
- Sods and pastures
- Rhizomes

In soil and water bioengineering it is also important to distinguish between woody (shrubs and trees) and herbaceous plant species.

Among the woody plant species it is important to differentiate rooted plant fragments from entire rooted plants.

In slope stabilisation intervention, the non rooted plant fragments are the most important live material type. This material must be prepared during their dormant period and must be collected from nearby plant communities. There are different typologies:

- Stakes: these are woody non branched buds with 3-7 cm of diameter and 50-150 cm of length.
- Branches: these are flexible and branched buds with a minimum length of 60 cm and variable diameters.
- Rods: these are straight buds, barely branched and with a minimum length of 150-300 cm and 3-5 cm of diameter.



Stakes Rods Branches

In fluvial scenarios, the *Salix* sp are the most common utilised genus in fluvial engineering works.

Woody plants, compared to herbaceous plants, reach deeper depths (up to 2.0 m depth) and because of this, they offer a greater protection against mass movements.

The plant families of *Salicaceas* and *Tamaricaceas*, among others, have been selected and assessed as good green material in soil and water bioengineering works.

It is also possible to select live material from the specialised nurseries. This will be done in the following cases:

- when the soil bioengineering work is not constructed during the dormant period.

- when revegetation actions are difficult and/or a complement for favouring plant diversity and plant succession is needed.

In these cases, an adequate cultivation plan is needed in order to achieve a correct plant supply. Plant supply may consist of plain rooted seedling or plants in containers. Plants must be young in order to ensure a good rooting process and therefore, a good survival rate.

When cultivated in containers, herbaceous plants must have a well developed root system for providing a suitable performance in soil and water bioengineering works.

6.1.2 Inert plant material

This material type includes logs, branches, entire trees and organic geoproducts. These elements provide structural functions and/or soil protection functions.

Inert plant material utilised in soil and water bioengineering works have no vegetative reproduction capacities.

Inert plant material examples are:

- Timber

- Organic geoproducts made of natural fibres

- Vegetated geoproduct structures

- Compost, organic amendments and soil protective covers.

<u>Timber</u>

Timber is utilised as a temporary consolidating element that stabilises the intervention area so plants can develop and, over time, take over the main stabilising and reinforcing functions. Timber can be used along with rocks and stones.

Logs with different diameters along with branches, entire logs and stumps can be utilised.

It is recommended the use of timber from local tree species. Genus such as *Pinus*, *Larix* and *Castanea* are very common. For improving the timber durability, the logs must be debarked. The length and diameter of the logs and timber utilised in the work will depend on both the bioengineering technique and the material availability.

Figure 15 Debarked logs for log crib walls and log palisades

Organic geoproducts made of natural fibres

Organic material such as organic mats and organic geogrids provide both a temporary protection against runoff and support for the vegetation establishment. The most common natural material utilised are coir, esparto, jute, straw, cellulose and, forestry residues. The materials can be made of more than one component (e.g., coir and straw).

According to the way the materials are manufactured we can find:

Organic mats: they fibers are woven.

Organic geogrids: the fibers are also interwoven giving place to an organic web.

Figure 16 Organic mat and Organic geogrid

Both organic mats and organic geogrids are biodegradable. They are used for achieving and immediate protection against erosion and, hence, allowing the vegetation both to settle down and eventually to develop the reinforcing effects. In fluvial scenarios, these organic materials can play the role of retaining the fine sediments and prevent the fill from being washed out.

Both esparto and coir fibers have a longer durability and tensile strength. Because of this, their use is more adequate for bioengineering fluvial interventions. The material type, fiber type and, fiber weight (gr/m^2) will be defined by the desired effect type (either a support effect or an erosion protection effect), by the soil granulometry, by the flow velocity and flow boundary stress, by the slope, etc.

In fluvial scenarios it is common the use of organic mats while in slopes the use of coir geogrids is more frequent.

Vegetated geoproduct structures:

Different manufactured products combine plant fibers with either seeds or topsoil or absorbent material or living plants or a combination of them such as the structured pastures, the vegetated coir biorolls or the vegetated mats.

Compost, organic amendments and protective covers:

Fertilisers, compost, organic amendments and protective covers are incorporated into the degraded lands in order to improve their physical, chemical and biological traits.

6.1.3 Inert natural material

This material Group is formed by natural material such as topsoil, Rocks, Stones, earthwork products, etc. They are earthy and stony material of different sizes used for earth fills, drainage fills and for supporting and protecting the soil and water bioengineering structures foundations.

Since 2006, in Europe, in case of fluvial rehabilitation works, shapes and weight of these destinated rocks are classified in CP (coarse particules), LM (Light mass) and HM (Heavy mass). This classification depends on fluvial conditions. Rock dimensions are found by application of scientific and experience based formulas with the aim to reduce quary impact, reduce costs of rock applying and increase on site sustainable activities.

Figure 17 Examples of natural materials (left: rocks; right: sand)

Figure 18 Example of a Rip-Rap installation on the Rhine River in Central Europe (EN 13383 1 and 2 standard specifications)

6.1.4 Manufactured material

This material group can be either metallic or synthetic. They are commonly used for fixing (staples, nails, …) or for reinforcing (webs, geogrids, etc.) the soil and water bioengineering structures. Whenever possible, the use of biodegradable material is preferred.

Fasterners: they can be flexible (wire) or rigid (steel rods, stables, mails, screws, …)

The nails used for assembling the wooden structures can be either corrugated steel rods with a 10-12 mm of diameter or screws.

Figure 19 Staples-corrugated steel rods-screws-steel nails

Reinforcing elements: they are synthetic geogrids, geocells, wire mesh or gabion wire boxes, etc.

Figure 20 Stainless steel wire mesh (left) and synthetic geogrid (right)

General note: the deterioration rate of some of the material included in the project must be included at the design stage. For example, the wood decay rate assessment can calculate the cross seectional loss of the logs used in the bioengineering structure. This can prevent the structure collapse and therefore ensure the development of the desired stabilising function transfer process between the living and non living materials of the soil bioengineering work (Tardio and Mickovski, 2016).

https://youtu.be/d81wN8xzqjw

https://youtu.be/3nzSBkim118

https://youtu.be/siCMN-u_AT0

https://youtu.be/Bj-31Z4O0f4

https://youtu.be/iUf4BgKTFSc

7. PLANTS BIOTECHNICAL PROPERTIES

The technical and biological properties constitute the biotechnical characteristics that characterize some plant faults and are essential for the success of naturalistic engineering interventions.

Technical properties

They consist in the capacity of live plants, through mechanical and hydrological actions, to protect the soil from the erosion of rainwater, used in anti-erosive settlements with herbaceous species, and in the stabilization of a surface layer of the soil through the "nailing effect" "Of the roots of the bushes (stabilizing accommodation).

The mechanical actions consist in the reduction of the erosion and the solid transport downstream; along a slope with a dense vegetal cover, the speed of water flow is about ¼ of what would be, with the same rainfall, on soils without vegetation and, consequently, the erosive action, which varies with the square of the speed, can go down to 1/16.

The main effects of vegetation on slope stability are shown in the following figure and table.

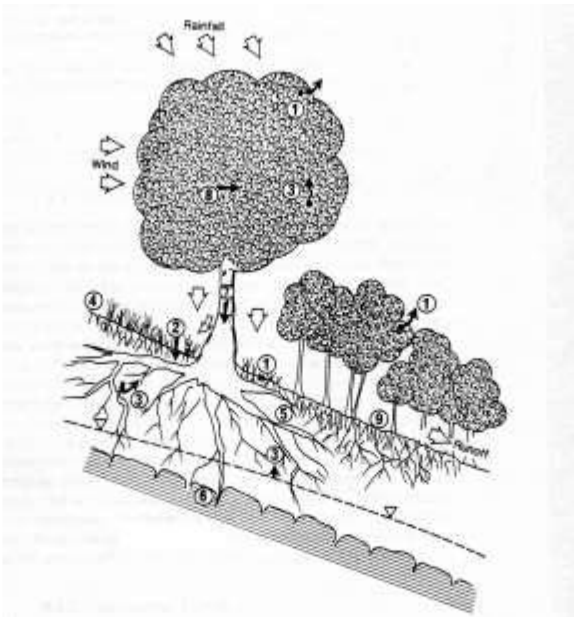


Figure 21 Effects of vegetation on slope stability (from Greenway, 1987)

In summary, in favorable geomorphological situations, the forest can represent the project objective of the interventions to reduce the hydrogeological risk, but in unfavorable ones (steep slopes, erodible substrates, etc.), the effect of the trees, due to the induced overload and of wind, can result in phenomena contrary to stability; it follows that in naturalistic engineeringinterventions on unstable slopes, without prejudice to the essential role of plant cover, the botanical project does not provide for planting trees, but anti-erosive, stabilizing and consolidating works based on the biotechnical characteristics of the herbaceous and shrub species.

Resistance of roots

Plants with high biotechnical value possess strong root systems with a capacity to consolidate the soil that derives from the shape and density of the roots and results in an increase in shear strength and cohesion.

The most effective consolidation of the soil is obtained when the radical interpenetration occurs in different layers and at various depths, so it is necessary to use different species.

For an assessment of the biotechnical attitudes of a species, some indicators are used:

• The relationship between the volume of the roots and the volume of the jets (Schiechtl, 1973)

• The resistance to the grubbing up of the whole plant

• The tensile strength of the roots with the classic resistance tests of the materials

Biological properties

In addition to the soil stabilization properties, many plants have biological properties, and in particular:

1. Reproductive capacity by vegetative means, or by cuttings. The ability of some species to conserve some meristematic cells within the specialized tissues is exploited, with the genetic message able to activate the biological processes of reconstruction of the entire individual: the genera Salix (willow), Populus. (Poplar), Tamarix (tamarind), Nerium oleander (oleander), Laurus nobilis (laurel), Atryplex halimus (atriplice), Artemisia arborescens (shrubby wormwood), Laburnum anagyroides (laburnum), Ligustrum vulgare (Ligustro), Sambucus nigra (elderberry)), Phragmites australis (rhizomes), Arundo pliniana (rhizomes), Corylus avellana (pit, root cutting), etc.

In carrying out naturalistic engineering works, only those species that have at least the ability to take root can be used conveniently 60-70%, since some root and reject insufficiently as, for example, Salix caprea (salicone) (Schiechtl, 1992).

In the interventions of soil and water bioengineering, the willows that have, in general, an excellent biotechnical attitude and a rapid vegetative propagation, are used above all in the hydraulic arrangements. The massive use of willows in the Mediterranean ecoregion, especially the meso-hygrophilous species, although compatible from an ecological point of view in wet stations (such as watercourses or mountains) it should be well evaluated in other stations, where it is often not feasible for ecological and climatic limits for lack of floristic-vegetational coherence and for availability difficulties.

The pruning of cuttings, however, is carried out in the period that generally coincides with that of vegetative rest (plants without leaves). From the experience in the Mediterranean it has been seen, however, that cutting is possible, depending on the ecology of the station (humidity, altitude, exposure, etc) even in some spring and autumn months, with the exception, however, of the period between flowering and fructification and the autumnal chromatic alteration of the leaves, with very low rooting capacity.

When cutting the willows, it should be remembered that the longer and thicker cutting has, due to a greater reserve of hormones stored in the cells, a better capacity for growth in the first three years of life. The most frequent willow species in the southern regions are:

Salix alba, S. purpurea, S. triandra, S. eleagnos, S. cinerea and S. caprea (used as a rooted plant and not by cuttings).

2. Ability to emit adventitious roots from underground stems: the genera Alnus (alder), Salix, Populus, Fraxinus (ash), Euonymus europaeus (priest's bonnet), Viburnum tinus (lentaggine), Cornus sanguinea (sanguinello), Acer pseudoplatanus (mountain maple), Corylus avellana (hazel), etc.

   On Mediterranean slopes, where the difficulties of the cuttings of the willows are real, since they are not coherent from an ecological point of view, one should promote the use of thermo-xerophilous species with the capacity to develop adventitious roots from the buried stem, to be used as rooted plants, but with the same function as cuttings. This biotechnical characteristic is reflected in nature in the resistance to the dressing of some plants: while an over-flooding covering causes the progressive decay due to asphyxiation of most species, some woody plants endure it without losing its vitality.
3. resistance to submersion even for prolonged periods: willows, populus alba (white poplar), alnus glutinosa (black alder), ash trees. The reparal associations can endure without damage submersions lasting from hours to more days, also several times a year, but not the total submersion asphyxiation. Ownership must be taken into account in the design of the interventions of B.E. in the hydraulic field.

8. VEGETATION REINFORCING ACTIONS (POTENTIALS AND LIMITATIONS)

This section is also included in Module 2 'Soil bioengineering and geotechnics' although in more detail.

8.1 General actions

Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce surface water runoff and erosion.

Evergreen trees and shrubs continue the metabolic activity known as evapo-transpiration, which extracts moisture from the soil, throughout the year. As logging or clearing occurs, water table levels rise, and soils remain saturated for longer periods, reducing soil cohesion and increasing the rate of land slides.

Roots reinforce the soil, increasing lateral soil sheer strength and cohesion during saturated conditions. Many slopes can persist beyond their angle of repose and remain stable as a result of the complex root networks within soil blocks.

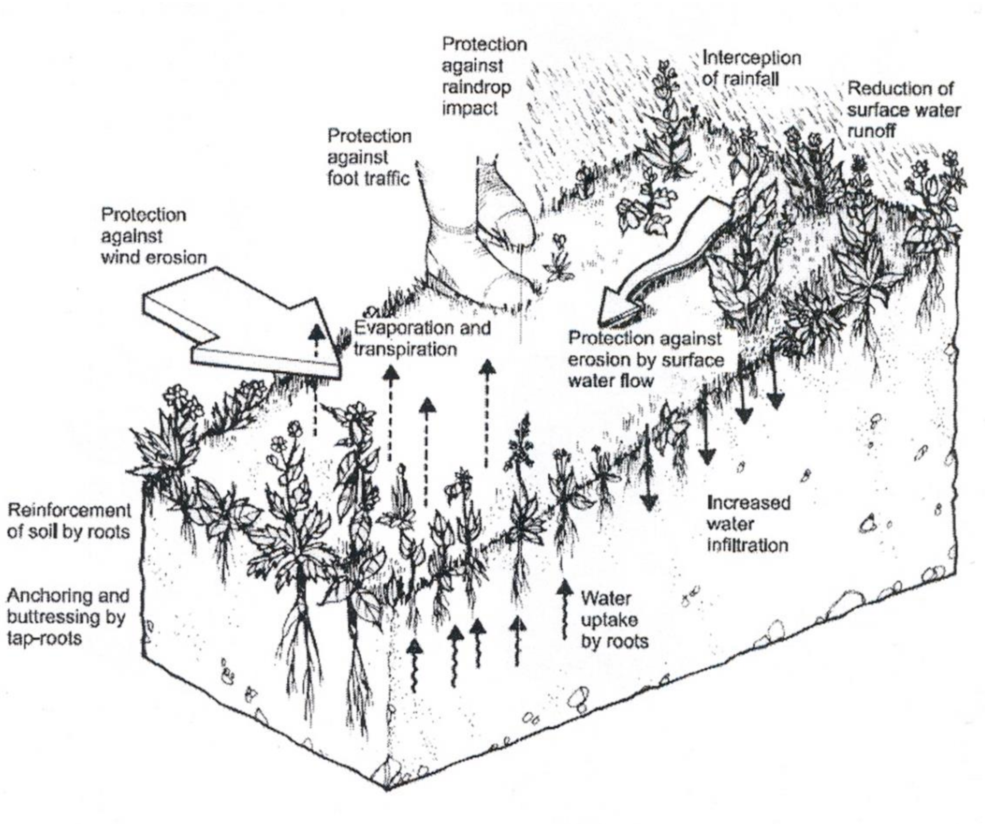


Figure 22 Some influences of vegetation on the soil

Tree roots anchor soil strata vertically and laterally by means of large-diameter structural roots. These roots may extend well beyond the tree's canopy or crown.

Roots, especially the fine feeder roots of trees, shrubs and groundcovers, bind soil particles at the ground surface, reducing their susceptibility to surface erosion and slumpage during saturated soil conditions.

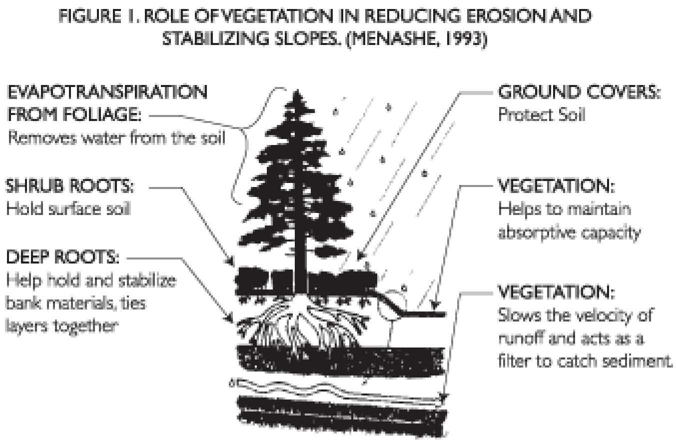
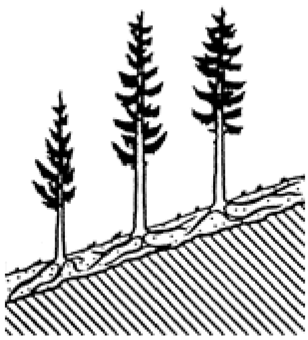


Figure 23 Role of vegetation in reducing erosion and stabilizing slopes (Menashe, 1993)

Large trees can arrest, retard, or reduce the severity and extent of failures by buttressing a slope. This works in much the same way as retaining walls. In the case of trees, though, the system is to some extent self-repairing, and it becomes progressively stronger over time, whereas engineering structures are strongest when installed and become progressively weaker over time. Obviously, planted trees need adequate time to develop root systems and become effective in stabilizing slopes.

In following pictures, different scenarios are shown where the combination of different plant roots types and stratigraphy give place to different plant reinforcng capacities:

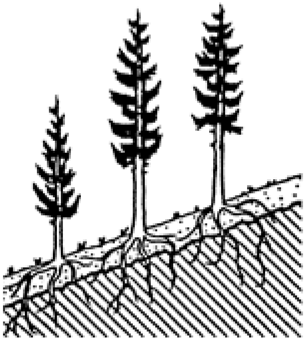
Type A



Characterized by shallow (less than 1 m depth) soils overlaying parent material (competent rock, glacial till, dense silt or clay) which resists root penetration. Surface soils are fully reinforced with tree roots. Lateral rooting, though shallow, often resists slope failures if tree density and distribution is adequate to provide an interconnected root-web matrix. Rooting is plate-like. Roots are at failure plane. Subject to rapid, shallow slides during extreme rain-on-snow events.

Stabilizing effect of roots: Moderate if not compromised. The soil tends to become rapidly unstable when disturbed, or subjected to increased hydrological influences. Anchoring - minor. Soil cohesion - high.

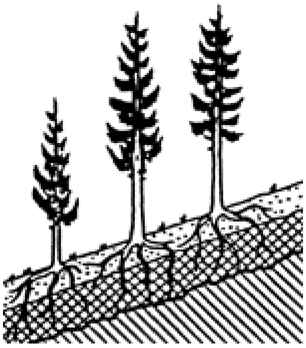
Type B



Characterized by shallow (less than 1 meter depth) soils overlaying parent material (dense sand, glacial till, etc.) which allows significant root penetration. Degree of anchoring into parent material by roots is dependent on the nature of the fractures in the parent material and the predominant tree species. Roots intersect potential failure plane, providing shear resistance.

Stabilizing effect of roots: High. Individual trees are stable without a significant dependence on adjacent trees. Both anchoring and soil cohesion benefits are high.

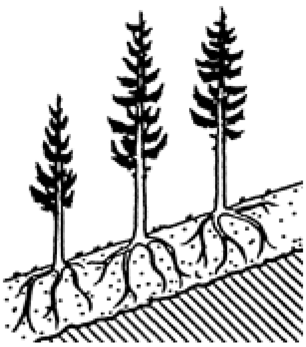
Type C



This scenarios is characterized by deeper soils (3-12 feet) with a non-distinct transition zone in which soil shear strength increases with depth. Assumptions include: (1) transition zone functions as a drainage moderator, allowing a concentration of groundwater and increased pore-water pressure; (2) failure plane passes through the transition zone; (3) soil zone is more easily penetrated and permeated by roots than in B, above. (Example: sandy loam over loose till over compacted till.)

Stabilizing effect of roots: Anchoring - high. Soil Cohesion - high.

Type D



Characterized by deep soils where both the failure plane and the soils are deeper than the root zone. The actual depth of the soil for this condition to occur depends on root morphology (depth, spread, etc.) of the particular tree species on the slope. For example, on a slope where Red alder predominates, a relatively shallower soil depth would exhibit Type D conditions, while on a slope forested by Douglas-fir the stabilizing effects would be significantly greater for the same depth.

Stabilizing effect of roots: Anchoring - minor. Soil Cohesion - moderate.

Some typical Mediterranean plants increase topsoil resistance to erosion and shallow landslides from runoff and superficial flow. Some Mediterranean species were subjected to root tensile strength, shear stress and/or pull-out tests, and also the architecture of their rooting system grown on slopes was studied. In general, the development of the root system is influenced by genetic and environmental factors, e.g. its lignin and cellulose content, soil structure and texture, temperature and water availability, seasons and altitude. In nature a wide variety of root systems can be observed, both on a horizontal and on a vertical plane. Consequently, their impact on soil reinforcement is somewhat heterogeneous. Moreover, they increase the resistance of top-soil to erosion and finer roots have a higher tensile strength per cross section unit area. On the other hand, thicker roots can be likened to biological nails, which probably tend more to pull out than to break; thicker roots use just a small part of their tensile strength. The importance of fine roots is also demonstrated. The literature also reports that as root tensile strengths are usually measured in tens or hundreds of megapascals and soil shear strengths are normally in the range of tens of kilopascals, interspecies differences in the tensile strength of living roots are probably less significant to slope stability than are interspecies differences in root distribution. The impact of root reinforcement on soil is generally expressed as an increase in soil cohesion. A number of factors influence the tensile strength test: species, season, age, soil compaction, deformation of roots, soil and root moisture, root preservation, field or lab test, type and size of testing equipment, procedure for clamping the root, test speed, and rate of elongation. The planting method, quality of planting and root pruning (undercutting) influence the root development when establishing a planted stand. Three main methods can be used: direct seeding on site, transplanting of seedlings sown in containers, planting of bare-root seedlings and transplanting of cuttings (bare-root or in containers).

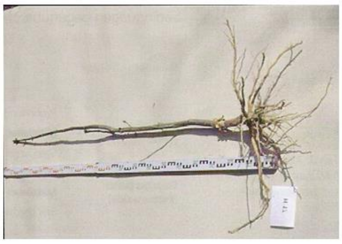
The main effects of plant roots are shown in the following figures:

Increasing soil cohesion

soil reinforcement – root growth

→ increase of shear strength

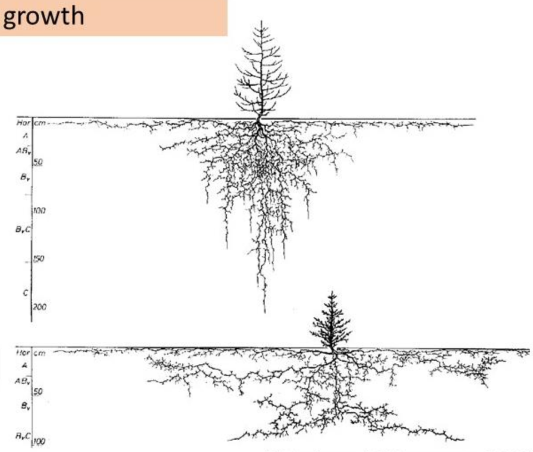
- mechanic stabilizing by the roots
- increase in capillary cohesion through water extraction
- formation of aggregates



soil reinforcement – root growth

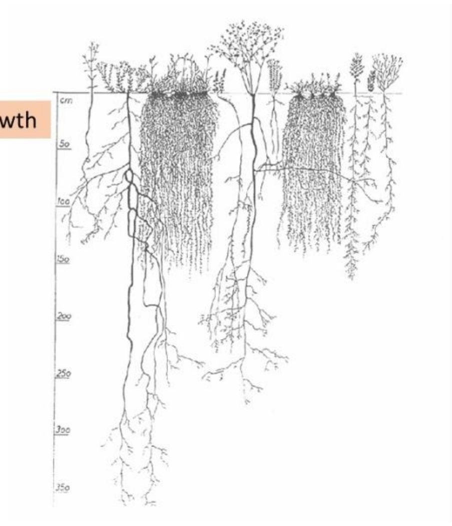
Larch, age of 7

Spruce, age of 11



(Kutschera, Lichtenegger, 1960)

soil reinforcement – root growth



Structuring

soil reinforcement –organic matter-root degradation

leaf litter decomposition → soil structuring

root degradation → advancement of the edaphon

- ✓ generating soil units
- ✓ increasing water and air permeability
- ✓ increasing of the water absorption
- ✓ less sliding surfaces

soil reinforcement –root growth

- ➡ strengthening the soil matrix
- ➡ different rooting types

soil reinforcement – root growth

strengthening the soil matrix
different rooting types

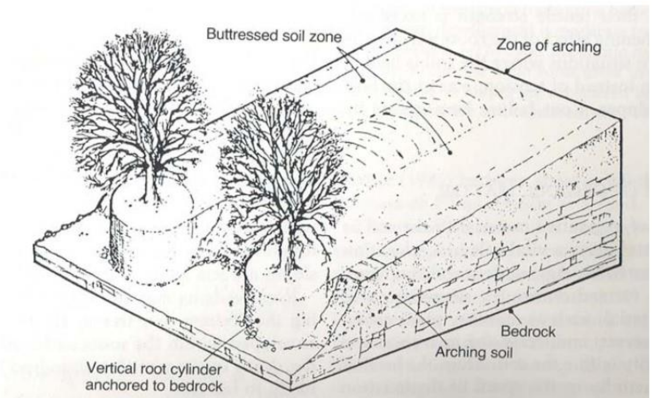
Supporting and buttressing

arching and buttressing

roots acting as piles

leading to soil stabilization by buttressing.

arching effects due to the spatial distribution



8.2 Mechanical Role of Roots

Roots provide mechanical support to a soil mass through its tensile strength, adhesive and frictional properties. Roots growing perpendicular to the soil surface provide resistance to shearing forces acting on the soil. Roots extending parallel to the soil reinforce the tensile strength of the soil zone. A soil mass is reinforced not only by these two strengthening aspects but also in terms of the spatial distribution it occupies. Fine roots (1-2 mm in diameter) are a tertiary root system and represent less than 5% of a tree's biomass but provide more than 90% of the water and nutrient uptake of all roots (Schwarz et al. 2009). Coarse roots are greater than 2 mm in diameter and consist of 15- 25% of a tree's biomass. They can be broken down into four classes: taproot, lateral roots, basal roots and adventitious roots.

These classes can be subdivided to primary and secondary roots, with secondary roots stemming from primary roots that originate from the root system. The major factors that govern shallow slope stability are: number, size, tensile strength and bending stiffness of roots penetrating the failure planes. A greater quantity of fine roots is more effective at reinforcing the soil than a smaller number of coarse roots since tensile strength increases as root diameter decreases. Furthermore, during a slope failure, fine roots tend to break off but remain fixed within the soil, while coarse roots can simply slip out. However, only coarse roots can penetrate great depths and firmly anchor the soil mass. Moreover, by extending deeply, coarse roots can fix large volumes of soil and reinforce shallow slopes. Coarse roots also have a higher bending stiffness meaning it can withstand greater bending stresses than fine roots. It is ideal to have a combination of both fine and coarse roots. A large density of fine roots in the upper layers of the soil stratum aids in resisting tension while coarse roots extending deep into the soil and crossing shear planes provide stability from bending and shearing forces. The effectiveness of mechanical slope stabilization depends on the depth of the weakest soil zone, the likely failure mechanism and the steepness of the slope. The environment surrounding the soil plays a large role in determining the effectiveness of root fixation. Factors that hinder the growth of roots, including but not limited to rocks and a water table, reduce the significance it has on a slope. The soil type also plays a significant role in determining the effectiveness of roots for the texture of the soil can influence the resistance of uprooting while the soil's nutrient level may dictate the spatial density and distribution of roots.

9. PLANT SELECTION – CHARACTERISTICS AND TECHNICAL FUNCTIONALITY

Selection of plant species for Soil Bioengineering

The species building the natural vegetation communities of each site, particular the ones corresponding the first successional stages, must build the first orientation for species selection.

Within this set of species and considering their individual characteristics the selection criteria are very diverse:

- Pioneer character (ecological strategy);
- Adaptation to the site and the projected ecological community (functional, ecological and genetic)
    - Adaptation to the local stress factors (soil and climate)
    - Resistance / resilience to disturbances
    - Resistance to local pathogens
    - Guarantee that the selected species combination ensures a balanced succession
    - Existence of development and dispersal conditions (mycorrhizae, pollinators, dispersers)
- Typology of vegetative propagation and establishment (seed, vegetative cutting, rooted plant, etc.);
- Availability of establishment material (ease to obtain and to establish on site or nursery);
- Establishment and development speed;
- Technical functionality (cover, typologies of root growing and development, influence on the balance of nutrients, absorption and retention of contaminants, etc.)
- Ease of maintenance.

Correspondence or adaptation to the site, ensuring that the selected plant material correspond to the ecological conditions of the site and the local vegetation communities and that all plant material is obtained in the vicinity in order to prevent genetic contaminations.

9.1 Plant database

For facilitating the plant selection decision making process, a plant database was generated within the Ecomed project framework.

The main variables used in the database structure were the following:

Climate

Habitat type

Soil

Plant type

By means of this tool any practitioner will be able to select a set of plants adapted to the environmental conditions of his/her intervention area.

The information associated to each selected plant species is the following:

Phenology, biological types, morphologies (Ellenberg numbers), ecology, reproduction, biotechnical characteristics, aerial characteristics, information about the root system, synthetic parameters (Cornellini et al, 2008).

10. PLANTS AND BIOENGINEERING TECHNIQUES ADAPTATIONS TO THE MEDITERRANEAN CLIMATE

In the Mediterranean climate, plants have evolved under conditions of low soil-water and nutrient availabilities and have acquired a series of adaptive traits that, in turn exert strong feedback on soil fertility, structure, and protection. As a result, plant-soil systems constitute complex interactive webs where these adaptive traits allow plants to maximize the use of scarce resources.

Mediterranean plant communities are generally dominated by sclerophyllous woody plants with an herbaceous or shrubby understory (Specht 1981; Orshan 1983).

The most specific structural characteristics of Mediterranean plants are those related to conservative mechanisms linked to the avoidance of water stress but frequently also to the scarcity of soil nutrients. The lack of soil resources has led to a narrow evolution of plant-soil systems.

Mediterranean plants have acquired a set of morphological and physiological adaptations in response to deficits of soil water. The development of deep and extensive root systems is among the most characteristic traits of plants in Mediterranean ecosystems. Deep root systems enable the uptake of water from deep soil layers in drought seasons when the upper layers are water depleted (Veneklas and Poot 2003; Padilla and Pugnaire 2007; Baldocchi and Xu 2007; Hernández-Santana et al. 2008). Moreover, in Mediterranean plant communities, plant species with root-systems that tend to occupy different soil layer usually coexist avoiding the root systems overlapping and consequently diminishing the competition intensity, and also allowing to exploit the sources throughout all the soil depth (Castell et al. 1994; Silva and Rego 2003; Lefi et al. 2004a, b; Mattia et al. 2005; Moreno et al. 2005; Filella and Peñuelas 2003b; Silva and Rego 2003; Mattia et al. 2005; Mereu et al. 2009). Plants with deep-roots have proved to resist better drought events than species with shallow-root systems (Padilla et al. 2007; West et al. 2012). Furthermore, Mediterranean plants have high root plasticity in the early stages of life (Padilla et al. 2007). At the foliage morphological level, Mediterranean plants improve their capacity of drought avoidance increasing their foliar sclerophylly by developing thick cuticule and increasing leaf mass area (LMA), high density of foliar trichomes (Table 1), and high plasticity of foliar morphology and size.

General adaptations to drought by Mediterranean plants at physiological level include a large capacity to maintain water flux and hydraulic lift (water conduction from soil to plant tissues) in the soil-plant continuum , including a large resistance to xylem cavitation and high stomatal control.

In Mediterranean conditions, the plantation technique to use, the place and the hole design (for runoff collecting) should be selected very carefully. In the same way, the season for planting must be chosen, preferably in autum, but not in the period of hydrological deficit (mainly summer).

11. PROJECT, CONSTRUCTION AND MAINTENANCE – BRIEF INTRODUCTION

11.1 Project

The correct choice of a Soil Bioengineering construction method as well of the association of plants to be applied is decisive to the fulfillment of the project targets. The decision criteria are defined according to following objectives:

- Protection
  - hydraulic, hydrological, geo-technical and safety-technical requests of the construction type and the future vegetation
- Ecological
  - amelioration of the ecological condition of for example a stream in terms of the development of its flora, fauna and river processes, functions and resources
- Biotope structure as habitat
- Landscape estetic
  - best possible integration of the construction in the landscape
  - insurance of the recognizability of a stream in the landscape
- Economical
  - use of plant material capable of vegetative reproduction and development as well as materials obtained locally or in the direct vicinity
  - use of durable and low maintenance construction types and materials
- Low cost construction and maintenance
- Sustainability
  - use of natural construction material able to further development: live plants, wood, earth, rocks.
  - use of low energy construction materials
- Societal
  - possibility of use by the population, tourism and leisure
  - creation of new green areas in urban areas

Application		Construction type	Protection against superficial erosion	Stabilization to a depth < 0.2 m	Stabilization to a depth > 0.2 m	Biological drainage function	Technical drainage function	Beginning of the effectiveness	Duration of the effectiveness	Spatial effectiveness	Cost
Sowing and revegetation methods		Dry sowing	3	1		1		2	2	3	1
		Hydroseeding	3	1		1		2	2	3	1
		Mulch seeding	3	1		1		1	2	3	2
		Seeding mat	3	1		1		2	2	3	3
		Sods, sod rolls	3	1		1		1	2	3	2
		Topsoil application	2	1		1		3	2	3	2
		Pit planting	2	1		1		2	3	1	2
		Angle planting	2	1		1		2	3	1	2
		Berm planting	2	1		1		2	3	1	2
		Contour planting	2	1		1		2	3	2	2
		Row planting	2	1		1		2	3	2	2
Slope drainage		Branch drainage	1	2			3	1	1	2	1
		Drainage fascines	1	2		3	2	2	3	2	1
		Seepage ditch	1	2			3	1	3	2	2
		Open drains	1	2			3	1	3	2	3
		Slope fascines	2	3		2		2	3	2	1
Slope stabilization	< 20 cm	Vegetated pile wall	3	3		1		1	3	2	2
		Live slope grid	3	3		1		1	3	3	3
	20 – 200 cm	Vegetated Cribwall	3		3	2		1	3	2	3
		Vegetated concrete Cribwall	3		3	2		1	3	2	3
		Vegetated rock paving	3		3	2		1	3	2	3
		Vegetated gabions	3		3	2		1	3	2	3
		Vegetated reinforced earth	3		3	2		1	3	2	3
		Brush layer	3		3	2		2	3	2	2

Application	Construction type	Protection against superficial erosion	Protection against deep erosion	Biological drainage function	Technical drainage function	Beginning of the effectiveness	Duration of the effectiveness	Spatial effectiveness	Cost
Longitudinal constructions	Tree spur	1	2			1	2	2	1
	Branch layering of gullies	1	2	2		2	2	2	1
	Vegetated rough bed channel	1	2	1	3	1	3	2	2
	Vegetated stone drain	1	3	1	3	1	3	2	3
	Vegetated wooden chase	1	3	1	3	1	2	2	3
Transversal constructions	Live palisade	1	2	2		3	2	1	1
	Vegetated block ramps	1	2	2		3	2	1	1
	Vegetated wooden weir	1	3	2		1	3	1	3
	Vegetated gabion weir	1	3	2		1	3	1	3
	Vegetated rock weir	1	3	2		1	3	1	3

Table 4 Decision Matrix

Legend			
Degree of technical achievment	1 = small	2 = medium	3 = high
Beginning of the effectiveness	1 = imediatly	2 = after severel weeks	3 = after several months
Duration of the effectiveness	1 = short term (1 - 5 years)	2 = medium term (5 - 10 years)	3 = long term (more than 10 years)
Spatial effectiveness	1 = puntual	2 = linear	3 = area
Cost	1 = small	2 = medium	3 = high

Table 5 Legend of Decision Matrix

11.2 Construction

The diversity of techniques and specific construction procedures determines that students should refer to the literature in particular the EFIB's Construction Type Manual

11.3 Maintenance works

- For grasses, reed and herbs following maintenance measures can be used:
  - **Mowing (partial, along stripes, seasonal, according to the maturation of seeds and fruits, using hardware and methods adapted to the biotope)**

  - Underwater mow
  - Amelioration works like
  - Reseeding
  - Fertilizing
  - Installation of sod slabs, new plants or plant parts
  - Irrigation
  - Collection and removal of garbage and refuse

- For trees and bushes following maintenance measures can be used:
  - Sprouting from the root (partial alternated rejuvenation)
  - Pollarding (on trees above the flood water level, along maintenance roads, according to cultural and ecological considerations)
  - Thinning / removal of individual plants due to hydraulic, ecological or esthetical reasons
  - Pruning
  - Removal of invasive species like *Robinia* trough the extraction of a 50 cm bark ring at circa 100 - 150 cm height
  - Repair interventions like
  - Replanting
  - Fertilizing
  - Maintenance of the tree cover density
  - Irrigation
  - Renew of the tree supports
  - Collection and removal of garbage and refuse

Basic maintenance principles

Maintenance must occur only when necessary - "let instead of do"

- The choice and application of the construction method must involve a minimum of maintenance costs
- It should fulfill the objectives as quick and with as low costs as possible
- The developed structure ensure the full and harmonious effectiveness of all technical, ecological, economical and esthetical objectives.
- Maximum diversity and biodiversity
- Safety for road, train and stream traffic
- Continuous contribution to an increased effectiveness

- It must be made clear that maintenance can also lead to negative developments. The adaptation of the maintenance approaches to the natural conditions and processes is the only method to avoid maintenance errors that can be more negative then no maintenance at all.
- The development of the maintenance works must be adapted to the development of the construction and the combined vegetation within the consideration of the defined target vegetation.
- Basic condition for fulfillment of the objectives of the intervention is the respect of the predefined maintenance steps within an expert monitoring of the evolution of the structures and vegetation.
- It is mandatory in Soil Bioengineering project the inclusion of the financial needs associated with an adequate maintenance by qualified personal.
- The maintenance organization must ensure the quality of the plant material (as construction material, support material, biomass, etc.), according to the same criteria used in the project.
- The moment and type of maintenance interventions must be recorded and documented.

Types of maintenance activities (EFIB Guidelines):

- Completion maintenance / growth maintenance

Measures taken after the completion of the construction until the fulfillment of the construction objectives or the acceptation conditions by the client. These conditions are defined according to the defined success criteria. These criteria must be clearly defined and located in the frame of the project and described in the project specifications.

- Development maintenance

Measures aimed at ensuring the best possible development until the end of the warranty or the establishment of a functional plant cover.

- Maintenance care

Measures to ensure the maintenance of the long term functionality of the installed vegetation.

- Extraordinary maintenance measures

Maintenance measures necessary after extraordinary or unforeseen events (floods, plagues, invasive Neophyte species, wind throw , wet snow etc.).

12. SAFETY IN THE CONSTRUCTION SITE

12.1 Main types of safety risks associated with construction works

- Cuts and abrasion
- Noise
- Projection of debris
- Fire
- External dangers: Landslide, Rock slide, Failure of working substrate

12.2 Preventive measures and instruction for the workers

12.2.1 Before the work, particularly with machines

Verify the integrity of the hand protection devices

Verify the correct functioning of the apparatus and its safety devices

Control the people present that can be endangered by the activity and use of the apparatus

Verify the integrity of components like the chainsaw chain, the integrity of the augers, the integrity of chains, ropes and other building apparatus

Verify the correct functioning of large machines and the stability of the working substrate

Determine the area of danger due to the operation of the equipment and define and enforce a safety zone

Verify the levers of noise associated with each equipment

Verify the adequacy of the protection gear used by the workers

Organize the construction yard ensuring accessibility, mobility, restricted and controlled access and adequate areas for the manipulation of pollutant materials.

12.2.2 During operation

Ensure the permanent assessment of the stability of the working site

Ensure that no other worker penetrates unnecessarily the safety zone of each operation

Ensure that the protection gear is permanently used by all workers

Correctly and safely dispose the work tools and machines during work pauses

Avoid works involving cutting vegetation or moving building material during and in the vicinity of the operation of large machines

Prevent al risks of pollution by fuel or lubricant spilling and implement no smoking rules

12.2.3 After operation

Clean all working material and machines

Control the integrity of all tools and apparatus

Verify and lubricate all machines

Report eventual malfunctions

Close the construction yard when not in operation

12.3 Individual protection gear

Gloves

Glasses and Face protection

Safety shoes

Safety garments

Noise protectors

Helmet

https://youtu.be/kqnS1BckPqk

https://youtu.be/biULs0jluTY

https://youtu.be/3C6js5JtClQ

http://www.labour.gov.hk/eng/public/os/D/ConstrutionSite.pdf

http://www.hsa.ie/eng/Publications_and_Forms/Publications/Agriculture_and_Forestry/Code%20of%20Practice%20Forestry%202009-.pdf

13. REFERENCES

EFIB, 2015. European Guidelines fro Soil and Water Bioengineering. Edited by EFIB (European Federation of Soil Bioengineering).

Stream System Protection, Restoration and Reestablishment. Website by the Watershed Science Institute, Natural Resource Conservation Service, USDA.

ECTC 2008, Erosion Control Technology Council (ECTC) Guideline for Installing Rolled Erosion Control Products in Slope, Channel and Shoreline Applications, Prepared by Erosion Control Technology Council, Texas, USA, May 2008.

Massachusetts Office of Coastal Zone Management (Massachusetts). 2016. StormSmart Coasts – StormSmart Properties.

European rock use manual in case of underwater foundations applied for SWB works

French Bioengineering Manuel B.Lachat

French geotechnical investigation needs

German Waterway Regulations DWA-M 519

Swiss Construction Type Manual EFBE 2007

14. ASSESSMENT AND FEEDBACK

This module is continuously assessed during the course of the semester. The assessment comprises practical works and theoretical exams. The pass mark for this module is 50% - you must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above.

Full details of the course works are contained in the Coursework Briefs which will be issued in due course.

Note: Failure to submit the coursework for the appropriate deadline without 'good cause' will be regarded as a non-submission, and hence will result in failure in this module. If you have a good reason for needing an extension to the deadline, you must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date.

To help you guide your development you will be provided with feedback on your performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort's overall performance will be provided. You will be given an opportunity to individually review your marked work to help you understand which aspects of your studies you are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. You are entitled to keep marked submissions for your review - however, you must return these when asked by the Module Leader or Module Tutor.

15. DIRECTED LEARNING AND PRIVATE STUDY

As you are expected to 'read' for your degree, you will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect you to be up to date with the current theme.

The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and you will be expected to demonstrate evidence of having sourced information from these in your coursework activities.

You should also make use of web-based materials and visit appropriate sites to develop a wider knowledge of the key issues and activities of not only your chosen discipline, but also in other related fields.

Please refer to the Module Descriptor for a detailed reading list. However, you may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section.

16. MODULE DIFFICULTIES AND EVALUATION

If you have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, you should speak with your employer or Academic tutor.

A module evaluation form will be made available to you on-line after the module is complete and you will be asked to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms are analysed (anonymously) and the findings considered by the appropriate professional organisation as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that you may have about the module in the first instance.

17. PERSONAL DEVELOPMENT PLANNING (PDP)

PDP is aimed at help you to develop as an independent and confident learner, not only during your time with us, but throughout your future career. It also allows more effective monitoring of your progress while undertaking your degree program studies. The process has been described as

"A structured & supported process undertaken by individuals to reflect upon their own learning and performance, and/or achievement, and to plan for their personal education and career development."

As a member of a professional graduate community, you will be required to undertake Continuing Professional Development throughout your career. Learning therefore must be seen as a lifetime activity, and the introduction of PDP at the early stages of your career prepares you for these future requirements. PDP provides an opportunity for you to develop your capacity for learning by getting you to reflect on why and how you are learning, and to become more capable of reviewing, planning and taking responsibility for your studies. All of the foregoing will of course be supported by staff, in particular your Academic Tutor. The key objectives of the PDP process can be summarized as follows:

- To help you become a more effective, independent and confident self-directed learner
- To understand how you are learning and be able to relate that learning to a wider context
- To improve your general skills for study and career management
- To articulate your personal goals and evaluate your progress towards these
- To encourage you to develop a positive attitude to learning throughout your professional life.

Access to a wide range of services, information and software can be made through the home page of the course: html.************************. You will be automatically given access to the resources of the different involved Universities and Enterprises. A common platform (e.g. Moodle) will be made available to allow the access to all learning resources and the permanent interaction between teachers and students as well as supporting many of the assessment procedures.

QUESTIONS FOR THE VIRTUAL LEARNING PLATFORM (VLP):

1. Soil and water bioengineering (SWB) uses:
   a) Only inert material
   b) Only living material
   c) Living and , if necessary, inert material.
2. The following material can be classified as living material:
   a) Geogrids
   b) Willow stakes
   c) Rip-Rap
3. Which one of the following techniques can be classified as a consolidation technique:
   a) Live slope grid
   b) Brush layers
   c) Live fascines
4. In soil and water bioengineering works the use of biodegradable material is:
   a) Used hardly ever. It is preferred the use of non-biodegradable material
   b) Used always
   c) Used just depending on the soil conditions
5. In soil and water bioengineering works, the followed strategy consists in:
   a) Stabilizing the intervention area by constructing permanent structures and element
   b) Looking for a transfer process between the initial rigid material used and the evolving plant communities
   c) stabilizing the area by letting the nature to restore by itself always
6. In soil and water bioengineering works, a maintenance stage throughout the work service life is:
   a) Not necessary
   b) Is sometimes necessary
   c) Is always necessary.
7. Geotechnical and/or hydraulic calculations are necessary for an adequate design of soil and water bioengineering works:
   a) True
   b) False
   c) It depends on the bioengineer's knowledge
8. Because of the manifold functions and targets pursued in soil and water bioengineering interventions, transdisciplinarity is:
   a) Sometimes necessary
   b) Always necessary
   c) Hardly ever necessary
9. The decay/deterioration processes of the biodegradable materials utilized in soil and water bioengineering works must be considered at the design stage:
   a) Only when human risks are present in the intervention area
   b) When the manufacturer prompts it.
   c) Always.
10. The typical stages in soil and water bioengineering works are:
    a) Design and monitoring stages
    b) Construction and maintenance stages

c) Design, construction maintenance and monitoring stages.

MODULE 2.

SOIL AND WATER BIOENGINEERING AND GEOLOGICAL ENGINEERING

Module

2

ECOMED

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

Module2	Soil and Water bioengineering and Geological Engineering

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

Soil and Water bioengineering and Geological Engineering

Authors:

João Paulo Fernandes, Aldo Freitas , Guillermo Tardío , Paola Sangalli , Ana Oliveira, Sílvia Faria , Ettore Marrone, Angela Salustri, Giuseppe Burricco, Vincenzo Astarita

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Module 2 **Soil and Water bioengineering and Geological Engineering**

1. MODULE DESCRIPTOR

Status: core

Credit Points (ECTS):6

Pre-requisite knowledge:none

Module structure:

Activity	Total Hours
Lectures	50
Tutorials	20
Seminars	20
Practicals	28
Independent learning	30
Assessment	2
Total	150hours

Summary of module content:

This module will present the basic issues related to the instability of slopes and soil erosion.

The main models will be presented and applied both for structural stability (mass movement) as for soil erosion.

The main Soil Bioengineering approaches to these problems will be presented and its efficiency evaluated according to the existing models.

Learning outcomes:

On successful completion of this module students should be able to:

Identify the main instability processes occurring in slopes and relating them to the slope geology, soil and drainage.

Handle the main models characterizing both erosion and mass movement processes

Identifying the critical issues to be controlled and the necessary technical approaches

Identify the viability of soil bioengineering interventions and assess their typology and limits of applicability

Identify and conceive the adequate soil bioengineering techniques for each situation

Evaluate their efficiency using the existing models

Teaching/Learning strategy:

Teaching will follow novel methods derived through the ECOMED project: lectures for imparting fundamentals of module and tutorials and practicals for application of the fundamentals. These will be supplemented with virtual learning content, case study analysis, site visits and work placements.

Other learning and teaching strategies will be developed and implemented, appropriate to student needs, to enable all students to participate fully in the module.

Indicative reading:

Bloemer, S. et al 2015. European Guidelines for Soil and Water bioengineering. EFIB

Bromhead, E. N. (1992) – The Stability of Slopes. 2nd. Ed. Blackie Academic & Professional. Chapman & Hall.

EFIB. European Guidelines for Soil and Water bioengineering. 2015. Edited by the European Federation for Soil and Water bioengineering (EFIB).

Ortigao, J.A.R. & Sayao, A.S.F.J. (Ed.)(2004) – Handbook of slope Stabilization. Springer. Heidelberg.

Coppin, N.J. y I.G. Richards (Eds.) 1990. Use of Vegetation in Civil Engineering. Construction Industry Research and Information Association (CIRIA). Butterworths, London

Cornelini, P., y G. Sauli. 2005. Manuale di Indririzzo delle scelte progettuali per interventi di Ingegnieria Naturalistica. Ministero dell'Ambiente y della Tutela del Territorio, Roma

Fernandes, J.P. e A. Freitas, 2011 - *Introdução à Engenharia Natural* - Colecção Nascentes para a Vida, EPAL, Lisboa

GRAY, D.H.; Leiser, A.T. (1982) *Biotechnical Slope Protection and Erosion Control*. Van Nostrand Reinhold Company, New York

Gray, D. H., Sotir, Robbin B. 1996. Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. Wiley-Interscience, ISBN 10: 0471049786 ISBN 13: 9780471049784.

Menegazzi, G., & Palmeri, F. (2013). Il dimensionamento delle opere di Ingegneria Naturalistica. *Direzione Infrastrutture, Ambiente e Politiche Abitative. Regione Lazio.*

Norris, J.E.; Stokes, A.; Mickovski, S.B.; Cammeraat, E.; van Beek, R.; Nicoll, B.C.; Achim, A. (Eds.) Slope Stability and Erosion Control: Ecotechnological Solutions. 2008, VI, 290 p., Hardcover. Springer.

SAULI, G.; Cornelini, R.; Preti, F., (2006) Manuale di Ingegnieria Naturalística, Sistemazione dei versanti. Regione Lazio, Roma

Schiechtl, H.M. 1980. Bioengineering for land reclamation and conservation. Univ. of Alberta Press. Edmonton/Alberta

Schiechtl, H. M., Stern, R. 1996. Ground Bioengineering Techniques: For Slope Protection and Erosion Control. Wiley-Blackwell, ISBN 10: 0632040610, ISBN 13: 9780632040612.

Studer, R, Zeh, H., De Cesare, G. 2014. Soil bioengineering – construction type manual. vdf Hochschulverlag AG der ETH Zürich, ISBN: 978-3-7281-3642-8

Transferable skills development:

Setting personal targets and time management.

Learning skills will be enhanced by use of open-source information and IT skills to research and collate information for case studies.

Communication skills will be enhanced by requiring the use of appropriate language when writing and speaking to fulfil assignments and when making presentations in seminars.

Group-work skills will be developed to address case study problems including the taking of initiative and assuming responsiblity in carrying out agreed tasks.

Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Class test	10	20	50	Project elaboration
Practical	18	40	50	Field characterization and construction practice
Exam	2	40	50	Unseen exam
Total	30			

Module contacts:

Module leader: Prof. João Paulo Fernandes

Module tutor (academic): Prof.Carlos Pinto Gomes, Prof. António Pinho

Module tutor (industry): Mr. Aldo Freitas, Dr. Guillermo Tardio

Topics for a Handbook – Exemplificative texts sample

2. INTRODUCTION TO SOIL BIOENGINEERING

Soil bioengineering is a discipline that combines technology and biology, making use of plants and plant communities to help protect land uses and infrastructures, and contribute to landscape development, particular in the domain of slope stability and erosion control.

Typically, plants and parts of plants are used as living building materials, in such a way that, through their development in combination with soil and rock, they ensure a significant contribution to the long-term protection against all forms of erosion. In the initial phase, they often have to be combined with non-living building materials, which may, in some cases, ensure more or less temporarily, most of the supporting functions.

2.1 Reinforcing effects of plants in the slopes

When speaking of slope instabilities and domains of intervention of Soil Bioengineering, we are dealing with two types of phenomena: superficial erosion and slope instabilities.

The reinforcing effects of vegetation regarding the superficial erosion are the following: interception, restraint, retardation and infiltration. All these processes will be explained in detail in the Module 3 'Water bioengineering, hydrology and hydraulics'.

The reinforcing effects of vegetating regarding slope mass movements are: soil reinforcement, moisture extraction, buttressing and arching. All these effects will be explained in this module.

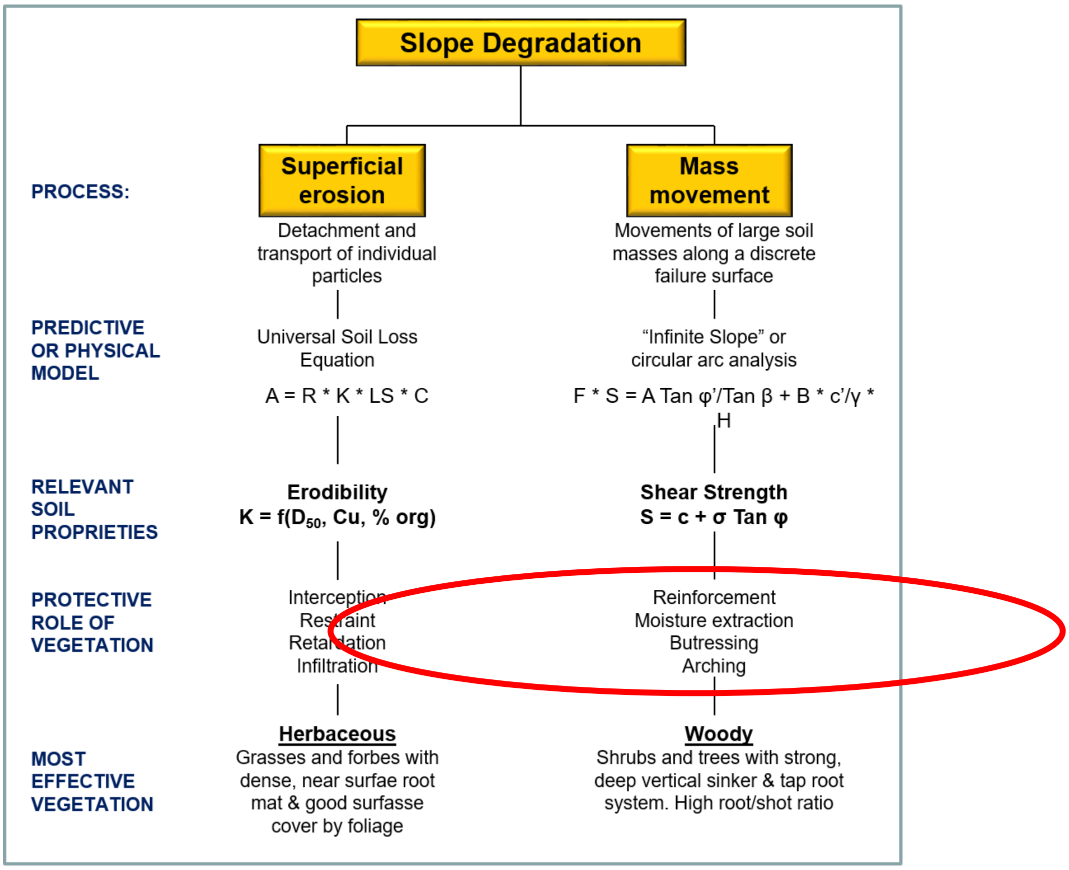


Ilustración 1 Slope degradation processes, determinant factors and most effective vegetation

As explained in Module 1 'Introduction to Soil and Water Bioengineering', the main reinforcing functions of the vegetation are landcover, anchoring, structuring, supporting and, buttressing. All theses reinforcing effects address the instability processes explained before.

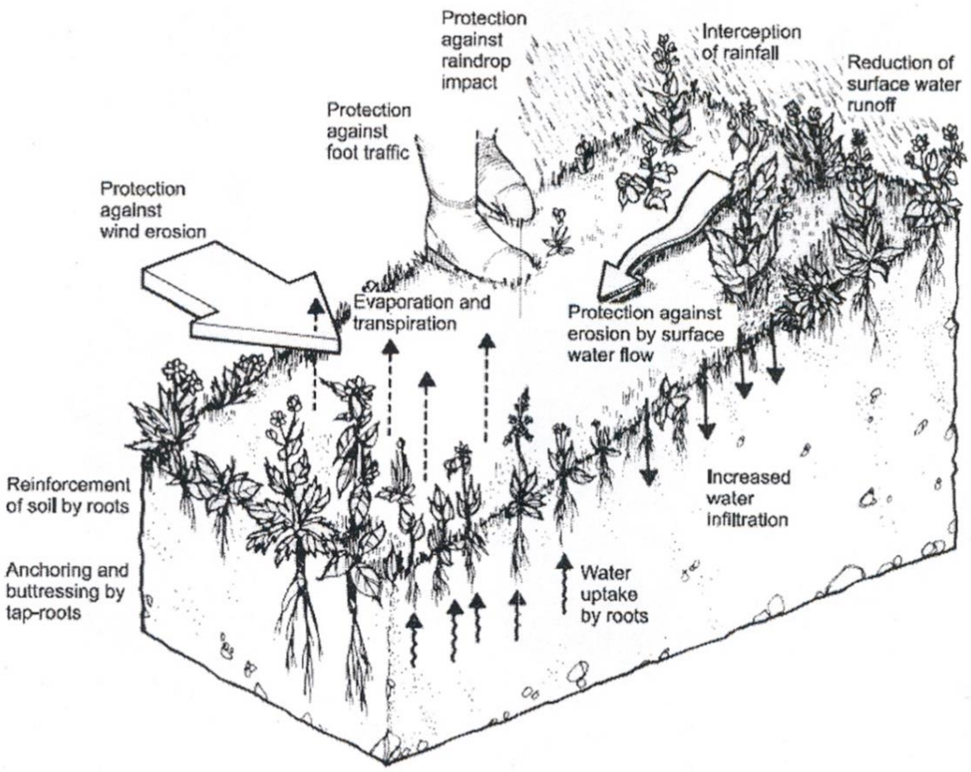


Ilustración 2 Influences of vegetation on the soil

Grass and shrubs are very effective at stopping soil erosion. This is primarily because plant roots tend to hold soil together, making it harder to erode. The leaves of the plants also help to reduce the velocity of raindrops falling on the ground, making it harder for them to dislodge the soil and erode it. Ornamental grass and low, spreading shrubs work best as they leave no areas of bare soil exposed to the elements.

Soils covered by vegetation run less risk of erosion from both water and land movement. The role roots play in slope stabilization has been recognized for many years, whereas interest in bio-mechanical tests on roots (of Mediterranean species in particular) has arisen only in more recent years.

3. SLOPE INSTABILITY

3.1 Mass movements

A landslide, also known as a landslip, is a geological phenomenon that includes a wide range of ground movements, such as rockfalls, deep failure of slopes and shallow debris flows. Landslides can occur in offshore, coastal and onshore environments. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific sub-surface conditions that make the area/slope prone to failure, whereas the actual landslide often requires a trigger before being released.

3.1.1 Causes of landslides

The causes of landslides are usually related to instabilities in slopes. It is usually possible to identify one or more landslide causes and one landslide trigger. The difference between these two concepts is subtle but important. The landslide causes are the reasons that a landslide occurred in that location and at that time. Landslide causes are listed in the following table, and include geological factors, morphological factors, physical factors and factors associated with human activity.

Causes may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable. The trigger is the single event that finally initiated the landslide. Thus, causes combine to make a slope vulnerable to failure, and the trigger finally initiates the movement. Landslides can have many causes but can only have one trigger as shown in the next figure. Usually, it is relatively easy to determine the trigger after the landslide has occurred (although it is generally very difficult to determine the exact nature of landslide triggers ahead of a movement event).

Geological causes	**Physical causes**
Weathered Materials e.g. heavy rainfall Sheared materials Jointed or fissured materials Adversely orientated discontinuities Permeability contrasts Material contrasts Rainfall and snow fall Earthquakes **Morphological causes** Slope angle Uplift Rebound Fluvial erosion Wave erosion Glacial erosion Erosion of lateral margins Subterranean erosion Slope loading Vegetation change Erosion	Intense rainfall Rapid snow melt Prolonged precipitation Rapid drawdown Earthquake Volcanic eruption Thawing Freeze-thaw Ground water changes Soil pore water pressure Surface runoff Seismic activity Soil erosion **Human causes** Excavation Loading Draw-down Land use (e.g. construction of roads, houses etc.) Water management Mining Quarrying

	Vibration Water leakage Deforestation Land use pattern Pollution

Although there are multiple types of causes of landslides, the three that cause most of the damaging landslides around the world are these:

3.1.2 Landslides and Water

Slope saturation by water is a primary cause of landslides. This effect can occur in the form of intense rainfall, snowmelt, changes in ground-water levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers.

Land sliding and flooding are closely allied because both are related to precipitation, runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area.

Landslides can cause flooding by forming landslide dams that block valleys and stream channels, allowing large amounts of water to back up. This causes backwater flooding and, if the dam fails, subsequent downstream flooding. Also, solid landslide debris can “bulk” or add volume and density to otherwise normal streamflow or cause channel blockages and diversions creating flood conditions or localized erosion. Landslides can also cause overtopping of reservoirs and/or reduced capacity of reservoirs to store water.

3.1.3 Landslides and Seismic Activity

Many mountainous areas that are vulnerable to landslides have also experienced at least moderate rates of earthquake occurrence in recorded times. The occurrence of earthquakes in steep landslide-prone areas greatly increases the likelihood that landslides will occur, due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water. The 1964 Great Alaska Earthquake caused widespread land sliding and other ground failure, which caused most of the monetary loss due to the earthquake. Other areas of the United States, such as California and the Puget Sound region in Washington, have experienced slides, lateral spreading, and other types of ground failure due to moderate to large earthquakes. Widespread rock falls also are caused by loosening of rocks as a result of ground shaking. Worldwide, landslides caused by earthquakes kill people and damage structures at higher rates than in the United States.

3.1.4 Landslides and Volcanic Activity

Landslides due to volcanic activity are some of the most devastating types. Volcanic lava may melt snow at a rapid rate, causing a deluge of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes, devastating anything in its path. These volcanic debris flows (also known as lahars) reach great distances, once they leave the flanks of the volcano, and can damage structures in flat areas surrounding the volcanoes. The 1980 eruption of Mount St. Helens, in Washington triggered a massive landslide on the north flank of the volcano, the largest landslide in recorded times.

3.1.5 Types of landslides

Debris flow

Ilustración 3 Debris flow channel

Debris flow channel with deposits left after 2010 storms in Ladakh,NW Indian Himalaya.

Slope material that becomes saturated with water may develop into a debris flow or mud flow. The resulting slurry of rock and mud may pick up trees, houses and cars, thus blocking bridges and tributaries causing flooding along its path.Debris flow is often mistaken for flash flood, but they are entirely different processes.

Muddy-debris flows in alpine areas cause severe damage to structures and infrastructure and often claim human lives. Muddy-debris flows can start as a result of slope-related factors and shallow landslides can dam stream beds, resulting in temporary water blockage. As the impoundments fail, a “domino effect” may be created, with a remarkable growth in the volume of the flowing mass, which takes up the debris in the stream channel. The solid-liquid mixture can reach densities of up to 2 tons/m^3 and velocities of up to 14 m/s. These processes normally cause the first severe road interruptions, due not only to deposits accumulated on the road (from several cubic metres to hundreds of cubic metres), but in some cases to the complete removal of bridges or roadways or railways crossing the stream channel. Damage usually derives from a common underestimation of mud-debris flows: in the alpine valleys, for example, bridges are frequently destroyed by the impact force of the flow because their span is usually calculated only for a water discharge. For a small basin in the Italian Alps (area = 1.76 km^2) affected by a debris flow, a peak discharge of 750 m3/s for a section located in the middle stretch of the main channelwas estimated. At the same cross section, the maximum foreseeable water discharge (by HEC-1), was 19 m^3/s, a value about 40 times lower than that calculated for the debris flow that occurred.

Earthflows

Earthflows are downslope, viscous flows of saturated, fine-grained materials, which move at any speed from slow to fast. Typically, they can move at speeds from 0.17 to 20 km/h (0.1 to 12.4 mph). Though these are a lot like mudflows, overall they are slower moving and are covered with solid material carried along by flow from within. They are different from fluid flows because they are more rapid. Clay, fine sand and silt, and fine-grained, pyroclastic material are all susceptible to earthflows. The velocity of the earthflow is all dependent on how much water content is in the flow itself: if there is more water content in the flow, the higher the velocity will be.

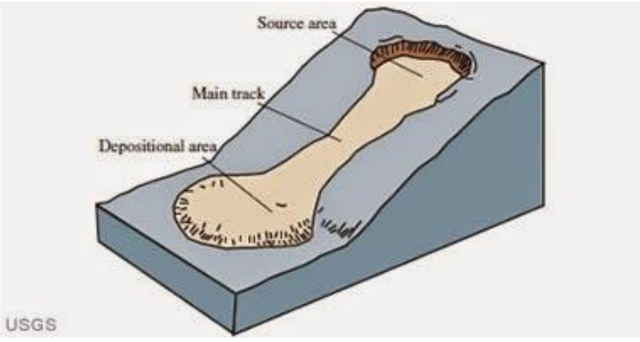


Ilustración 4 Earthflows

These flows usually begin when the pore pressures in a fine-grained mass increase until enough of the weight of the material is supported by pore water to significantly decrease the internal shearing strength of the material. This thereby creates a bulging lobe which advances with a slow, rolling motion. As these lobes spread out, drainage of the mass increases and the margins dry out, thereby lowering the overall velocity of the flow. This process causes the flow to thicken. The bulbous variety of earthflows are not that spectacular, but they are much more common than their rapid counterparts. They develop a sag at their heads and are usually derived from the slumping at the source.

Earthflows occur much more during periods of high precipitation, which saturates the ground and adds water to the slope content. Fissures develop during the movement of clay-like material which creates the intrusion of water into the earthflows. Water then increases the pore-water pressure and reduces the shearing strength of the material.

Debris landslide

A debris slide is a type of slide characterized by the chaotic movement of rocks soil and debris mixed with water or ice (or both). They are usually triggered by the saturation of thickly vegetated slopes which results in an incoherent mixture of broken timber, smaller vegetation and other debris. Debris avalanches differ from debris slides because their movement is much more rapid. This is usually a result of lower cohesion or higher water content and commonly steeper slopes.

Steep coastal cliffs can be caused by catastrophic debris avalanches. These have been common on the submerged flanks of ocean island volcanos such as the Hawaiian Islands and the Cape Verde Islands. Another slip of this type was Storegga landslide.

Movement: Debris slides generally start with big rocks that start at the top of the slide and begin to break apart as they slide towards the bottom. This is much slower than a debris avalanche. Debris avalanches are very fast and the entire mass seems to liquefy as it slides down the slope. This is caused by a combination of saturated material, and steep slopes. As the debris moves down the slope it generally follows stream channels leaving a v-shaped scar as it moves down the hill. This differs from the more U-shaped scar of a slump. Debris avalanches can also travel well past the foot of the slope due to their tremendous speed.

Sturzstrom

A sturzstrom is a rare, poorly understood type of landslide, typically with a long run-out. Often very large, these slides are unusually mobile, flowing very far over a low angle, flat, or even slightly uphill terrain.

Shallow landslide

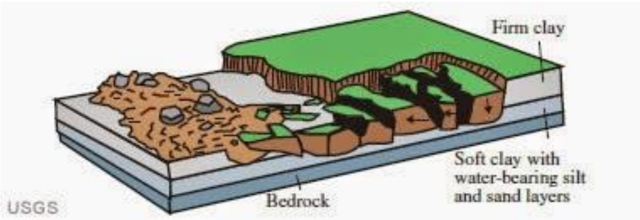


Ilustración 5 Lateral Spreads

Landslide in which the sliding surface is located within the soil mantle or weathered bedrock (typically to a depth from few decimetres to some metres)is called a shallow landslide. They usually include debris slides, debris flow, and failures of road cut-slopes. Landslides occurring as single large blocks of rock moving slowly down slope are sometimes called block glides.

Shallow landslides can often happen in areas that have slopes with high permeable soils on top of low permeable bottom soils. The low permeable, bottom soils trap the water in the shallower, high permeable soils creating high water pressure in the top soils. As the top soils are filled with water and become heavy, slopes can become very unstable and slide over the low permeable bottom soils. Say there is a slope with silt and sand as its top soil and bedrock as its bottom soil. During an intense rainstorm, the bedrock will keep the rain trapped in the top soils of silt and sand. As the topsoil becomes saturated and heavy, it can start to slide over the bedrock and become a shallow landslide. R. H. Campbell did a study on shallow landslides on Santa Cruz Island California. He notes that if permeability decreases with depth, a perched water table may develop in soils at intense precipitation. When pore water pressures are sufficient to reduce effective normal stress to a critical level, failure occurs.

Deep-seated landslide

Ilustración 6 Deep-seated landslide

Deep-seated landslide on a mountain in Sehara, Kihō, Japan caused by torrential rain of Tropical Storm Talas

Landslides in which the sliding surface is mostly deeply located below the maximum rooting depth of trees (typically to depths greater than ten meters). Deep-seated landslides usually involve deep regolith, weathered rock, and/or bedrock and include large slope failure associated with translational, rotational, or complex movement. This type of landslides are potentially occur in an tectonic active region like Zagros Mountain in Iran. These typically move slowly, only several meters per year, but occasionally move faster. They tend to be larger than shallow landslides and form along a plane of weakness such as a fault or bedding plane. They can be visually identified by concave scarps at the top and steep areas at the toe.

Types and classification

The following table shows a schematic landslide classification (USGS)

Tabla 1schematic landslide classification (USGS)

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
COMPLEX		Combination of two or more principal types of movement		

Read more : http://www.geologypage.com/2015/04/landslide.html#ixzz5FZL0Cz2O
Follow us: @geologypage on Twitter | geologypage on Facebook

3.2 Soil erosion

Note: this topic will be covered in more detail in the Module 3 'Water bioengineering, hydrology and hydraulics'

Soil erosion is a continuing long term problem. Erosion involves the detachment, transport and deposition of soil particles and aggregates. Sediment yield is defined as the total amount of eroded material to be delivered from its source to a downstream control point. Thus, sediment yield rates are directly dependent upon both soil loss rates and the transport efficiency of surface runoff and channel flow.

Natural processes such as the production of soil occur at an alarmingly slower rate than soil can be lost. It is estimated that over 3 billion metric tons of soil are eroded off of our fields and pastures each year by water erosion alone. The main variables affecting water erosion are **precipitation** and **surface runoff**. Raindrops, the most common form of precipitation, can be very destructive when they strike bare soil. With impacts of over 20 mph, raindrops splash grains of soil into the air and wash out seeds. Overland flow, or surface runoff, then carries away the detached soil, and may detach additional soils and then sediment which can be deposited elsewhere.

Sheet and **interrill erosion** are mainly caused by rainfall. However, some of the more severe erosion problems such as **rill erosion**, **channel erosion**, and **gully erosion** all result from concentrated overland flow. Other types of erosion by water include **landslides**.

Soil erosion is, at its core, a natural process. Put simply, it is when topsoil, which is the upper-most layer of the ground, is moved from one spot to another. Why this matters is because topsoil is the part of the land that is highest in organic matter and best suited for farming and other fertile activities, which is why soil erosion can have the greatest impact on farmers and agricultural land. In other words, soil erosion is a naturally occurring and slow process that refers to loss of field's top soil by water and wind or through conversion of natural vegetation to agricultural land.

When farming activities are carried out, the top soil is exposed and is often blown away by wind or washed away by rain. When soil erosion occurs, the movement of the detached topsoil is typically facilitated by either a natural process – such as wind or water movement – or by the impact of man, such as through tilling farmland.

The process of soil erosion is made up of three parts:

- **Detachment:** This is when the topsoil is actually "detached" from the rest of the ground.
- **Movement:** This is when the topsoil is relocated to another area.
- **Deposition:** Where the topsoil ends up after this process.

When it comes to our planet, natural resources are typically affected by two things – either naturally-occurring ones such as weather, or from man-made influence. Soil erosion, or the gradual reduction of topsoil in a geographic area, can be caused by both natural and unnatural processes, but it can also have great effects on inhabitants of an affected area. One of the major concerns regarding soil erosion is that it can permanently affect the land, which can be devastating for farmers or those with agricultural pursuits.

3.2.1 Causes of Soil Erosion

As mentioned, the predominant causes of soil erosion are either related to naturally-occurring events or influenced by the presence of human activity. Some of the principal causes of soil erosion include:

- **Rain and rainwater runoff:** In a particular heavy rain, soil erosion is common. First of all, the water starts to break down the soil, dispersing the materials it is made of. Typically, rainwater runoff will impact lighter materials like silt, organic matter, and finer sand particles, but in heavy rainfall, this can also include the larger material components as well.
- **Farming:** When land is worked through crops or other agricultural processes, it reduces the overall structure of the soil, in addition to reducing the levels of organic matter, making it more susceptible to the effects of rain and water. Tilling in particular, because it often breaks up and softens the structure of soil, can be a major contributor to erosion. Farming practices that reduce this activity tend to have far less issues with soil erosion.
- **Slope of the land:** The physical characteristics of the land can also contribute to soil erosion. For example, land with a high hill slope will perpetuate the process of rainwater or runoff saturation in the area, particularly due to the faster movement of the water down a slope.
- **Lack of vegetation:** Plants and crops help maintain the structure of soils, reducing the amount of soil erosion. Areas with less naturally-occurring flora may be a hint that the soil is prone to erosion.
- **Wind:** Wind can be a major factor in reducing soil quality and promotion erosion, particularly if the soil's structure has already been loosened up. However, lighter winds will

typically not cause too much damage, if any. The most susceptible soil to this type of erosion is sandy or lighter soil that can easily be transported through the air.

3.2.2 Effects of Soil Erosion

A major problem with soil erosion is that there is no telling how quickly or slowly it will occur. If largely impacted by ongoing weather or climate events, it may be a slow-developing process that is never even noticed. However, a severe weather occurrence or other experience can contribute to rapid-moving erosion, which can cause great harm to the area and its inhabitants.

4. FACTORS CONTRIBUTING TO EROSION AND SLOPE INSTABILITY

4.1 Factors that affect erosion risk

4.1.1 Introduction to Water Erosion Risk

The assessment of relative risk of erosion to bare soil involves consideration of slope class erodibility. Previous vegetative covers are not taken into consideration for water erosion risk analysis. Also, it is not important whether the land was cleared from its vegetative cover for residential or agricultural purposes.

The important factors affecting water erosion risks are:

i. Slope class

ii. Soil erodibility; and

iii. Soil resistance to detachment.

Erosion gets increase with increase in slope gradient. The shape of slope also affects the rate of soil loss to some extent.

The soil erodibility is a complex type of land property affecting the erosion potential. There is very large difference between soils regarding their susceptibility to water erosion. These differences may be in terms of resistance to detachment of soil particles, e.g., structural breakdown due to raindrop impact or sheet of water flow and the infiltration characteristics, which allow absorbing the rainwater as it falls on the ground surface; and thus limiting the runoff. In this way, the soil erodibility reflects two subsidiary qualities; they are the soil resistance to detachment and rainfall acceptance.

The resistance of soil to detachment or breakdown largely depends on the texture, structure and dispersability. The soil texture affects the soil resistance, surface structure and aggregate stability, is an important parameter. The other factors which affect the resistance to detachment or breakdown, are the surface gravel and stone cover, soil surface condition and surface structure.

Assessment of Water Erosion Risk:

For land capability studies the assessment of water erosion risk to bare soil is very important requirement. The water erosion risk is defined as the intrinsic susceptibility of land to water erosion. The climate, landform and soil factors decide it. The land use and land management factors are not considered for this purpose.

The erosion risk denotes to an intrinsic quality of the land, whereas hazard refers to the combination of risk and land use/management factors. Water erosion is the process, in which the soil particles are detached and transported from one point to another on the land surface by the action of rainfall, runoff, seepage and/or ice. The splash, sheet, rill, gully, stream bank and tunnel erosions are the common forms of water erosion.

The most satisfactory method for assessing the erosion hazard is the soil loss predicting models, derived by taking into account the effects of climate, soil erodibility, slope, slope length, vegetative cover and soil conservation practices. Amongst all the USLE, i.e. Universal Soil Loss Equation is considered to be very useful empirical model for this purpose. The USLE predicts the rate of soil loss on the basis of several factors (R, K, LS, C and P), simply by multiplying them together.

The slope class and soil erodibility are the parameters, mainly considered for assessment of relative risk of soil erosion to bare soil.

The slope classes and soil erodibility parameters are outlined as under:

- Slope Class:
- Soil Erodibility

The water erosion risk can be determined on the basis of slope class and soil erodibility rating. The soil erodibility rating is determined based on the soil resistance to detachment, and runoff producing factors, i.e., the rainfall acceptance, which can be obtained by using the land resource survey data or land characteristics.

All the preceding topics, concepts and the erosion risk assessment procedures will be explained in detail in the Module 3 'Water bioengineering, hydrology and hydraulics'.

4.2 Factors Influencing Landslide Risk

4.2.1 Slope Characteristics

Height: The height of a slope can generally indicate landslide risk. While sediment strength depends on several factors, the thicker the sediment deposit, the more likely its weight will cause subsurface movement or slippage that leads to a landslide. The risk of a landslide increases when mud slopes have a height of twenty feet or more. In general, the higher the exposed slope face the greater the risk of a landslide.

Sediment type: Earth material that makes up a slope influences the risk of a landslide occurring. Clay and silt (muddy) sediment are the most unstable materials that can make up a slope. These fine-grained sediments are weak and prone to moving in the form of slow-motion creep, moderate-sized slumping, or large landslides. Sand and gravel deposits tend to be stronger and better drained than muddy sediment. Landslides can occur in coarse-grained slopes although they are less frequent than muddy landslides.

Slope: The angle of a slope face varies due to factors such as the sediment type and rate of erosion at the slope base. Slope is also affected by the history of slumps and landslides at the site. Some slopes are uniformly straight while others are terraced or uneven due to earth movements. In general, the steeper the slope, the easier it is for gravity to initiate a landslide.

Vegetation: Types, shapes, and distribution of vegetation above and on a slope face can be used as an indication of site stability. In areas where the soil has shifted, either due to previous landslides or to gradual surface creep, many tree trunks can become tilted or twisted in the same direction. Curved tree trunks near the roots often indicate land movement down the face of a bluff. Large trees on the bluff face may be moved by wind and resulting root motion may loosen slope sediment. Natural vegetation that consists only of small shrubs and trees may indicate recent slope erosion or a landslide.

Bedrock: Crystalline rock or ledge is much more stable than any sediment slope or cliff and not likely to erode or slide. The elevation of bedrock is important in determining landslide risk. Bedrock exposures may slow erosion and make sediment less susceptible to land sliding. Beneath a sediment slope, bedrock may rise toward the surface and reduce the overall thickness of sediment and thus reduce the risk of deep-seated movement below the ground surface.

4.2.2 Natural Conditions

Waves, tides, and sea level: Several marine processes affect the risk of landslides along a coastal slope. A gradual, but ongoing rise in sea level at a rate of about an inch per decade is causing chronic erosion along the base of many slopes. As sea level rises, wave action and coastal flooding can reach higher and farther inland and scour more sediment from a bluff. Sea ice erodes tidal flats and the base of bluffs by abrasion and freezing sediment in ice blocks. Erosion can increase the slope declivityand make it more susceptible to land sliding. Tides are also important in washing away eroded sediment which helps wave action move inland. Storms that create wind, waves, and flooding can cause more extreme erosion at the base of a slope or a cliff, increase the slope declivity, and make a landslide more likely.

Surface water: The amount, type, and location of surface water can influence slope stability and may contribute to some landslides. Wetlands, ponds, and streams above the slope can supply water to the slope face and also to the ground water. The elevation or topography of the land surface determines which way surface water will flow. Water that runs over the face of a slope can wash sediment, increase the declivity, and weaken the remaining sediment holding up the slope.

Ground water: Ground water comes from surface sources, such as rain or a stream, uphill in the local watershed. Ground water tends to flow horizontally beneath the surface and may seep out the face of a slope or cliff. Seeps and springs on the slope face contribute to surface water flow and destabilize the surface. In addition, a high water table can saturate and weaken sediment and make the material more prone to slope failure.

Weathering: Weathering in clay and silt but also in consolidated rocks can change the strength and stability. Drying of clay can increase resistance to sliding. The seasonal cycle of freezing and thawing of the slope face can lead to slumping after a thaw.

Earthquakes: Landslides can be triggered by earthquakes. Ground vibration loosens sediment enough to reduce the strength of material supporting a slope and a landslide results.

4.2.3 Human Activity

Land use: Human activity and land use may contribute to or reduce the risk of a landslide. Actions that increase surface water flow to the slope surface, watering lawns or grading slopes, add to natural processes destabilizing it. Surface water, collected by roofs, driveways, paths, and lawns flows toward and down the slope surface causing erosion and, through infiltration, loss of cohesion. Walkways down the face of a slope can lead to greater erosion from foot traffic or the concentration of surface water flow. Both surface and ground water above a slope can be supplied by pipes, culverts, surface drains, and septic systems. Increased water below ground can weaken the cohesion of the material and contribute to internal weakness that leads to a landslide. Greater seepage of water out of the slope face (piping) can also increase the risk.

Clearing of vegetation from the slope face can lead to greater erosion resulting in a steeper surface that is more prone to landslide. Vegetation tends to remove ground water, strengthen soil with roots, and lessen the impact of heavy rain on the surface.

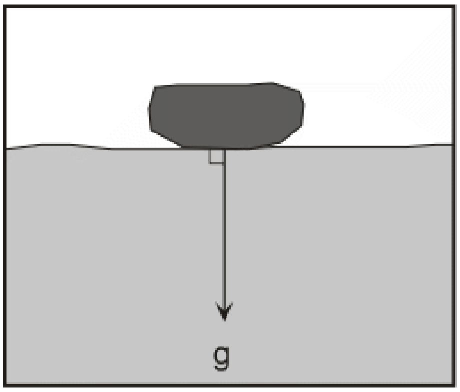
Adding weight to the top of a slope can increase the risk of a landslide. Buildings, landscaping, or fill on the top of the slope can increase the forces that result in a landslide. Saturating the ground with water that raises the water table also adds weight. Even ground vibration, such as well drilling or deep excavation, may locally increase the risk of a landslide.

In general, human activities that increase the amount or rate of natural processes may, in various ways, contribute to landslide risk.

4.3 Understanding the factors that Influence Slope Stability

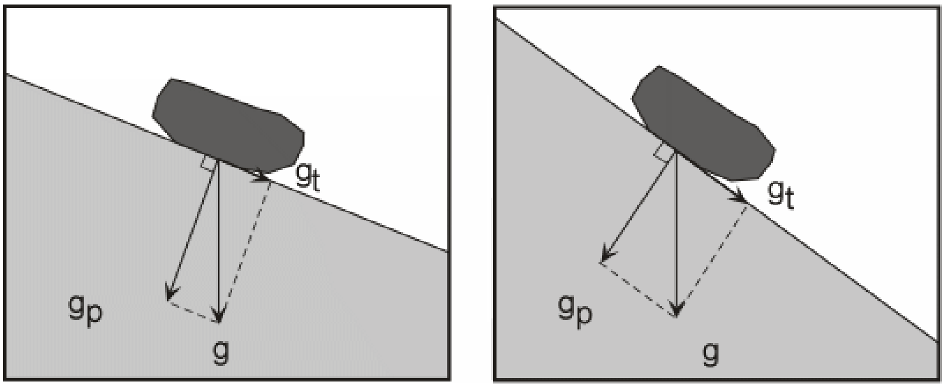
4.3.1 Gravity

The main force responsible for mass movement is gravity. Gravity is the force that acts everywhere on the Earth's surface, pulling everything in a direction toward the center of the Earth. On a flat surface the force of gravity acts downward. So long as the material remains on the flat surface it will not move under the force of gravity.



Of course if the material forming the flat surface becomes weak or fails, then the unsupported mass will move downward.

On a slope, the force of gravity can be resolved into two components: a component acting perpendicular to the slope and a component acting tangential to the slope.



- The perpendicular component of gravity, g_p, helps to hold the object in place on the slope. The tangential component of gravity, g_t, causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope.
- On a steeper slope, the shear stress or tangential component of gravity, g_t, increases, and the perpendicular component of gravity, g_p, decreases.
- The forces resisting movement down the slope are grouped under the term ***shear strength***, which includes frictional resistance and cohesion among the particles that make up the object.
- When the sheer stress becomes greater than the combination of forces holding the object on the slope, the object will move down-slope.
- Alternatively, if the object consists of a collection of materials like soil, clay, sand, etc., if the shear stress becomes greater than the cohesional forces holding the particles together, the particles will separate and move or flow down-slope.

Thus, down-slope movement is favoured by steeper slope angles which increase the shear stress, and anything that reduces the shear strength, such as lowering the cohesion among the particles or lowering the frictional resistance. This is often expressed as the safety factor, F_s, the ratio of shear strength to shear stress.

4.3.2 F_s = Shear Strength/Shear Stress

Shear strength consists of the forces holding the material on the slope and could include friction, and the cohesional forces that hold the rock or soil together. If the safety factor (FOS) becomes less than 1.0, slope failure is expected.

$$FOS = \frac{c + \cos^2 \alpha \left[\gamma_s \left(d_p - d_w\right) + \left(\gamma_s - \gamma_w\right) d_w\right] \tan\varphi}{d_p \gamma_s \sin\alpha \cos\alpha}$$

where c is the cohesion, α is the slope angle, γs and γw are the specific weights of soil and water, dp is the thickness of soil above the failure plane, dw is the thickness of saturated soil above the failure plane, and φ is the angle of internal friction

https://youtu.be/xg-Gw1NrkX8

https://youtu.be/bR-z7mG344w

4.3.3 The Role of Water

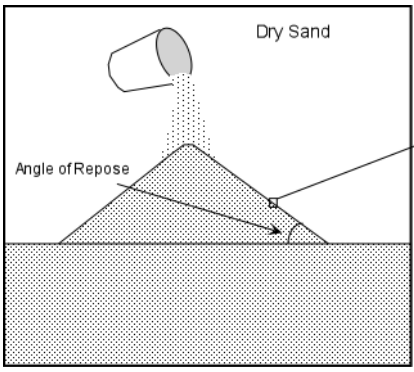
Although water is not always directly involved as the transporting medium in mass movement processes, it does play an important role.

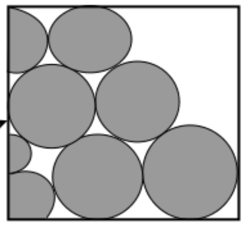
Water becomes important for several reasons

Addition of water from rainfall or snow melt adds weight to the slope. Water can seep into the soil or rock and replace the air in the pore space or fractures. Since water is heavier than air, this increases the weight of the soil. Weight is force, and force is stress divided by area, so the stress increases and this can lead to slope instability.

Water has the ability to change the angle of repose (the slope angle which is the stable angle for the slope).

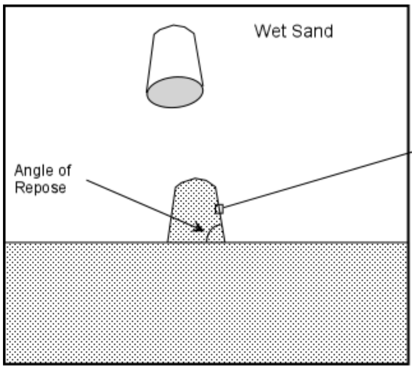
Dry unconsolidated grains will form a pile with a slope angle determined by the ***angle of repose***. The angle of repose is the steepest angle at which a pile of unconsolidated grains remains stable, and is controlled by the frictional contact between the grains. In general, for dry materials the angle of repose increases with increasing grain size, but usually lies between about 30 and 45 °.

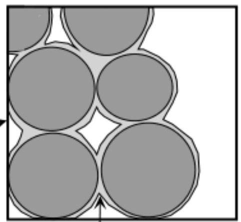




Grain to Grain frictional contact

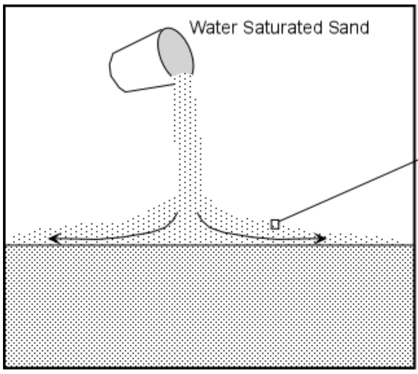
Slightly wet unconsolidated materials exhibit a very high angle of repose because surface tension between the water and the solid grains tends to hold the grains in place.

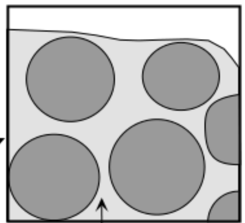




Surface tension of thin film of water holds grains together

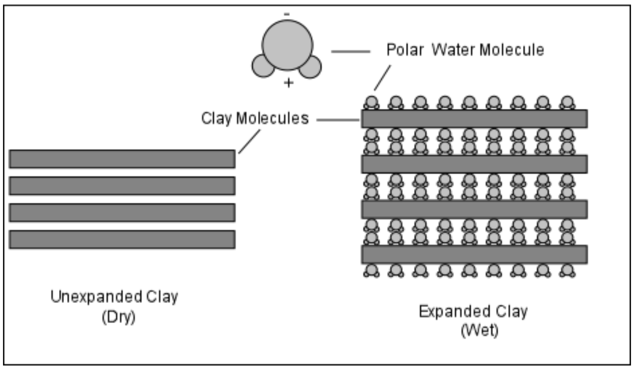
When the material becomes saturated with water, the angle of repose is reduced to very small values and the material tends to flow like a fluid. This is because the water gets between the grains and eliminates grain to grain frictional contact.





Water completely surrounds all grains and eliminates all grain to grain contact.

Water can be adsorbed or absorbed by minerals in the soil. Adsorption, causes the electronically polar water molecule to attach itself to the surface of the minerals. Absorption causes the minerals to take the water molecules into their structure. By adding water in this fashion, the weight of the soil or rock is increased. Furthermore, if adsorption occurs then the surface frictional contact between mineral grains could be lost resulting in a loss of cohesion, thus reducing the strength of the soil.

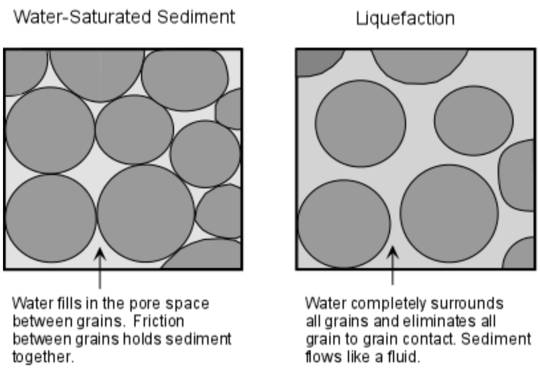


In general, wet clays have lower strength than dry clays, and thus adsorption of water leads to reduced strength of clay-rich soils.

Water can dissolve the mineral cements that hold grains together. If the cement is made of calcite, gypsum, or halite, all of which are very soluble in water, water entering the soil can dissolve this cement and thus reduce the cohesion between the mineral grains.

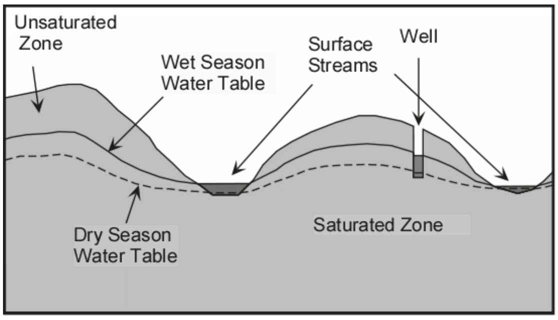
Liquefaction - As we have already discussed, liquefaction occurs when loose sediment becomes oversaturated with water and individual grains loose grain to grain contact with one another as water gets between them.

This can occur as a result of ground shaking, as we discussed during our exploration of earthquakes, or can occur as water is added as a result of heavy rainfall or melting of ice or snow. It can also occur gradually by slow infiltration of water into loose sediments and soils.



The amount of water necessary to transform the sediment or soil from a solid mass into a liquid mass varies with the type of material. Clay bearing sediments in general require more water because water is first absorbed onto the clay minerals, making them even more solid-like, then further water is needed to lift the individual grains away from each other.

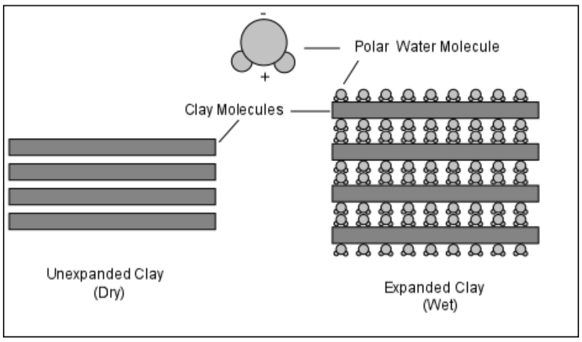
Groundwater exists nearly everywhere beneath the surface of the earth. It is water that fills the pore spaces between grains in rock or soil or fills fractures in the rock. The water table is the surface that separates the saturated zone below, wherein all pore space is filled with water from the unsaturated zone above. Changes in the level of the water table occur due changes in rainfall. The water table tends to rise during wet seasons when more water infiltrates into the system, and falls during dry seasons when less water infiltrates. Such changes in the level of the water table can have effects on the factors (1 through 5) discussed above.



Another aspect of water that affects slope stability is fluid pressure. As soil and rock get buried deeper in the earth, the grains can rearrange themselves to form a more compact structure, but the pore water is constrained to occupy the same space. This can increase the fluid pressure to a point where the water ends up supporting the weight of the overlying rock mass. When this occurs, friction is reduced, and thus the shear strength holding the material on the slope is also reduced, resulting in slope failure.

4.3.4 Troublesome Earth Materials

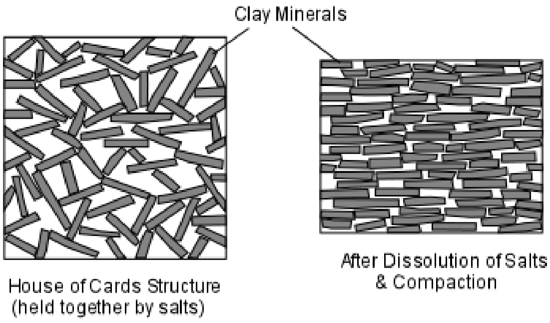
Expansive and Hydrocompacting Soils - These are soils that contain a high proportion of a type of clay mineral called smectites or montmorillinites. Such clay minerals expand when they become wet as water enters the crystal structure and increases the volume of the mineral. When such clays dry out, the loss of water causes the volume to decrease and the clays to shrink or compact (This process is referred to as hydrocompaction).



Another material that shows similar swelling and compaction as a result of addition or removal of water is peat. Peat is organic-rich material accumulated in the bottoms of swamps as decaying vegetable matter.

Sensitive Soils - In some soils the clay minerals are arranged in random fashion, with much pore space between the individual grains. This is often referred to as a "house of cards" structure. Often the grains are held in this position by salts (such as gypsum, calcite, or halite) precipitated in the pore space that "glue" the particles together.

As water infiltrates into the pore spaces, as discussed above, it can both be absorbed onto the clay minerals, and can dissolve away the salts holding the "house of cards" together.



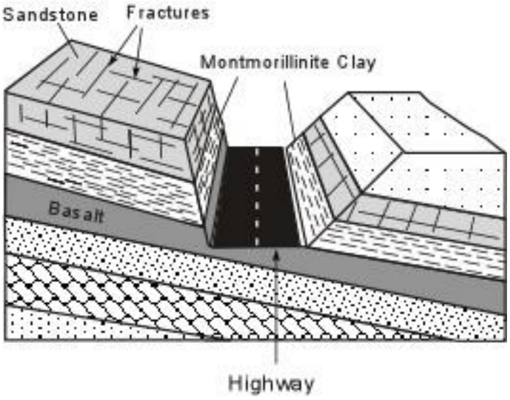
Compaction of the soil or shaking of the soil can thus cause a rapid change in the structure of the material. The clay minerals will then line up with one another and the open space will be reduced.

But this may cause a loss in shear strength of the soil and result in slippage down slope or liquefaction. This is referred to as ***remolding***. Clays that are subject to remolding are called ***quick clays***.

Some clays, called ***thixotropic clays***, when left undisturbed can strengthen, but when disturbed they lose their shear strength. Thus, small earthquakes or vibrations caused by humans or the wind can suddenly cause a loss of strength in such materials.

4.3.5 Weak Materials and Structures

Bedding Planes - These are basically planar layers of rocks upon which original deposition occurred. Since they are planar and since they may have a dip down-slope, they can form surfaces upon which sliding occurs, particularly if water can enter along the bedding plane to reduce cohesion. In the diagram below, note how the slope above the road on the left is inherently less stable than the slope above the road on the right.



Weak Layers - Some rocks are stronger than others. In particular, clay minerals generally tend to have a low shear strength. If a weak rock or soil occurs between stronger rocks or soils, the weak layer will be the most likely place for failure to occur, especially if the layer dips in a down-slope direction as in the illustration above. Similarly, loose unconsolidated sand has no cohesive strength. A layer of such sand then becomes a weak layer in the slope.

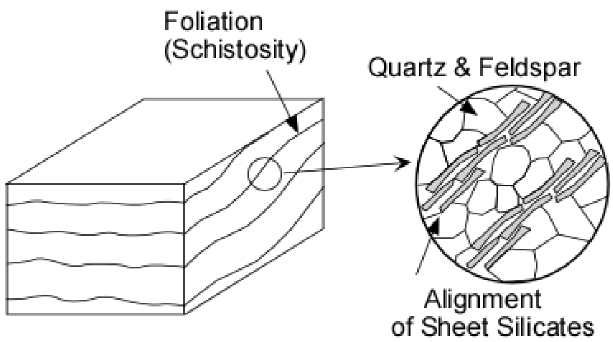
Joints & Fractures - Joints are regularly spaced fractures or cracks in rocks that show no offset across the fracture (fractures that show an offset are called faults).

Joints form as a result of expansion due to cooling, or relief of pressure as overlying rocks are removed by erosion.

Joints form free space in rock by which water, animals, or plants can enter to reduce the cohesion of the rock.

If the joints are parallel to the slope they may become a sliding surface. Combined with joints running perpendicular to the slope (as seen in the sandstone body in the illustration above), the joint pattern results in fractures along which blocks can become loosened to slide down-slope.

Foliation Planes - During metamorphism of rock, differential stress causes sheet silicate minerals, like clay minerals, biotite, and muscovite, to grow with their sheets parallel to one another. This results in the rock having a foliation or schistosity. Because the sheet silicates can break easily parallel to their sheet structure, the foliation or schistosity may become a slip surface, particularly if it it dips in the down-slope direction.



In summary, the main factors affecting slope stability are:

- Strength of soil and rock.
- Type of soil and stratification.
- Discontinuities and planes of weakness.
- Groundwater table and seepage through the slope.
- External loading.
- Geometry of the slope.

4.4 Triggering Events

A mass movement event can occur any time a slope becomes unstable. Sometimes, as in the case of creep or solifluction, the slope is unstable all of the time and the process is continuous. But other times, triggering events can occur that cause a sudden instability to occur. Here we discuss major triggering events, but it should be noted that it if a slope is very close to instability, only a minor event may be necessary to cause a failure and disaster. This may be something as simple as an ant removing the single grain of sand that holds the slope in place.

4.4.1 Shocks

A sudden shock, such as an earthquake may trigger slope instability. Minor shocks like heavy trucks rambling down the road, trees blowing in the wind, or human made explosions can also trigger mass movement events.

4.4.2 Charges upon the top of the slope

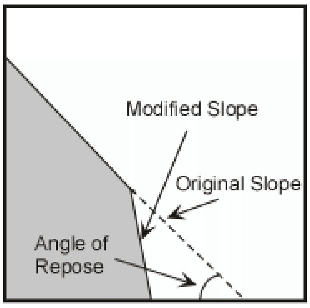
Changing the charges on the top of the slope (constructions, deposits, etc.) increases the acting gravity forces on the slope determining higher stress on the resistance forces.

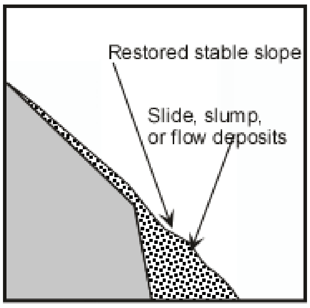
4.4.3 Change of the slope internal water balance

Changing the drainage, increasing infiltration or quick changing the groundwater level determines changes in the slope material cohesion and derived shear strength.

4.4.4 Slope Modification

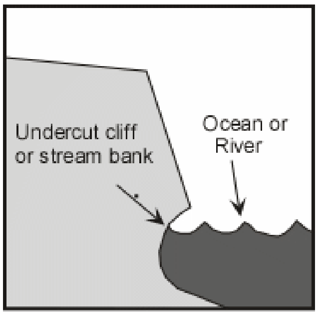
Modification of a slope either by humans or by natural causes can result in changing the slope angle so that it is no longer at the angle of repose. A mass movement event can then restore the slope to its angle of repose.

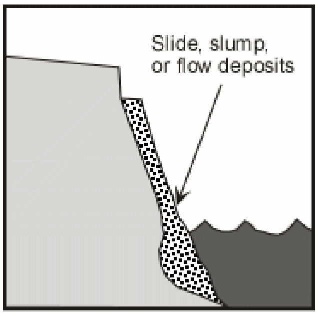




4.4.5 Undercutting

Streams eroding their banks or surf action along a coast can undercut a slope making it unstable.





Undercutting is particularly important when building infrastructures demand more space and therefore it is necessary to remove the base of adjoining slopes. The inadequate consolidation of these cuts is one of the main man made causes of slope faillure.

4.4.6 Fracture systems

Fracture systems in the rocks run parallel to the bedding planes and perpendicular to bedding planes. The latter fractures had formed as a result of glacial erosion which had relieved pressure on the rocks that had formed deeper in the Earth.

4.4.7 Volcanic Eruptions

Produce shocks like explosions and earthquakes. They can also cause snow to melt or empty crater lakes, rapidly releasing large amounts of water that can be mixed with regolith to reduce grain to grain contact and result in debris flows, mudflows, and landslides.

4.4.8 Changes in Slope Strength

Anything that acts to suddenly or gradually change the slope strength can also be a triggering mechanism. For example, Weathering creates weaker material, and thus leads to slope failure.

4.4.9 Changes on the vegetation cover

Vegetation holds soil in place and slows the influx of water. Trees put down roots that hold the ground together and strengthen the slope.Removal of trees and vegetation either by humans or by a forest fire, often results in slope failures in the next rainy season.

In summary, the main causes of slope failure are:

- Erosion.
- Rainfall.
- Earthquakes.
- Geological factors.
- External loading.
- Construction activities such as excavation of slopes and filling of slopes.
- Rapid drawdown*.
- Increment of pore water pressure.
- The change in topography
- Change of drainage and infiltration

*Drawdown : a lowering of water level.

4.5 Assessing and Mitigating Mass Movement Hazards

As we have seen mass movement vents can be extremely hazardous and result in extensive loss of life and property. But, in most cases, areas that are prone to such hazards can be recognized with some geologic knowledge, slopes can be stabilized or avoided, and warning systems can be put in place that can minimize such hazards.

4.5.1 Hazard Assessment

If we look at the case histories of mass movement disasters discussed above, in all cases looking at the event in hindsight shows us that conditions were present that should have told us that a hazardous condition existed prior to the event.

Because there is usually evidence in the form of distinctive deposits and geologic structures left by recent mass movement events, it is possible, if resources are available, to construct maps of all areas prone to possible mass movement hazards.

Planners can use such hazards maps to make decisions about land use policies in such areas or, as will be discussed below, steps can be taken to stabilize slopes to attempt to prevent a disaster.

4.5.2 Prediction

Short-term prediction of mass movement events is somewhat more problematical. For earthquake triggered events, the same problems that are inherent in earthquake prediction are present. Slope destabilization and undercutting triggered events require the constant attention of those undertaking or observing the slopes, many of whom are not educated in the problems inherent in such processes. Mass

movement hazards from volcanic eruptions can be predicted with the same degree of certainty that volcanic eruptions can be predicted, but again, the threat has to be realized and warnings need to be heeded. Hydrologic conditions such as heavy precipitation can be forecast with some certainty, and warnings can be issued to areas that might be susceptible to mass movement processes caused by such conditions. Still, it is difficult of know exactly which hill slope of the millions that exist will be vulnerable to an event triggered by heavy rainfall.
Some warning signs can be recognized individual by observations of things around you:

- Springs, seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements or sidewalks.
- Soil moving away from foundations.
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house.
- Tilting or cracking of concrete floors and foundations.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls or fences
- Offset fence lines.
- Sunken or down-dropped road beds.
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels though rain is still falling or just recently stopped.
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
- A faint rumbling sound that increases in volume is noticeable as the landslide nears.
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris.

4.5.3 Prevention and Mitigation

All slopes are susceptible to mass movement hazards if a triggering event occurs. Thus, all slopes should be assessed for potential mass movement hazards. Mass movement events can sometimes be avoided by employing engineering techniques to make the slope more stable. Among them are:

- Retaining
- Covering
- Draining
- Reshaping

Some slopes, however, cannot be stabilized. In these cases, humans should avoid these areas or use them for purposes that will not increase susceptibility of lives or property to mass movement hazards.

5. MODELATION OF EROSION AND SLOPE STABILITY

5.1 Soil erosion

The USLE, developed by ARS scientists W. Wischmeier and D. Smith, has been the most widely accepted and utilized soil loss equation.

The USLE (Universal Soil Loss Equation) for estimating average annual soil erosion is:

$A = RKLSCP$

- **A** = average annual soil loss (mass per unit of area)
- **R** = rainfall erosivity index
- **K** = soil erodibility factor
- **LS** = topographic factor - L is for slope length & S is for slope
- **C** = cropping factor
- **P** = conservation practice factor

Evaluating the factors in USLE:

R - the rainfall erosivity index

Most appropriately called the erosivity index, it is a statistic calculated from the annual summation of rainfall energy in every storm (correlates with raindrop size) times its maximum 30 - minute intensity. As expected, it varies geographically.

K - the soil erodibility factor

This factor quantifies the cohesive, or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow.

LS - the topographic factor

Steeper slopes produce higher overland flow velocities. Longer slopes accumulate runoff from larger areas and also result in higher flow velocities. Thus, both result in increased erosion potential, but in a non - linear manner. For convenience L and S are frequently lumped into a single term.

C - the crop management factor

This factor is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. The most computationally complicated of USLE factors, it incorporates effects of: tillage management (dates and types), crops, seasonal erosivity index distribution, cropping history (rotation), and crop yield level (organic matter production potential).

P - the conservation practice factor

Practices included in this term are contouring, strip cropping (alternate crops on a given slope established on the contour), and terracing.

This method along with other procedures will be explained in detail in the Module 3 'Water bioengineering, hydrology and hydraulics'

https://youtu.be/yM3tly6bhRc

5.2 Mass movements, Landslides

The SLIP4EX model (Greenwood, 2006; Norris and Greenwood, 2006) is one of the many available models for evaluating slope stability and for the slope stability simulations. The main reason for this selection is the fact that SLIP4EX is a model especially designed to evaluate the influence of vegetation in slope stability and compare the factors of safety with and without vegetation. Furthermore there are already highly diversified applications of the method allowing for an easier assessment of the results (e.g. Stokes, 2000).

The SLIP4EX model is based on the original Greenwood equation for calculating the factor of safety of a slope (Greenwood, 1989; Morrison and Greenwood, 1989) using the traditional stability equation integrating the effect of hydraulic forces (Greenwood, 2006; Norris and Greenwood, 2006), which is proven reliable and consistent:

$$= \frac{\sum[c'l + (W\cos\alpha - ul - (U_2 - U_1)\sin\alpha)\tan\varphi']}{\sum W\sin\alpha}$$

where c' is effective cohesion at base of slice, l is length along base of slice, W is weight of soil, α is the inclination of base of slice to horizontal, φ' is effective angle of friction at base of slice, u is water pressure on base of slice, U_1 and U_2 are interslice water forces on left and right hand side of slice (based on assumed hydrostatic conditions below the phreatic surface or derived from a flow net for more complex hydraulic situations). Considering the effects of vegetation, the equation is changed in the following way (Greenwood, 2006):

$$= \frac{\sum\left[(c' + \boldsymbol{c'_v})l + \left((W + \boldsymbol{W_v})\cos\alpha - (u - \Delta\boldsymbol{u_v})l - \left((U_2 + \Delta\boldsymbol{U_{2v}}) - (U_1 + \Delta U_{1v})\right)\sin\alpha - \boldsymbol{D_W}\sin(\alpha - \beta) + \boldsymbol{T\sin\theta}\right)\tan\varphi'\right]}{\sum[(W + \boldsymbol{W_v})\sin\alpha + \boldsymbol{D_W}\cos(\alpha - \beta) - T\cos\theta]}$$

where the factors displaying the influence of the vegetation are displayed in bold: c'_v is the enhanced cohesion due to the roots, W_v is weight of vegetation, Δu_v is the change in water pressure due to vegetation, ΔU_{1v} and ΔU_{2v} are changes in interslice water forces due to vegetation, D_w is wind force, T is tensile force of roots and θ is the angle of roots to slip surface.

https://youtu.be/2wT2he6Numk

https://youtu.be/b8WEeGrPhgc

https://www.geostru.eu/slope-stability-analysis/

https://people.eng.unimelb.edu.au/stsy/geomechanics_text/Ch11_Slope.pdf

http://civil.utm.my/azril/files/2016/04/Chapter-4-Slope-stability.pdf

http://web.pdx.edu/~i1kc/programming/slopes/LandslideNotes.pdf

6. INTERVENTIONS TO SLOPE STABILIZATION:

6.1 Basic principles of soil bioengineering

The basic principles that apply to conventional soil erosion control also apply in general to soil bioengineering. These principles are mostly common sense guidelines that involve planning, timing, and minimizing site disturbance as well as the design of individual measures themselves. Applicable principles can be summarized as follows:

6.1.1 Fit the soil bioengineering system to the site

This means considering site topography, geology, soils, vegetation, and hydrology. Avoid extensive grading and earthwork in critical areas and perform soil tests to determine if vigorous plant growth can be supported. At a minimum, collect the following information:

6.1.1.1 Topography and exposure

- Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture.
  The likely success of soil bioengineering treatments can best be determined by observing existing stable slopes in the vicinity of the project site.
- Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.
- Look for areas of vegetation that may be growing more vigorously than other site vegetation. This is generally a good indicator of excess moisture, such as seeps and a perched water table, or it may reflect a change in soils.

6.1.1.2 Geology and soils

- Consult geologists about geologic history and types of deposits (colluvium, glacial, alluvium, other).
- Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.
- Determine soil type and depth. Use the soil survey report, if available, or consult soil scientists.

6.1.1.3 Hydrology

- Determine the drainage area associated with the problem area. Note whether water can be diverted away from the problem area.
- Determine the annual precipitation. Are there concentrated discharges?
- Calculate peak flows or mean discharge through the project area.
- If a seep area was noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face.

6.1.2 Retain existing vegetation whenever possible

Vegetation provides excellent protection against surface erosion and shallow slope failures. Soil bioengineering measures are designed to aid or enhance the reestablishment of vegetation.

6.1.3 Limit removal of vegetation

- Limit cleared area to the smallest practical size
- Limit duration of disturbance to the shortest practical time
- Remove and store existing woody vegetation that may be used later in the project
- Schedule land clearing during periods of low precipitation whenever possible

6.1.4 Stockpile and protect topsoil

Topsoil removed during clearing and grading operations can be reused during planting operations.

6.1.5 Protect areas exposed during construction

Temporary erosion and sediment control measures can be used.

6.1.6 Divert, drain, or store excess water

- Install a suitable system to handle increased and/or concentrated runoff caused by changed soil and surface conditions during and after construction.
- Install permanent erosion and sediment control measures in the project before construction is started if possible.

6.2 Design considerations

6.2.1 Earthwork

Typically, sites require some earthwork prior to the installation of soil bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability. The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors.

6.2.2 Scheduling and timing

Planning and coordination are needed to achieve optimal timing and scheduling. The seasonal availability of plants or the best time of year to install them may not coincide with the construction season or with tight construction schedules. In some cases, rooted stock may be used as an alternative to unrooted dormant season cuttings.

6.2.3 Vegetative damage to inert structures

Vegetative damage to inert structures may occur when inappropriate species or plant materials that exceed the size of openings in the face of structures are used. Vegetative damage does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium.

6.2.4 Moisture requirements and effects

The backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free draining, granular material. Excessive amounts of clay, silt, and organic matter are not desirable. Free drainage is essential to the mechanical integrity of an earth-retaining structure and also important to vegetation, which cannot tolerate waterlogged soil conditions. The establishment and maintenance of vegetation, however, usually requires the presence of some fines and organic matter in the soil to provide adequate moisture and nutrient retention. In many instances, these biological requirements can be satisfied without compromising engineering performance of the structure. With cribwalls, for example, adequate amounts of fines or other amendments can be incorporated into the backfill. Gabions can be filled with rock and soil drifted into them to facilitate growth of vegetation. Woody vegetative cuttings can be placed between the baskets during filling and into the soil or backfill beyond the baskets. The needs of plants and the requirements of structures must be taken into account when designing a system.

6.3 Drainage

Depending on the inclination of the slope or embankment, one of the most effective ways to help prevent erosion is to create diversions which will channel excess water down the slope along a predetermined path. One of the simplest ways to do this is to create open ditches or drains by simply digging along the slope at regular intervals. Use of pipes and gutters is also very effective, and work just as well as natural drains when designed and installed properly.

6.3.1 The drainage hierarchy

The drainage problems of an individual neighbourhood are part of a hierarchy of problems related to the drainage network of the whole city and corresponding with the hierarchy of drains which compose it. These drains range from the major canals or large sewers which collect water from large areas of the city down to the small ditches or drainpipes that run along the roadside or serve individual properties.

At the most basic position in the hierarchy is the receiving water body into which the system discharges. This may be the sea, a lake or a river. The water level in the receiving water body fixes the minimum level of the drainage channels, because the pumping of stormwater is not feasible for any but the wealthiest communities. Even if it were possible to afford pumps large enough to handle the amounts of water involved, they would not be practical because of the many difficulties of maintenance and the extent of the damage that would result from malfunction or breakdown of the pumps. The water level in the receiving water body comes very close to ground level in many flat low-income areas, which means the drains cannot be made very deep.

Next in the hierarchy is the primary drainage system, composed of main drains, sometimes called interceptor drains. These serve large areas of a city or the city as a whole, and often follow the line of natural drainage channels such as rivers or streams. The design, construction and maintenance of a city's primary drains require extensive engineering skills and a large financial base, and are well beyond the means of an individual community. These drains are not considered here.

Finally there is the secondary drainage system, a network of small drains within each neighbourhood. These are sometimes known as micro-drainage or laterals, and each serves a small catchment area, ranging from a single property to several blocks of houses. This publication deals principally with the secondary level of the drainage system. At this level, improvements can be made with modest investments, and low-cost solutions are often appropriate.

6.3.2 Factors affecting storm water flows

Not all the water falling as rain needs to be removed by the drainage system. Some of it will infiltrate into the ground, while some may stand in puddles and other depressions and eventually evaporate. The proportion that runs away over the ground surface and has to be carried in the drainage system is known as the runoff coefficient. In practice, there is little chance for evaporation during a rainstorm, so that the runoff coefficient to use when calculating the size of the drains required is based on the infiltration capacity of the ground. This depends mainly on soil conditions, the slope of the terrain, and on land use:

Soil conditions. Water seeps more readily into sandy soil than into clay or rocky ground.

Terrain. Water flows more rapidly down a steep slope, leaving it less time to infiltrate than when it stands or moves slowly in a flat area.

Land use. Vegetation traps much of the water and also loosens the soil, thus making infiltration easier. Roofs and paved surfaces, on the other hand, prevent infiltration.

Runoff coefficients are therefore higher in areas of clay soil or rock, on steep slopes and in densely built-up areas with little vegetation. As an example of this, the quantity of water to be drained from a high-density housing area may be 5-6 times greater than it was when the area was undeveloped and covered with vegetation.

The rate at which water enters the drainage system depends on the runoff coefficient, but also on the rate of rainfall. Of course this can vary, from a heavy downpour to a light shower, and it is hard to estimate the maximum intensity of rainfall that will occur in a given year, because of the unpredictability of the weather. However, by analysing past rainfall records, it is possible to make an estimate of the probability of any particular rate occurring. The more severe the rainstorm (i.e., the higher the rate of rainfall), the lower the probability of its occurring.

This probability is usually expressed as a "return period". A rainstorm with a probability of 1 in 20 of happening in any particular year is said to have a return period of 20 years, and is called a 20-year storm. This does not mean, of course, that it happens exactly every 20 years, but that on average it will happen that often-an average of five times a century.

If a drainage system is designed for an unusually severe rainstorm with a 100-year return period, it may never be fully used within its lifetime. The money spent in constructing a system with such a large capacity might have been better spent on building smaller drains in areas that have none. Choosing the optimal return period for the design of an urban drainage system is a difficult judgement based on weighing the risk of the drains overflowing, and the damage this might cause, against the cost of building larger drains to prevent it.

A return period of five years is widely used to design primary drainage systems in tropical cities, but shorter periods (three years or less) are more suitable for micro-drainage within residential areas, where an occasional overflow is less likely to cause serious damage. In a low-income area, where the value of property liable to damage is relatively small, and only limited funds are available for drainage, the appropriate return period may be shorter still. In Mombasa, for example, a one-year return period has been adopted for all but the largest drains. In Calcutta some drains have been designed for a return period of only two months. A few inches of flooding several times each year may be a great improvement on waist-deep water for weeks on end.

The damage that can be done to roads by storm water is often the major justification for drainage in low-income areas. On steep slopes, a single heavy rainstorm that makes the drains overflow can cause enormous damage by erosion, so that a longer return period may be justified than in flat areas.

6.3.3 Problems of steep slopes

Sloping land easily suffers from erosion when the vegetation cover is damaged and when intensive land use bares the soil. It is therefore important to prevent water from rushing down in uncontrolled flows that may undermine houses and turn paths and streets into impassable gulleys. As a rule of thumb, slopes of more than 5% can be considered steep slopes.

On steep terrain, the only way to keep water in the soil is through terracing so as to reduce the slope. Various methods exist and are used to control erosion on agricultural land. However, these can be applied in an urban area only if the neighbourhood has not already been fully built up.

When the water is concentrated in a natural or artificial line of drainage running down a steep slope, it can flow at great speed and thus cause considerable damage. Various methods can be used to lead the water down gradually and in manageable quantities:

(a) Diverting the water horizontally by a bank built along the contour or by turnout drains, thus reducing the speed of water flow and avoiding the accumulation of all the water from the whole slope in a single drain.

(b) Leading the water in a controlled zigzag through baffles built into the drain to slow down the flow

(c) Building steps into the drain. The area on to which the water falls from each step is built to resist the force of the falling water. Step drains are practical if the slope exceeds 30%, but otherwise they become too expensive.

(d) Checkdams (checkwalls) are a less expensive solution to the problem, and can be used in unlined drains. The water deposits silt behind each checkwall, gradually building up a stepped drain. The checkwalls should be set well into the ground on each side and beneath them, to ensure that the water does not cut a way past them. In particular, the foundation of each wall should not be higher than the crest of the next one downstream.

Checkdams can be built of various materials besides concrete or masonry. Piles of large stones help to dissipate the energy of the water as it flows through the tortuous spaces between the stones. The stones must be large enough to resist being carried downstream by the water.

In areas where rocks of sufficient size are not available, smaller rocks may be tied together in a large bundle or bale known as a gabion. A gabion is made by filling a large basket of galvanized wire mesh with stones, to make a large rectangular bundle of about 0.5-1.0 m^3. These can be built up into a wall; however, it is advisable to fill them only after putting them in position. Bamboo strips may be used as a substitute for wire, although they will rot away in a few years. As the bamboo deteriorates, weak cement can be applied sparingly to the exterior of the gabion, taking care not to block completely the spaces between the rocks. When a gabion is newly placed, the rocks have to settle down; a weak concrete would easily crack whereas wire and bamboo are flexible.

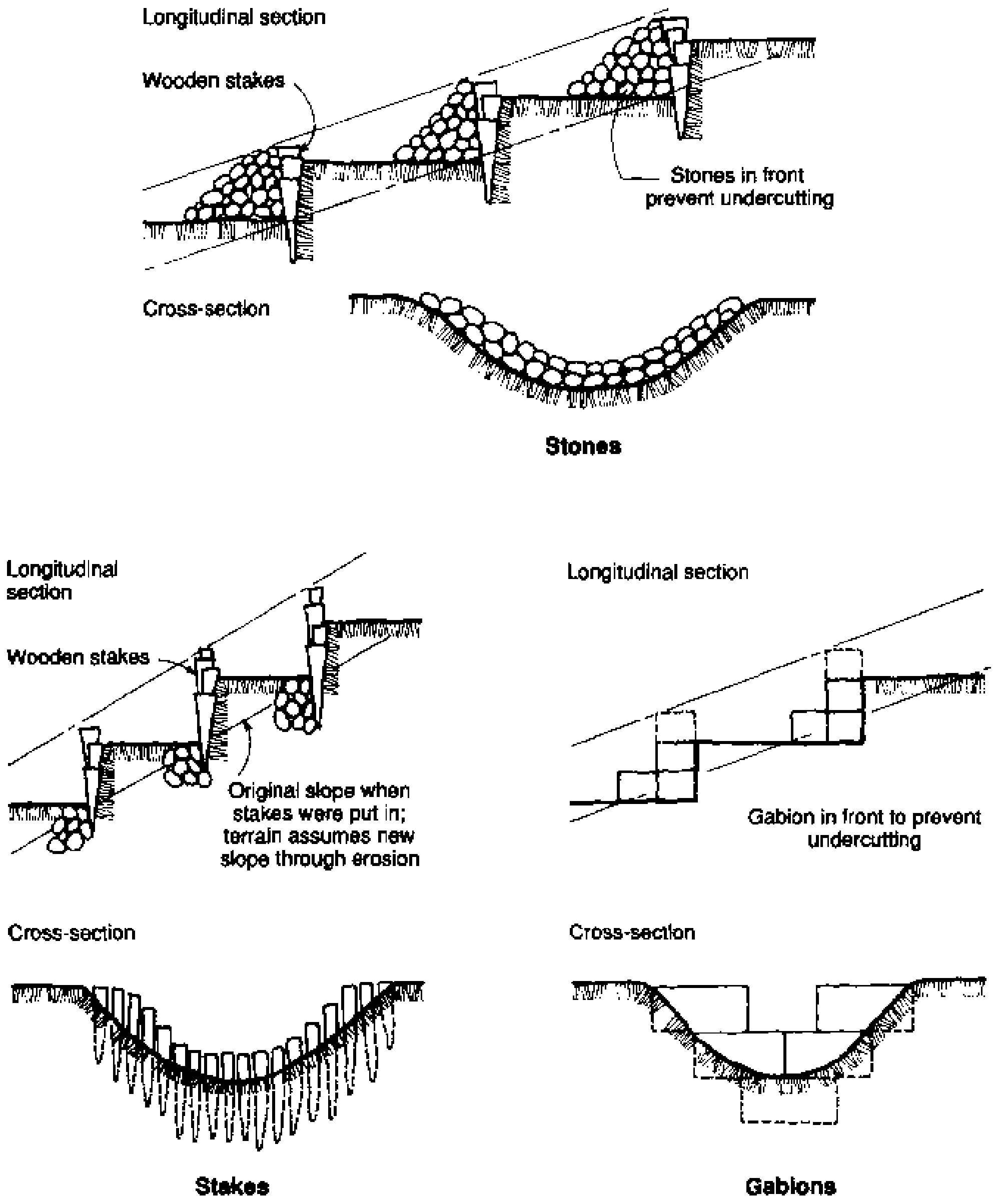


Ilustración 7 Types of checkdams or dissipators

In areas with a moderate ground slope of about 4-10%, drainage channels may be lined with concrete, masonry or vegetation to prevent scouring of the channel bottom.

7. SOIL BIOENGINEERING TECNIQUES

7.1 Soil protection techniques

7.1.1 Sowing

Description

Manual spreading of seed mixtures:

a) with commercial mixtures of certified origin (species origin, blend composition, degree of purity, degree of germination);

b) with flowers harvested directly in the field from stations of conditions similar to those in which it must operate.

The covering is immediate, with an anti-erosion surface effect determined by the radical reticule deepened in the ground (10 - 30 cm).

Application fields

Flat surfaces or slopes of less than 25 ° - 30 °, intended for revegetation, according to the ecological conditions (examination of the pedoclimatic conditions, floristic and / or vegetational analysis), to avoid run-down and wind erosion and to limit drying.

Materials

Wherever there is need, sowing is combined with the spread of organic and / or inorganic fertilizers, the quantity of which varies according to the period of intervention: in spring it will be greater because the season allows the plants to use most of them; in autumn to avoid leaching the amount not used by plants for the arrival of the cold season.

An improved sowing variant is the Schiechteln Method which includes, in addition to sowing, the laying on the ground of mulching with long fiber straw and fixing it with an emulsion cold sprayed hydro-flat. It is very suitable for substrates poor in organic matter, shallow and dry soils located at high altitudes, mountainous areas in the Mediterranean area.

7.1.2 Hydroseeding

Description

The spreading is made by a hydroseeding machine, equipped with barrel, of a mixture composed mainly of seeds, adhesives, fertilizers and water. The various components of the mixture are mixed in the mechanical ways, which is then sprayed onto the surfaces to be grassed by means of pumps and nozzles with adequate pressure, which does not damage the seeds. The presence of adhesives guarantees the protection of seeds during the first phase of germination.

Application fields

Surfaces characterized by absence or however lack of humus, steep surfaces or scarcely accessible areas of considerable surface development. The anti-erosion effect is immediate thanks to the presence of the film due to the adhesive and then the radical reticule deepened in the ground (10 - 30 cm). In a short time an environment suitable for the microfauna is developed.

Materials

The seeds will be provided with certification of seed origin and in quantities not less than 30 - 60 gr / m2, water, fertilizers / fertilizers, soil improvers, adhesives. The percentage of the various components of the mixture varies from case to case; it is therefore necessary to carry out first a staging analysis that allows evaluating the composition.

Hydroseeding applied over a 3D layer

Description

Spread in two passes by means of a seed mixture hydroseeding machine,soil conditioners, adhesives, organic fiber (mulch) and water for surface coating. The distribution must be homogeneous and the layers will have thickness from 0.5 to 2 cm. The use of adhesives promotes the fixing of the seeds to the substrate and the formation of an anti-erosion film, of support in the initial phases of seed germination. The use of organic fiber (mulch) enhances the functions of moisture retention and organic support, facilitating seed germination and plant development.

Application fields

Floating surfaces free of vegetal soil, subject to erosion, sometimes is combined with vegetative coatings in wire mesh and mats, green reinforced earth, etc. Road and railway embankments in trenches, rock quarries, aggregates dumps. Slopes with excessive slope, areas with prolonged periods of drought, slopes subject to movement of the ground. This technique is well adapted to the Mediterranean ecoregion.

Materials

Mechanical medium (hydroseeding machine), organic fiber (mulch) (300-700 g / m^2), fertilizers and fertilizers, seeds, polymer based adhesives, water. The composition of the mixture and the quantity of seeds must be chosen following a stational analysis, which takes into account the local pedoclimatic and vegetation characteristics.

7.1.3 Biomats

Description

Vegetable fiber mats (straw, coconut, mixed) or woven in jute or coconut yarn (of remarkable resistance), used in the anti-erosion treatments of slopes that are poor in organic matter and subject to meteoric erosion. The mat is laid out and fixed to the substrate by pegs of various shapes. It is normally combined with sowing and planting of cuttings and / or shrubs.
This technique has a quick and simple execution, with immediate protection of the surface. It allows the soaking of steep surfaces, with soils with poor physical-organic endowment, suitable on regularized slopes. The earthy material underlying the mat is retained, thus preventing it from being transported downstream.

Application fields

The jute mat is suitable on slopes with low slope, on loose rocks (gravels, clays), denuded or newly formed substrates, even irregular, possibly with an earthy substratum on the surface, dry and excessive substrates drainage: water infiltrates, but does not stagnate and does not erode. The meshes of the mat allow the plants to grow, thus ensuring the protection of the surface once the mat has undergone complete degradation.

The mats woven in coco yarn are suitable on slopes with greater slope on dry and strong drainage substrates. They are also suitable on erosion banks subject to periodic submersion. The mats protect the escarpments from meteoric and wind erosion, improve the water and thermal balance on the ground, bring organic substance. The duration in time is variable, the coconut fiber in particular lasts up to 5 - 6 years, but the final degradation is complete.

Materials

Biodegradable mats made of organic straw, coir or mixed fibers weighing not less than 250 g / m2, generally supported by a biodegradable photo-fiber mesh, with a minimum mesh of 1x1 cm, or paper sewed with biodegradable yarn, possibly pre-formed; woven mats (generally with wires of jute or coconut); brackets or pegs in steel iron, U-shaped or wooden; seed mixture (40 g / m2); cuttings and native shrubs.

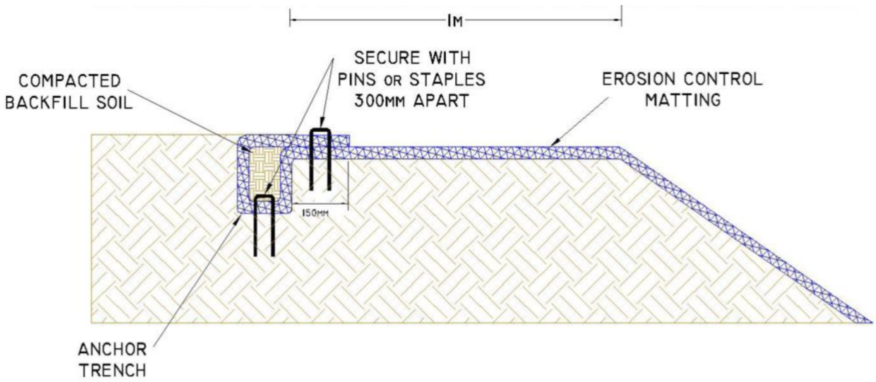


Ilustración 8 Detail of erosion control matting. Source: ECTC, 2008.

7.2 Ground stabilising techniques

7.2.1 Live stakes

Description

Driven woody cuttings and / or branches of plant species with capacity of vegetative propagation in the soil or in the fissures between boulders, insertion in live palisades, gabions and reinforced earths. The use of willows is classic, as well as other species such as privet and tamarisks (the latter resistant to alternate conditions of strong aridity and the presence of salts in the soil). The plant density increases as the slope of the land increases: from 2-5 cuttings / sq m to 5-10 cuttings / sq. M. The stabilizing / consolidating effect at depth increases with the length of the infixed part of the cuttings. The stability of the slope and the superficial consolidation of the ground are limited to the development of an adequate root system. Occasional pruning of hardening and thinning should be performed to avoid monospecific populations.

The drainage effect (the willows are real "water pumps") is due to absorption and transpiration of the live material used.

The branches must be collected and used quickly. Storage for longer periods may be carried out in cold storage at low temperatures (4-5 ° C) and 90% humidity or submerged in cold water tanks.

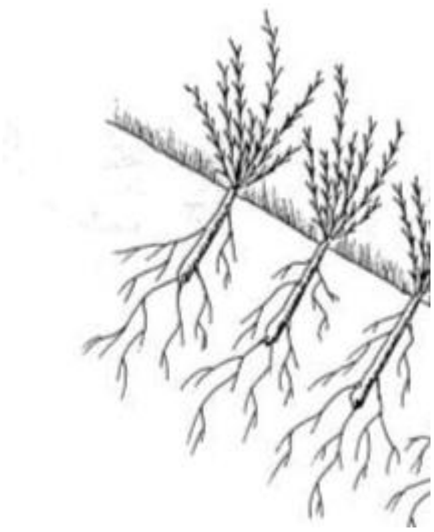
Application fields

Slopes with limited inclination; interstices and fissures of cliffs, walls, gabions, reinforced lands; like live stakes in laying networks, mats, fascinate, viminate. The action is initially punctual, but extensive and covering after development (6 months ÷ 1-2 years).

They find wide applicability, with exclusion of lithoid and particularly arid substrates: the various species of willows cover a wide range of environments from sea level up to 2000 m a.s.l. and beyond, but they fear the conditions of strong aridity of the stenomediterranean climates, the salinity of the substratum (proximity to the sea), the excess of shading. For the preceding situations, the *Tamarix* sp resist well but cannot be used at altitudes of more than 4-500 m a.s.l.

Materials

Ground driven: non-branched jets, of 2 or more years, ø 2 ÷ 5 cm, L = 0.50 ÷ 0.80 m, woody trees in general shrub with vegetative propagation capacity (willow); insertion during construction: live branches of L 1 ÷ 5 m e diam. 1-5 cm.



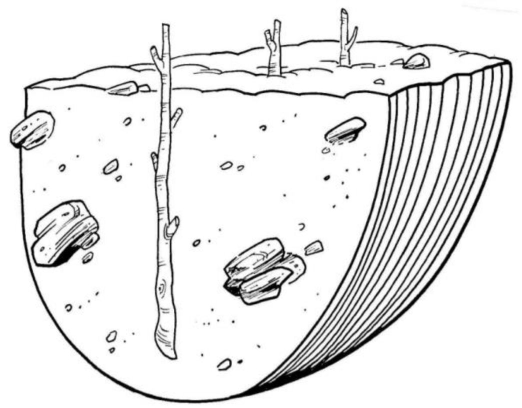


Ilustración 9 Source: Polster, 2001

7.2.2 Shrubs plantation

Description

This technique consists in planting of young indigenous shrubs in clods in pots or phytocells (of nursery production) in specially prepared holes of appropriate size to accommodate the entire root or the entire root volume of the plant. The plantation must take place according to a sixth of irregular planting and with different species arranged in mosaic. For the first few years the plants must be equipped with a guard pole, mulch at the base to reduce competition with the herbaceous species and cylinder in the net for protection from the fauna. The bare root transplant, widely used in central Europe and also in the Italian alpine areas, is not very feasible in the southern regions. The stabilization of the soil is limited to the development of an adequate root system and therefore this condition must initially be guaranteed by other material.

Application fields

Low slope surfaces, preferably with the presence of organic soil. In Soils without this substance should prepare holes in the substrate and fill them with a certain amount of plant soil, organic fiber and fertilizers suitable to guarantee the rooting of the plants; in such land will still be from to prefer the choice of plants with a pioneer behavior of the corresponding stages of the natural potential dynamic range of the site.

Materials

Nursery shrubs in containers; height between 0.30 and 0.80 m; discs mulching, or pine bark; pali guardians; anti-fraud protection networks.

7.2.3 Wattle fence

Description

This technique consists of Intertwining of wooden species rods with vegetative propagation capacity, around wooden stakes. A rapid stabilization is obtained up to 25-30 cm of depth and immediate containment of the material. It is a technique adaptable to the morphology of the slope. Its execution requires considerable workmanship and long and elastic rods in sufficient quantity are not always available for weaving. The stabilization is immediate for the superficial layers of soil, and there is an improvement when the rods emit roots, even if the rooting is modest compared to the amount of material used.

It can often happen that the posts are broken due to an excess of load from the backfill or due to the rocks falling from above. In this case they are necessary maintenance works and the replacement of broken posts. The stabilizing effect occurs only in the case of underground and basement voids, in which the phenomena of undergrowing and undermining are reduced.

Application fields

Slips with maximum inclination of 40 ° and subjected to surface movement of the land or modest landslides. Banks of watercourses at medium-low speed and reduced solid transport. It is not a technique that can be used in high-energy watercourses.

This technique can be used on stony or rocky soils when combined with soil bearing.

Materials

Elastic woodworm rods, suitable for weaving and with capacity for vegetative propagation (willows, *Tamarix* sp), not very branched, L min. 1.50 m and ø at the base no less than 2 - 4 cm; posts in coniferous or chestnut wood ø 5 ÷ 8 cm, L= 1.00 ÷ 1.50 m; pegs of iron ø 14 ÷ 16 mm, L 50 cm ÷ 1m; wirecooked.

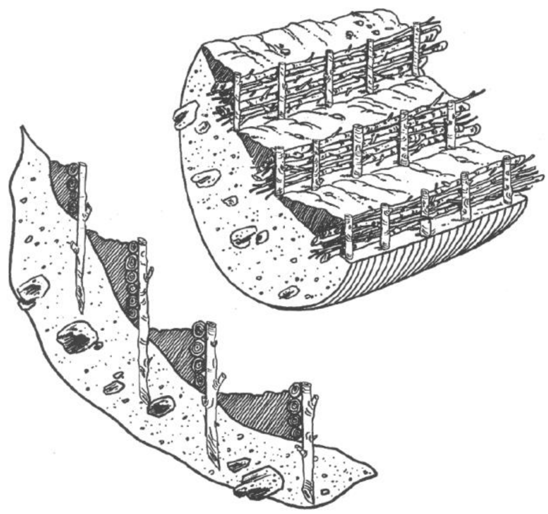


Ilustración 10 Wattle fence (source: Dave Polster, 2002)

7.2.4 Brush layers

Description

It consists of planting, inside steps or terraces excavated in parallel rows on slopes, of branches of woody plants with vegetative reproduction capacity (*Salix* sp, *Tamarix* sp, etc) and / or native rooted shrubs and subsequent covering with the material coming from the upper excavations. A deep rooting with drainage effect is obtained; both erosion and soil movement are prevented; surface runoff is slowed down. The planting of hardwoods rooted in the rows allows to reach more quickly an advanced stage of the series of potential vegetation. The technique is expensive due to the high requirement of plant material. In the case of the embankment, the placement of cuttings at the same time as the formation of the layer survey determines an effect similar to that of the land reinforced, for deep consolidation.

Application fields

Incoherent slopes, shallow landslides, detected during the execution phase. Stabilization of landslides in morainic or alluvial material, with a maximum slope of 40 °.

Materials

Branches or rods of species with vegetative breeding capacity; shrubbery rooted.

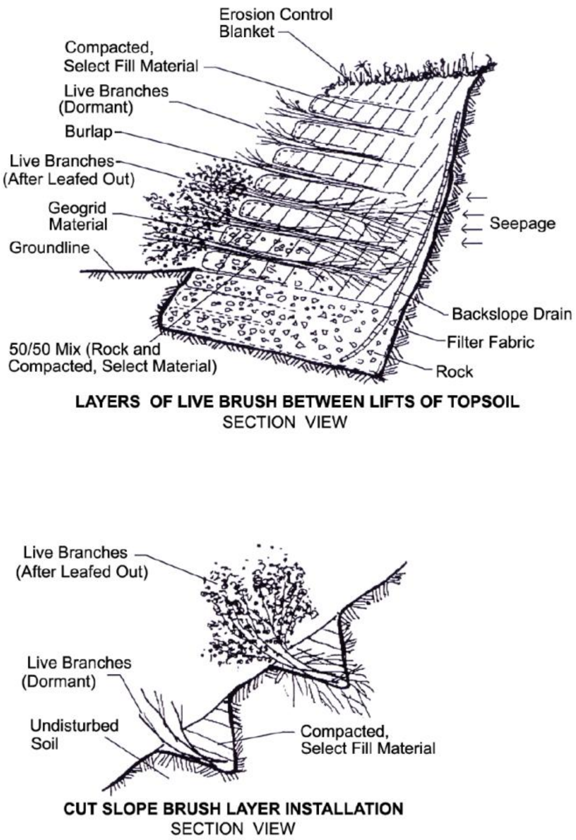


Ilustración 11 Brush layers details (Water Science Institute, NRCS)

7.2.5 Live fascines

Description

Planting of live bundles of wood species with propagation capacity vegetative (rods tied together with iron wire) inside a furrow:

a) on the slope: secured with pegs struck through the bundles or in front of them;

b) on the bank: infixing wooden stakes with alternating orientation, for thus making the structure more elastic and supportive in the event of full realization of bank spines causes a narrowing of the riverbed; it is therefore necessary to provide the space necessary for the regular flow of water. Stabilization is quick and easy to implement. The costs are also contained for the poor earth movement. However the depth effect is limited and the bundles are sensitive to falling stones. The outermost branches are subject to abrasion. Sui slopes serves as a biotechnical drain and facilitates the draining of the waters.

c) dead: along banks of water courses at low water speed and limited solid transport, dead bundles of wood species are placed, arranged longitudinally on the bank below the average water level. It is obtained immediate protection of the foot in a small space and with limited use of material. Executable at any time of the year, also acts as a shelter for small aquatic animals. Usually this type is not applied as the only intervention solution, but combined with other techniques involving the use of live material. The dead fascinate is therefore a further basic protection for other naturalistic engineering techniques.

Application fields

This technique can be used in slopes with an inclination of no more than 35 °, with the need for biotechnical drainage, road and railway embankments, landfill escarpments. Medium-energy water courses with relatively constant flow rates and average level.

Materials

a) and b) wooden woodworms with vegetative propagation capacity (willow, tamerici) ø min. 1 cm and L min. 2.00 m; wire; wooden posts ø 5 cm or iron stakes ø 8 ÷ 14 mm and L min. 60 cm; land.

c) dead woodworm rods ø min. 2 cm and L min. 2.00 m; wooden posts ø 5 cm or iron stakes ø 8 ÷ 14 mm and L min. 60; stone.

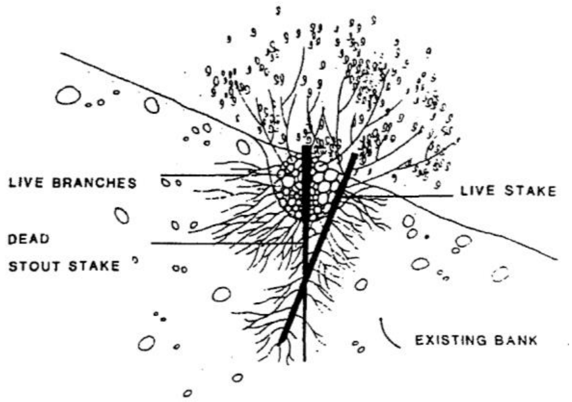


Ilustración 12 Detail of a live fascine. Source: Robbin B. Sotir and Associates)

7.2.6 Live palisade

Description

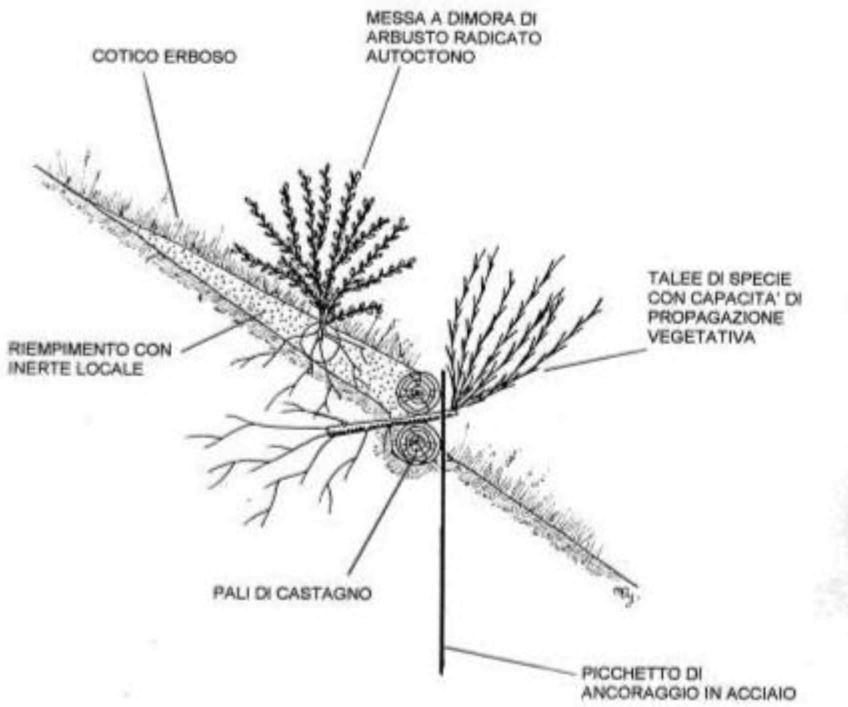
Intervention for the stabilization of embankments consisting in the construction of timber structures, transversal to the line of maximum inclination, made up of two overlapping rows of trunks fixed with iron pegs, planting cuttings between the two trunks and planting upstream shrubs in the raised step. This intervention is characterized by a wide applicative value, limited to the superficial stabilization of the slopes, both in excavation and in relief.

Application fields

Escarpments in excavation, consolidation of erosion furrows, stabilization superficial surveys and / or accumulation of loose material, on fire routes, etc.

Materials

Chestnut or coniferous trunks (except fir) ø 15 ÷ 25 cm, L = 2.00 ÷ 5.00 m; iron pegs ø 14 (16) mm, L 40 ÷ 100 cm; woody cuttings of willows; indigenous, inert shrubs; native seeds.



7.3 Combined construction techniques: consolidation techniques

7.3.1 Live slope grid

Description

Roundwood structure obtained by laying vertical and horizontal trunks arranged perpendicular to each other, the latter superimposed on the vertical ones and nailed to them. Inside the chambers thus obtained, cuttings of willows and / or rooted shrubs (sometimes supported by pieces ofelectro-welded mesh) are placed during construction, and the whole is covered with inert earthy aggregate. A small grating can also be performed with the use of live astones. The stabilization is immediate thanks to the wood reinforcement and the effect increases with the rooting of the plant species, which also perform a draining action. The wood rotates over time, so that in addition to good nailing, it is necessary that the plants inserted in the structure are vital and deeply rooted, thus replacing the function of support and consolidation of the slope once the wood has lost its functions.

Application fields

Reconstruction of the profile of landslides with slopes between 45 ° and 55 ° that not they can be reduced; slopes of road infrastructures.

Materials

Chestnut or coniferous trunks (except fir) ø 15 ÷ 25 cm, L = 2.00 ÷ 5.00 m; iron pegs ø 14 (16) mm, L = 40 ÷ 100 cm; woody cuttings of willows L min. 1.00 m; inert; suitable seeds; native shrubs; electrically welded mesh of containment of the inert between the rooms.

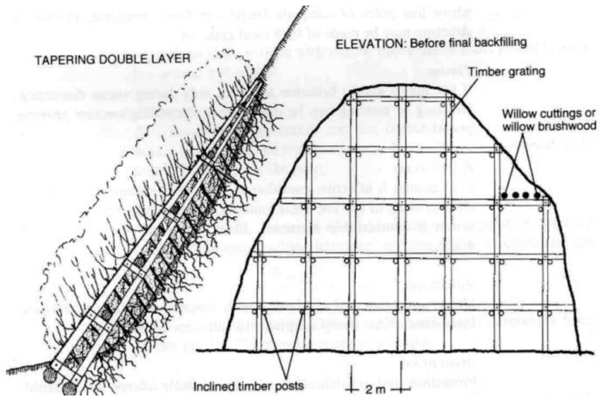


Ilustración 13 Detail of a live slope grid. Source: Schiechtl and Stern, 1996

7.3.2 Live log crib wall

Description

Timber structure consisting of a frame of logs to form chambers in which cuttings and / or fascines of species with vegetative propagation capacity are inserted. The work, placed at the base of a slope or a bank, is completed by filling with inert earthy material and stones in the part below the average level of water. The stones and the bundles placed to close the cells to the outside guarantee the structure from emptying. The cuttings inserted in depth are necessary to guarantee the rooting of the plants that in Mediterranean environments suffer from dry conditions. The consolidating effect is notable, it is initially linked to the durability of the wood and is replaced over time by the development of the vegetation (plant aerial biomass ad root system). In this sense, heights of less than 2.5 m are recommended. The consolidation is fast and robust, with an immediately pleasing visual effect and a great landscape effect, linked to the rapid development of the branches.

The wood with time decays, so besides good nailing, it is necessary that the plants inserted in the structure have a good development in order to, over time, fulfill the support and consolidation function on the slope. The stabilizing role transfer between the logs and the vegetation must be ensured by means of a good design of the technique.

Application fields

This technique can be utilized for consolidation of slopes and landslides; at the foot of road embankments or railways; fluvial banks subject to erosion of medium-energy watercourses - high with solid transport also of medium size. The one-wall variant (simple log crib wall case) is preferable in limited space or excavation possibilities.

Materials

Trunks of chestnut or resinous peeled ø 20 ÷ 30 cm; metal studs ø12 ÷ 14 mm; cuttings and twigs (to be combined with living willow blades ø 20 ÷ 30 cm and dead fagots ø 25 ÷ 30 cm in the case of piled banks); inert earthy and stone (in the piled bank); native shrubs.

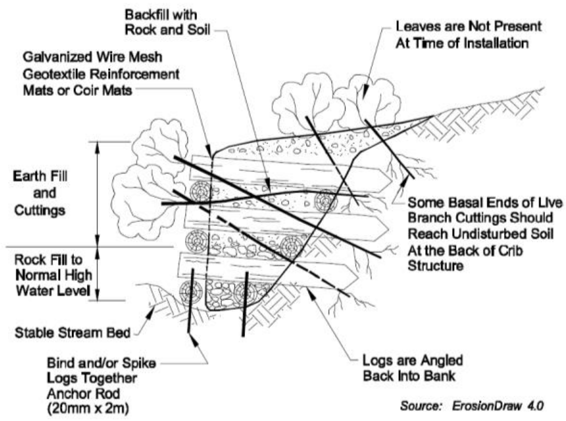


Ilustración 14 Log crib wall detail (source: ErosionDraw 4.0)

7.3.3 Live gabion wall

Description

Technique suitable for both linear arrangements and point-like arrangements, consisting of gabions in double-twisted galvanized wire mesh and hexagonal mesh, filled on the spot with small stones of a minimum size of 15 cm, arranged in parallel overlapping rows. Inside the gabions are inserted willow or tamarisk cuttings with irregular or row arrangement in the first mesh of the upper gabion (not between one gabion and the other). To avoid erosion of the foot, before laying the gabions, a suitable prolonged foundation is prepared towards the riverbed center (mattress). Elastic support structure, very suitable for accommodation in conditions of steep slope and in limited spaces; the use of local pebbles ensures a visual coherence of the structure with the local lithology; over a period of 1-2 years the roots of the willows or tamarisks increase the stability of the structure itself, which is also masked by the development of the aerial parts. In their combined use with living plants they lend themselves to various applications of naturalistic engineering, which are susceptible to further evolution due to the adaptability of the materials. Already their traditional use has considerable plasticity giving rise to spontaneous renaturalization processes over time. They can perform both a protection function against river erosion and at the same time support of the bank in case of gravitational instability. They are permeable structures that do not hinder the filtration of water to and from the banks. They must be used verifying the stability with respect to the dragging tensions due to the action of the water. Generally, it is not recommended for use in presence of intense solid transport characterized by large material. They are used to build gravity support structures characterized by high flexibility and permeability. They must be sized as support works by carrying out the appropriate stability checks. The execution is quick and simple, with immediate containment effect. The realization is preferable in areas with availability of stone material.

Application fields

Longitudinal and / or transverse defense of watercourses; foot of wet slopes and unstable; erosion slopes; bridle in floodplains flooded occasionally; phytodepuration systems; defense and support of lake shores; reconstruction and / or replacement of concrete retaining walls in unstable ground.

Materials

River pebbles ø 15 ÷ 30 cm or stones; box in galvanized steel wire (must have a protective cover if in contact with water), double twisted type 8 x 10 mesh; galvanized iron wire ø 2.2 mm or mechanized metal points in steel ø 3.0 mm; cuttings of willow or *Tamarix* sp long enough to touch the natural soil behind the gabion, generally 1.5 - 2 m and ø min. 2 cm.

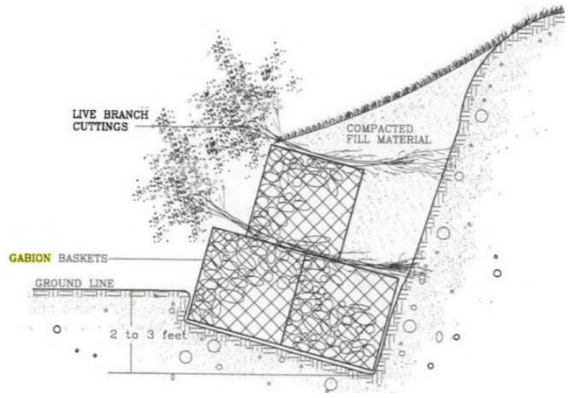


Ilustración 15 Source: Gray and Sotir, 1996

7.3.4 Vegetated geogrids

Description

Support work realized through the combination of reinforcement materials in nets of synthetic or metallic plastic, inert filling and coating in mats on the external front, in order to allow the growth of the plants. From a static point of view, the stability of the structure is guaranteed by the weight of the soil consolidated internally by the reinforcements; the surface stability of the work is ensured by the mats on the face and the plants. It is a support structure very suitable for accommodation in limited spaces or near road infrastructures.

The plasticity of the morphologies achievable and the total revegetation make it one of the most easily re-enforcing techniques. To guarantee the rooting and growth of the plants and the turf, the fronts must have a maximum slope of 60 ° to allow the supply of rainwater.

The only grassy depletion over time and does not guarantee the anti-erosion function of the wedge of vegetable earth, which tends to wash away; when the mats lose their function, it is therefore essential to insert, recommended during construction, cuttings and rooted shrubs and the combined use of permanent synthetic mats. The artifacts result to have a high temporal duration and the construction for modules allows you to obtain multiple shapes, suitable for the local soil conditions.

Therefore, it is an elastic and permeable work, even if, due to the costs and the overall dimensions, it is larger than the concrete wall structures. It is necessary to find filling material with suitable geotechnical characteristics.

Application fields

It can used to support of embankment scarps, consolidation of road and railway embankments, consolidation of banks and embankments, anti-noise earthworks, modeling and reconstruction in cases of limited space.

Materials

Depending on the different construction type, geosynthetics are used; metal and geosynthetic grid; grid and metal armor; pre-assembled elements in double-twisted wire mesh. In all cases, staples, inert filler material, plant soil, live willow cuttings, rooted shrubs, normal or thick hydroseeding are used.

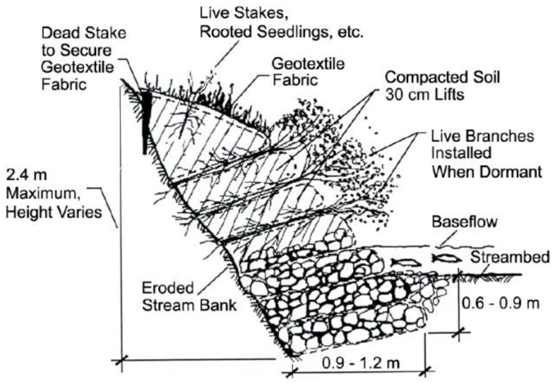


Ilustración 16 Detail of a vegetated geogrid with rock toe key (Watershed Science Institute, NRCS)

An alternative classification of soil and water bioengineering techniques is the following:

7.4 Using only vegetation:

Technique	Soil cover	Stabilisation
Manual seeding	X	
Hydroseeding	X	
Cover seeding (with geotextiles)	X	
Hay seeding	X	
Dry mulching	X	
Cuttings		X
Living brushes and combs		X
Plantation of rooted branches		X
Living bush matress	X	X
Fascines		X
Wattle fence		X
Bush layer		X
Planting of rhizomes		X
Plantation of woody plants		X
Hedge layer		X
Sod		X
Log branch cutting		X
Sod rolls	X	
Transplantation of live soil	X	

7.5 Combined techniques

Technique	Soil cover	Stabilisation
Rock fill and pavement	X	
Reno matresses	X	
Dry stone walls	X	X
Use of soil agregating substances	X	
Geotextiles	X	
Mulching	X	
Anchors		X
Wire mesh	X	
Gabions		X
Reinforced earth with geotextiles	X	X
Log Cribwall and other suport log structures		X
Slope grid	X	X
Cuttings		X
Fascines		X

Mass movements

https://youtu.be/0IUn5_7fHmE

https://youtu.be/EDZYMaSu9Tk

https://youtu.be/sYqVjyuK5vs

Soil erosion

https://youtu.be/Kdm-Z-_AGnU

https://youtu.be/aRfUTVIV63g

https://youtu.be/QLrrPRikq0A

8. MODELATION OF SLOPE INTERVENTIONS

The stability analysis of supporting structures (gravity walls, gabions, cribwalls, ...) and the developed vegetation scenario uses the Coulomb method for calculating the active and passive thrusts of the structure and of the root apparatus which is supposed to have developed over time. The active thrust (Pa) corresponds to the following equation (Garcia-Vega et al., 2014):

$$Pa_{soil} = 0.5 \times k_a \gamma H^2$$

where γ is the soil density, H is the total height of the structure (considering it is not vertical), and k_a can be estimated as:

$$k_a = \frac{\sin^2(\beta + \varphi)}{\sin^2 \beta \sin(\beta - \varphi) \left[1 + \sqrt{\frac{\sin(\varphi+\delta)\sin(\varphi-\varepsilon)}{\sin(\beta-\delta)\sin(\beta+\epsilon)}}\right]^2}$$

where β is wall inclination, φ is soil friction angle, δ is soil friction angle at the base of the structure and ε is slope of retained fill. The overturning stability corresponds to the ratio between the moment of overturning Mo and the moment of resistance *Mr*, which are functions of the active and passive thrusts, the height, and the weight of the wall. The sliding stability is a function between the resisting forces and the disturbing forces acting on the sliding plane, as well as the passive actions determined by the foundation depth. The first set of forces are function of the weight, the vertical component of the active thrust and the soil angle of friction, while the second are function of the horizontal component of the active thrust. The pressure on the soil at the heel and toe (bearing capacity) is calculated considering the width of the base (*b*), the total vertical actions (Σ W) and the eccentricity of the load (e), following the formulas:

minimum pressure at heel:

$$P_{min} = \frac{\sum W}{b}\left[1 - \frac{6e}{b}\right]$$

maximum pressure at toe:

$$P_{max} = \frac{\sum W}{b}\left[1 + \frac{6e}{b}\right]$$

9. VEGETATION ACTIONS TO SLOPE STABILIZATION (POTENTIALS AND LIMITATIONS)

9.1 General actions

Plants' roots uptake nutrients and water as well as provide mechanical support against wind, snow and gravitational forces exerted by the plant itself. Roots also aid in binding the soil it is contained within, improving the stability of the slope and reducing soil erosion. The study of root systems and slope stability is challenging and comprehensive; therefore empirical data on this topic is difficult to obtain. Research is limited due to many methodological issues. Firstly, roots are difficult to sample. They can grow to great depths below the ground and occupy large amounts of area. This makes sampling tedious and highly difficult to gather solid and accurate data. Secondly, trees and shrubs occupy a wide range of root dimensions and are elaborately and extensively intertwined. Thirdly, the complex nature of the interactions between abiotic and biotic features, such as rocks and other debris further complicate the problem.

9.2 Basic Soil Mechanics

The Principle of Effective Stress Consider a soil mass that is subjected to a normal stress, . This is the stress being applied to a soil plane. Newton's third law states that in order to achieve equilibrium, the stresses in the soil must be equal and opposite to The reactive forces in the soil can be denoted by and u, for effective stress and pore water pressure, respectively. Effective stress is defined as the stress acting on the soil particles while pore water pressure is the pressure of the water present in a soil mass. The principle of effective stress is the single most important principle in soil mechanics. Karl Von Terzaghi, whom is considered to be a pioneer of soil mechanics, discovered it in the mid-1920s.

This principle explains that the deformation of soils is a function of effective stresses and not total stresses. Moreover, the principle of effective stress only applies to normal stress and not shear stresses. Shear stresses can be defined as the stress applied parallel to the soil plane and is calculated by dividing the applied force over a cross sectional area. Effective stress cannot be a negative value due to the fact that soils cannot sustain tension. However, pore water pressures can be positive or negat Seepage As water flows through the soil particles in a soil mass it exerts a frictional drag on the soil particles. The frictional force that acts on the soil particles is known as seepage. When seepage occurs downward it acts in the same direction as the gravitational effective stresses, which causes a decrease in effective stress within the soil. Conversely, when seepage occurs upwards, the opposite occurs and there is an increase in effective stress. When the pore water pressure is equal to the normal stress at that point, the effective stress will be zero causing the soil to have no frictional resistance to deformation. Moreover, the soil will have very little strength and slope failures at this point are common. Zero effective stress and upward seepage is also associated with liquefaction and quicksand.

9.2.1 Slope Stability and Factor of Safety

One method of calculating the factor of safety of a slope is by using the assumption of an infinite slope to simplify calculations. As the name implies, an infinite slope assumes dimensions that extend over an infinite distance and deal with planar slip surfaces. Each vertical block is assumed to have the same forces acting on it. The factor of safety is calculated by the driving forces, or shear strength of the soil, divided by the resisting forces. The shear strength of soil is based on the Mohr-Coulomb failure criterion, where for an effective stress analysis of the soil is the minimum shear strength required to maintain stability is the normal effective stress is effective angle of internal friction A two-dimensional method of calculating slope stability is Bishop's method. It is used for circular slip surfaces and results in only roughly 1% error. Simplifying assumptions are made to reduce a two-dimensional analysis into a solvable statically determine problem. The method divides a slope into an arbitrary number of slices where the forces and moments of each slice are then summed up. Increasing the number of slices will result in a more accurate answer but also creates more calculations. The following is Bishop's factor of safety equation for an effective stress analysis. FS= is effective angle of internal friction is the total weight of a slice including any external load is the pore water pressure at the base of each slice is the interslice shear force is the moment force of each slice is the inclination of the slip surface within the slice to the horizontal plane Factor of safety can be defined as the resisting forces divided by the driving forces. A factor of safety of less than 1 means the slope has failed while a factor of safety greater than 1 means the slope is intact. Generally, a higher factor of safety costs more financially. Moreover, when human lives are at stake, the factor of safety is well over 1. Bishop's method and the infinite slopes method of calculating slope stability make many assumptions in order to simplify calculations. It is important to understand that a real life slope stability analysis is a three-dimensional problem and therefore the calculations mentioned above have degrees of error. There are many abiotic and biotic features of a slope that are not taken into account and are very difficult to measure so it is important to always be conservative with the results.

9.2.2 Causes of Slope Failures

Slope failures are, as already referred, initiated by a variety of causes including: natural forces, human misjudgement and activities, and burrowing animals. A slope failure in steep, mountainous landscapes can result in shallow landsliding. This is the common erosional process in these environments and is often comprised of colluvial sediments. As the debris flow accumulates along its long path downwards, it deposits sediment and scours the slope along the way. Shallow landslides can have large implications when it occurs near human values. Water quality and fish habitat are at risk, and in areas where unstable slopes border human activity, infrastructure and human welfare are at stake as well. The following are some of the common human and natural induced activities that compromise the stability of a slope.

Erosion

The weathering and transportation of solids on natural slopes is a continuous process. Erosion alters a slope's geometry where it may lead to slope failure. In a forestry example, erosion is commonly seen when the soil is heavily compacted after harvesting. Forest harvesting exacerbates erosion by exposing mineral soil and removing the fo floor. The forest floor protects the underlying soil from the impact of rain drops and helps absorb water. Roads also lead to increased rates of erosion by changing the natural drainage pattern.

Earthquakes

Earthquakes apply seismic loading that reduces the shear strength in soils. These shear forces cause the grains in the soil to compact closer together, reducing the soil pores. Water then quickly fills the spaces between the soil grains. This occurs so quickly that even coarse-grained soils cannot dissipate the excess pore water pressures. This phenomenon is known as liquefaction. Sometimes the dynamic forces are so great that the pore water pressure is increased to values near total vertical stress, resulting in the total effective stress to approach zero.

Rainfall

A slope experiencing prolonged periods of rainfall may be susceptible to failure. Rain saturates, softens and erodes soil by entering cracks in the soil and weakening soil layers due to increasing seepage forces. Failure in these cases can lead to mud slides.

External loading

Loads placed on top of a slope add to the gravitational load and may cause a slope to fail. Conversely, loads placed at the toe of the slope, also known as a berm, increase the stability of the slope. Piling rocks, for example at the berm of a slope can help stabilize weak slopes. Tension cracks Although tension cracks may not always be a significant factor in slope failures, they are worth mentioning because they are quite common. Firstly, a tension crack modifies the slip surface. When a tension crack is present, the slip surface intersects the base of the tension crack and not the base surface of the road (Budhu 2007). Secondly, when a tension crack is filled with water, there is a hydrostatic pressure applied along the depth of the crack (Budhu 2007). The result is a decrease in the factor of safety due to an increasing moment of force. Lastly, the tension crack provides an opening for water to seep through the slope and into underlying soil layers. This can induce seepage forces, which compromise the slope.

Hydrological Role of Roots

Shallow slope failures can occur when the pore water pressure is increased and effective stress is decreased due to large rainfall events. Site-specific factors, such as "preferential hydrological flowpaths, slope steepness, soil thickness, and material properties" can also contribute to slope failure. Roots are responsible for creating macropores and cavities in the soil thereby improving infiltration. However, an increasing rate of infiltration also leads to a higher water table, thus increasing seepage pressures. The contiguous chain of macropores beneath the forest floor that transports subsurface water is known as pipeflow. Pipeflow plays a role in slope stability and landslide initiations "since the spatial variation in hydrologic response is attributed to the influence of pipeflow". Researchers have discovered that 50-90% of landslide scars contained soil pipes at the headscarps or origin of the slide. During intense rainfall events, closed ended soil pipes can cause slope instability by preventing the dissipation of water. This causes the pore water pressure to increase, thus lowering the effective stress in the soil mass. When water enters the cavity of a soil pipe, it accelerates and a frictional drag is exerted on the soil particles. When seepage occurs at high velocities, it can cause erosion. This erosional process is known as piping. This can cause the pipe wall to collapse and result in sediment discharge. Consequently, soil pipes can improve slope stability by improving drainage and lowering pore water pressures. However, repetitive pipe erosion over prolonged periods of time can be detrimental to slopes. The collapse of a soil pipe will typically divert water to a different outlet, but if the water cannot flow through a different cavity, it will become trapped. This can cause a large build up of pore pressure that lowers the effective stress of the slope and eventually initiate a landslide. A majority of the slope failures in unsaturated conditions result from large rainfall and infiltration events. As negative pore water pressure is reduced, the shear strength of the soil decreases below the critical value along the potential slip surface, causing failure. When soils drain rapidly, suction occurs and creates negative pressure. The soil has no real strength and will fail. Decreasing the degree of saturation would decrease the permeability of the soil. Increasing the degree of saturation in a soil mass causes an increase in permeability because the existing water film on the soil particles result in a lower frictional resistance to flow. If the soil is not completely saturated, the rate of flow would decrease as the inflow of water works to saturate the soil by filling the voids and forming thin films of water around the dry soil particles. Material properties such as the type of soil and their grain size play a major role in determining the permeability of a soil mass and ultimately, slope failure. Permeability is important because it relates directly to pore water pressure. Fine-grained soils such as clay have much greater surface areas and thus absorb large amounts of water and cause swelling and undrained conditions, while coarse-grained soils are looser packed and have large void ratios. Permeability is indirectly controlled by particle size. Since void ratio is a function of particle size, fine particles that exist within the sand would interfere with water flowing through the relatively large pores between the coarse- grained particles. As the fine particles migrate and accumulate in the soil sample, the blockage of water flowing will increase and the result will be a decreased permeability.

9.2.3 Mechanical Role of Roots

Roots provide mechanical support to a soil mass through its tensile strength, adhesive and frictional properties. Roots growing perpendicular to the soil surface provide resistance to shearing forces acting on the soil. Roots extending parallel to the soil reinforce the tensile strength of the soil zone. A soil mass is reinforced not only by these two strengthening aspects but also in terms of the spatial distribution it occupies. Fine roots (1-2 mm in diameter) are a tertiary root system and represent less than 5% of a tree's biomass but provide more than 90% of the water and nutrient uptake of all roots (Schwarz et al. 2009). Coarse roots are greater than 2 mm in diameter and consist of 15- 25% of a tree's biomass. They can be broken down into four classes: taproot, lateral roots, basal roots and adventitious roots. These classes can be subdivided to primary and secondary roots, with secondary roots stemming from primary roots that originate from the root system. There is documentation proving a positive correlation between fine roots and soil reinforcement but the same cannot be said of coarse roots as its data is unproven. The effectiveness of coarse roots highly depends upon its depth and spatial density. If the spatial density is not sufficient, the strengthening effect of the roots is negligible as the soil can easily move around the roots. In general, fine roots are more effective at soil reinforcement but for shallow slope stability, the advantage of fine roots is less obvious. The major factors that govern shallow slope stability are: number, size, tensile strength and bending stiffness of roots penetrating the failure planes. A greater quantity of fine roots is more effective at reinforcing the soil than a smaller number of coarse roots since tensile strength increases as root diameter decreases. Furthermore, during a slope failure, fine roots tend to break off but remain fixed within the soil, while coarse roots can simply slip out. However, only coarse roots can penetrate great depths and firmly anchor the soil mass. Moreover, by extending deeply, coarse roots can fix large volumes of soil and reinforce shallow slopes. Coarse roots also have a higher bending stiffness meaning it can withstand greater bending stresses than fine roots. It is ideal to have a combination of both fine and coarse roots. A large density of fine roots in the upper layers of the soil stratum aids in resisting tension while coarse roots extending deep into the soil and crossing shear planes provide stability from bending and shearing forces. The effectiveness of mechanical slope stabilization depends on the depth of the weakest soil zone, the likely failure mechanism and the steepness of the slope. The environment surrounding the soil plays a large role in determining the effectiveness of root fixation. Factors that hinder the growth of roots, including but not limited to rocks and a water table, reduce the significance it has on a slope. The soil type also plays a significant role in determining the effectiveness of roots for the texture of the soil can influence the resistance of uprooting while the soil's nutrient level may dictate the spatial density and distribution of roots.

Root reinforcement of slopes - Hardwoods vs. Softwoods

Tree species has an effect on slope stability due to the variability of root strength between species. Each species has its own unique root depth, density and spatial distribution. Some species have shorter life spans while others are more prone to disturbances. Hardwoods, specifically red alder, are noted to have a competitive advantage over softwoods in recently disturbed areas and are often the first to regenerate. Studies conducted in the Oregon Coast Range have shown that many landslides have occurred in close proximity to hardwoods. It was discovered that over 60% of the landslides occurred an average of 6 m or less away from a live hardwood while nearly 80% of the landslides were a distance of 6 m or greater from a live conifer. Due to the short life span of red alder and some hardwood species, there may be periods where soil reinforcement from root penetration is lacking. It was discovered that both hardwoods and conifers have similar median rooting depth values. However, conifers were found to have over 25% of their roots penetrating depths greater than 60 cm and 10% of the roots at depths of 90 cm. In comparison, only 0.5% of hardwood roots reached depths of 90 cm. A greater rooting depth can reinforce a larger volume of soil and potentially reduce the risk of landslides.

Spatial-temporal factors of roots

Three plantations of Japanese cedar were studied to determine the influence of various parameters on slope stability. The study helped to show the differences in root density and slope stability depending on stand age and structure. Root density was found to be highest in the juvenile stand, but decreased in the intermediate stand and increased again in the mature stand. Similar findings of root density over time have been documented in other species. It is unclear what causes peaks in root density over different ages of tree development. However, at the juvenile stage, root density increases quickly because younger trees need to allocate more resources to belowground biomass in order to uptake water and nutrients. As a tree reaches maturity, there is an increase in root density, perhaps due to the decrease in aboveground biomass as a result of a lack of nutrients. There is less demand for nutrient and water from fine roots at maturity because the productivity and relative amount of tree foliage biomass decreases. As a result, the fine roots eventually become coarse roots in order to provide structural support for the mature tree. In the three plantations, root density was found to be greatest in the upper 0.20 m of soil. The upper soil layers consist of greater nutrients and better aeration and moisture content. Root density decreased dramatically with depth due to the lack of nutrients and favourable growing conditions. Through the calculations of factor of safety, stage age and stand structure were found to have an effect on slope stability. Juvenile and intermediate stands were discovered to have the highest values of factor of safety while mature stands had the lowest. The factor of safety for juvenile stands without roots was 1.59 and 2.03 with roots, 1.58 and 2.03 for intermediate stands and 1.32 and 1.54 for mature stands. Vegetation increased the factor of safety at all stand ages by 15-27% but had the greatest increase in the juvenile stand. This can be attributed to the high stems per hectare and high root density of younger stands. A partial reason why mature stands had a lower factor of safety was a result of the large openings common in older stands. The factor of safety was also found to increase as the number of trees increased and the distance between trees decreased. It is therefore important to be extremely careful when planning to implement any silvicultural treatments on unstable slopes, especially in aging stands.

The Influences of Vegetation

The primary factors reflecting the effect of vegetation on slope stability are documented by J. R. Greenwood. These include: enhanced cohesion, additional weight added from vegetation, windthrow force, increasing strength of soil due to the removal of moisture by roots. Figure 4 shows the factors that Greenwood incorporates in his calculation of slope stability. Enhanced Cohesion The additional effective cohesion (c') is difficult to measure and hence the contribution it has on slope stability is hard to quantify. Since the distribution of roots is concentrated within 1 m of the surface of the soil, the contribution of c' is limited to this area. Fine roots provide cohesion to the soil and values of c' are typically measured in the laboratory with direct shear tests.

9.3 Soil erosion

When it comes to finding solutions for soil erosion, the most useful techniques found tend to be those that emphasize reinforcing the structure of the soil, and reducing processes that affect it.

- **Careful tilling:** Because tilling activity breaks up the structure of soil, doing less tilling with fewer passes will preserve more of the crucial topsoil.
- **Crop rotation:** Plenty of crop rotation is crucial for keeping land happy and healthy. This allows organic matter to build up, making future plantings more fertile.
- **Increased structure for plants:** Introducing terraces or other means of stabilizing plant life or even the soil around them can help reduce the chance that the soil loosens and erodes. Boosting areas that are prone to erosion with sturdy plant life can be a great way to stave off future effects.
- **Water control:** For those areas where soil erosion is predominantly caused by water – whether natural or man-made – specialized chutes and runoff pipes can help to direct these water sources away from the susceptible areas, helping stave off excess erosion. Having these filters in particular areas rather than leading to natural bodies of water is a focus to reduce pollution.
- **Increased knowledge:** A major factor for preventing soil erosion is educating more and more people who work with the land on why it is a concern, and what they can do to help reduce it. This means outreach to farmers in susceptible areas for ways that they can help protect crops from inclement weather, or ways that they can help make sure their soil remains compact without restricting their plant growing activities.

- https://youtu.be/im4HVXMGI68
- https://study.com/academy/lesson/soil-erosion-effects-prevention.html

9.4 Landslides

9.4.1 Value, Benefits and Limitations of Vegetation in Reducing Erosion

By Elliott Menashe, Greenbelt Consulting

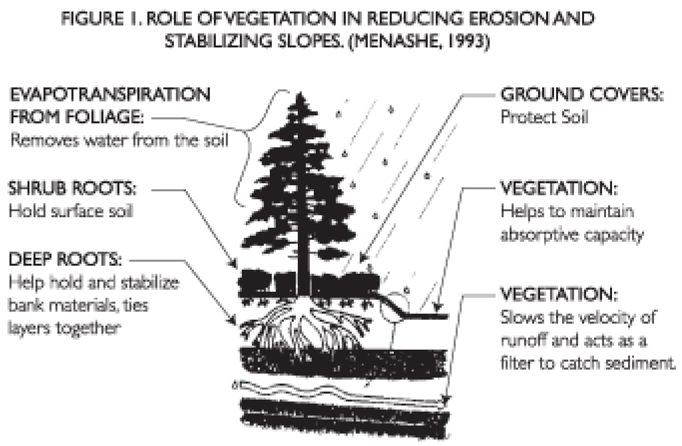


Ilustración 17 Role of vegetation in reducing erosion and stabilizing slopes (Menashe, 1993)

Trees, shrubs, and groundcovers can maintain slopes and reduce erosion from surface water, shallow groundwater and, to some extent, coastal processes. Evergreen trees and other vegetation are most valuable and able to protect soil and remove water during the winter months when deciduous plants are dormant. A diverse mix of both evergreen and deciduous plants provides the greatest protection.

Plants can also have value as sight and sound barriers, discourage access to hazardous areas, and define space in a yard. Native plants enhance wildlife habitat by providing nesting and hiding cover, food, and safe travel corridors. Once established, native plants require little maintenance or care. Species should be chosen for their ease of establishment, adaptability, usefulness, and availability.

Extensive lawns, especially in the vicinity of the bank crest, should be avoided because grass tends to increase surface-water sheetflow during wet conditions when soils are saturated. Low-growing evergreen or perennial plants should be established on the upper crest of the bank.

9.4.2 The Value of Vegetation in Stabilizing Slopes

Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce surface water runoff and erosion.

Evergreen trees and shrubs continue the metabolic activity known as evapo-transpiration, which extracts moisture from the soil, throughout the year. As logging or clearing occurs, water table levels rise, and soils remain saturated for longer periods, reducing soil cohesion and increasing the rate of land slides.

Roots reinforce the soil, increasing lateral soil sheer strength and cohesion during saturated conditions. Many slopes can persist beyond their angle of repose and remain stable as a result of the complex root networks within soil blocks.

Tree roots anchor soil strata vertically and laterally by means of large-diameter structural roots. These roots may extend well beyond the tree’s canopy or crown.

Roots, especially the fine feeder roots of trees, shrubs and groundcovers, bind soil particles at the ground surface, reducing their susceptibility to surface erosion and slumpage during saturated soil conditions.

Large trees can arrest, retard, or reduce the severity and extent of failures by buttressing a slope. This works in much the same way as retaining walls. In the case of trees, though, the system is to some extent self-repairing, and it becomes progressively stronger over time, whereas engineering structures are strongest when installed and become progressively weaker over time. Obviously, planted trees need adequate time to develop root systems and become effective in stabilizing slopes.

Limitations of Vegetation

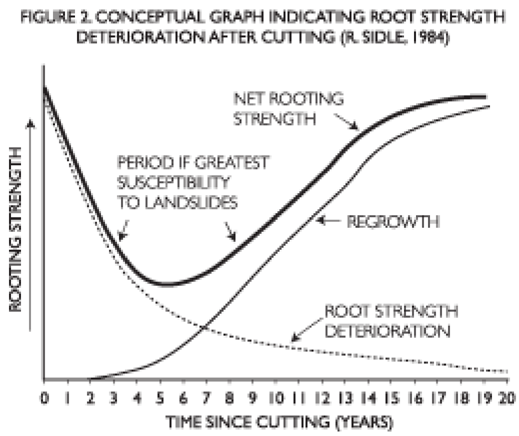


Ilustración 18 Conceptual graph indicating root strength deterioration after cutting (R. Sidle. 1984)

The limitations of vegetation in preventing, reducing or arresting slope failures and erosion is often due to previous land management practices such as logging, topographic alterations, increased or channelized surface water flow, and wholesale clearing. Once initiated, slope failures require an expenditure of time, effort, critical planning and money to stabilize them successfully. The use of vegetation in particular requires foresight and several years of monitoring and maintenance until plants are established and effective. Establishment can take up to three years. It can take up to 15 years for shrubby vegetation to develop the values discussed above, even longer for trees to reach sufficient stature to be effective. The impacts of tree cutting on steep slopes can take several years to become apparent, as illustrated in figure 2.

Landowners need to be aware that not all vegetation provides effective erosion control. Just because it is green does not necessarily mean it works. Such common species as Himalayan blackberry, horsetails, English ivy, and red alder are often present on disturbed slopes and have limited erosion control value. Blackberry and ivy, in particular, tend to discourage more desirable vegetation from becoming established.

In some situations a combination of geotechnical engineering and vegetative techniques are required to assure a practical solution to slope problems. The best time to employ inexpensive relatively vegetative means is before severe failures occur. Note: It should be clearly understood that unusually harsh climatic conditions prior to full development of a vegetative root matrix could result in failure or partial failure of such a slope stabilization system. Landscape contractors should have an understanding of the processes affecting slopes, techniques to be employed to ensure success, and the potential hazards of working on steep slopes in vulnerable areas.

There are several situations where vegetation is relatively or completely ineffective in protecting a slope from failure. These include: (1) lower banks subject to wave attack; (2) areas of deep-seated geologic instability; (3) bluffs near vertical; and (4) unstable areas too wet or dry for vegetation to become established.

9.4.3 Recommendations

Plantings in areas that have not recently been subjected to slope failures are a wise investment. Preventive measures, employed before serious problems occur, are relatively inexpensive. Bear in mind that plantings of more desirable species to replace existing species such as red alder should be well established (2-3 years) before alders are removed, in order to maintain adequate soil-binding benefits within the effective root zone (ERZ) of the cut trees. The ERZ can be approximated as a one-foot radius of lateral root extent for every inch of diameter of the tree's trunk. Preparatory to planting, alders (as well as cherry) can be thinned to a spacing that will not compromise slope integrity during the establishment period. Tree cutting on slopes without replanting can have serious future consequences as illustrated in figure 2.

Proper selection of shrub and tree species for position on the slope will minimize view maintenance requirements while greatly improving slope stability. Care should be taken in selecting species that thrive under site-specific conditions found locally on the slope. These include soil moisture, light/shade, and rooting type.

10. EXAMPLES OF CASE STUDIES ANALYSED WITHIN THE ECOMED PROJECT FRAMEWORK

Case study analyses throughout the project, construction and monitoring stages are presented in teh Ecoe dporject web site (www.ecomedbio.eu) . The assessment of the intervention performance, conclusions and improvements are also shown. The main sections to be addressed for analysisng the soil bioengineerign work troughout its service life are the following:

The intervention area description:

Main problems to be addressed in the intervention:

Main information for the project description:

Main strategy followed within the project:

Main results and calculation obtained in the project:

Main soil and water bioengineering techniques used:

Construction stage analysis:

Monitoring stage analysis:

Performance analysis:

Proposals of improvements for future soil and water bioengineering works:

11. REFERENCES

EFIB, 2015. European Guidelines fro Soil and Water Bioengineering. Edited by EFIB (European Federation of Soil Bioengineering).

Stream System Protection, Restoration and Reestablishment. Website by the Watershed Science Institute, Natural Resource Conservation Service, USDA.

ECTC 2008, Erosion Control Technology Council (ECTC) Guideline for Installing Rolled Erosion Control Products in Slope, Channel and Shoreline Applications, Prepared by Erosion Control Technology Council, Texas, USA, May 2008.

Massachusetts Office of Coastal Zone Management (Massachusetts). 2016. StormSmart Coasts – StormSmart Properties.

12. ASSESSMENT AND FEEDBACK

This module is continuously assessed during the course of the semester. The assessment comprises practical works and theoretical exams. The pass mark for this module is 50% - you must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above.

Full details of the course works are contained in the Coursework Briefs which will be issued in due course.

Note: Failure to submit the coursework for the appropriate deadline without ‘good cause’ will be regarded as a non-submission, and hence will result in failure in this module. If you have a good reason for needing an extension to the deadline, you must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date.

To help you guide your development you will be provided with feedback on your performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort’s overall performance will be provided. You will be given an opportunity to individually review your marked work to help you understand which aspects of your studies you are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. You are entitled to keep marked submissions for your review - however, you must return these when asked by the Module Leader or Module Tutor.

13. DIRECTED LEARNING AND PRIVATE STUDY

As you are expected to 'read' for your degree, you will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect you to be up to date with the current theme.

The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and you will be expected to demonstrate evidence of having sourced information from these in your coursework activities.

You should also make use of web-based materials and visit appropriate sites to develop a wider knowledge of the key issues and activities of not only your chosen discipline, but also in other related fields.

Please refer to the Module Descriptor for a detailed reading list. However, you may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section.

14. MODULE DIFFICULTIES AND EVALUATION

If you have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, you should speak with your employer or Academic tutor.

A module evaluation form will be made available to you on-line after the module is complete and you will be asked to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms are analysed (anonymously) and the findings considered by the appropriate professional organisation as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that you may have about the module in the first instance.

15. PERSONAL DEVELOPMENT PLANNING (PDP)

PDP is aimed at help you to develop as an independent and confident learner, not only during your time with us, but throughout your future career. It also allows more effective monitoring of your progress while undertaking your degree program studies. The process has been described as

"A structured & supported process undertaken by individuals to reflect upon their own learning and performance, and/or achievement, and to plan for their personal education and career development."

As a member of a professional graduate community, you will be required to undertake Continuing Professional Development throughout your career. Learning therefore must be seen as a lifetime activity, and the introduction of PDP at the early stages of your career prepares you for these future requirements. PDP provides an opportunity for you to develop your capacity for learning by getting you to reflect on why and how you are learning, and to become more capable of reviewing, planning and taking responsibility for your studies. All of the foregoing will of course be supported by staff, in particular your Academic Tutor. The key objectives of the PDP process can be summarized as follows:

- To help you become a more effective, independent and confident self-directed learner
- To understand how you are learning and be able to relate that learning to a wider context
- To improve your general skills for study and career management
- To articulate your personal goals and evaluate your progress towards these
- To encourage you to develop a positive attitude to learning throughout your professional life.

Access to a wide range of services, information and software can be made through the home page of the course: html.************************. You will be automatically given access to the resources of the different involved Universities and Enterprises. A common platform (e.g. Moodle) will be made available to allow the access to all learning resources and the permanent interaction between teachers and students as well as supporting many of the assessment procedures.

QUESTIONS FOR THE VIRTUAL LEARNING PLATFORM (VLP)

1. The reinforcing effects of the vegeatig regarding slope stabilization are:
    a) Soil additional cohesion
    b) Soil reinforcement and buttressing
    c) Soil reinforcement, moisture extraction, buttressing and arching
2. The causes of landslides are:
    a) Only geological or geotechnical
    b) Physical, hydrological, geological, climatic and human
    c) Geological, physical, morphological and human
3. Earthflows are always:
    a) Fast
    b) Slow
    c) Can be fast and slow

4. Slope class and soil resistance to detachment are the main factors affecting water erosion risks:
   a) True
   b) This is true only when soil is saturated
   c) Soil erodibility is also a major factor affecting water erosion risks.
5. The USLE method is used to:
   a) Estimating the slope stability
   b) Generate DEM (Digital Elevation Models)
   c) Estimating average anual soil erosion
6. The SLIP4EX model is used for:
   a) Hydraulic simulations
   b) Plant communities dynamic simulation
   c) Incorporating plant effects in slope stability analysis
7. Checkdams are structures used for:
   a) Protecting riverbanks
   b) Fixing dunes
   c) Erosion control in gullies
8. The live stakes can be classified as a:
   a) Soil protection technique
   b) Ground stabilization technique
   c) Combined construction technique
9. In slope stability analysis, a factor of safety greater than 1 means that:
   a) The soil of the slope is saturated
   b) The slope is unstable
   c) The slope is stable
10. The mechanical reinforcement provided by plant roots can be expressed as:
    a) An additional cohesion
    b) A higher angle of internal friction
    c) A higher soil moisture content

MODULE 3.

HYDROLOGY, HYDRAULICS AND WATER BIOENGINEERING TECHNIQUES

Module 3

ECOMED

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

Source: Naturalea

Module 3 **Hydrology, Hydraulics and Water Bioengineering Techniques**

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

Module 3 Hydrology, Hydraulics and Water Bioengineering Techniques

Authors:

José L. García, Paola Sangalli, Guillermo Tardío, José C. Robredo,

Rafael Escribano, Martín Giménez and Clara Cordón

Department of Forest and Environmental Engineering and Management

Institution. Universidad Politécnica de Madrid

SCIA SL
Sangalli Coronel y Asociados
Bioingeniería y Paisaje

TABLE OF CONTENT

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TABLES

1. MODULE DESCRIPTOR

Status: core

Credit Points (ECTS): 3

Pre-requisite knowledge: Physics and Mathematics,

Module structure:

Activity	Total Hours
Lectures	20
Tutorials	10
Seminars	2
Practical	10
Independent learning	30
Assessment	3
Total	75 hours (1ECTS=25 hrs)

1.1 Summary of module content:

Soil and water bioengineering techniques play an important role within the restoration of fluvial scenarios for both riverbanks stabilization and the regeneration and revitalization of fluvial ecosystems.

For an adequate and effective design and construction of water bioengineering techniques, both hydrology and hydraulics concepts are essential. From the watershed scale to the river reach detail, the analysis of morphological, hydrological, hydraulic and biotic parameters will support the decision making process regarding the intervention approach and the intervention intensity. The necessary background in Hydrology and Hydraulics is shown below.

In watercourses, the Hydraulics and Hydrology module analyses the surface processes in which water intervenes in the watershed.

The components of the hydrological cycle involved in the generation of runoff and peak flow are analysed, as well as those that subtract water by interception, infiltration, evapotranspiration. The flow regime, ordinary and extraordinary, is analysed, its generation through water balances or event models respectively. From the point of view of the effects that the different flows exert on the surface of the watershed, surface erosion on hillslopes and slopes is studied.

All the preceding analyses are necessary for an effective technique selection, design and construction of the bioengineering intervention in a fluvial scenario, always complying with the “minimum intervention” principle.

1.2 Learning outcomes:

On successful completion of this module students should be able to:

Framing bioengineering within in the overall fluvial restoration process.

The correct selection, design and construction of the water bioengineering techniques based on the development of the following skills and analyses:

Ability to interpret and analyse water erosion processes. Establish control measures.

Ability to use hydrological models for the calculation of runoff and the characterization and alteration of the flow regime.

Ability to prepare hydrological studies and reports on watersheds, as well as to prepare diagnoses and cartographies that allude to hydrological and water erosion issues.

Ability to write watershed restoration projects, including measures to control water erosion.

Knowledge of the basic bibliography of Hydraulics and Hydrology and scientific journals and main Hydraulics and Hydrological information web pages

Integration of the knowledge acquired about Hydraulics and Hydrology in other subjects of the course, for the elaboration of multidisciplinary projects and works

Use of basic hydrological models and models of water erosion

Ability to measure and estimate hydrological cycle processes

Ability to diagnose problems related to the hydrological functioning of watersheds and propose actions for improvement and hydrological restoration

Understanding of hydrological processes and identification of the key factors that determine or limit their action in each basin

Acquisition of skills for the observation, quantification and investigation of hydrological processes.

1.3 Teaching/learning strategy:

The teaching and learning strategy will encompass a diverse range of teaching and learning methods with support material and communication available through the VLE. The delivery of the modules will encourage an investigative approach and students will be expected to consider how theories, principles and concepts impact upon learning and application in the work place.

Relevant individual tutorials, discussion groups, group tutorials, practical laboratory and gym workshops, live data and direct consultation with industry through guest speakers will inform students, and may prove to be useful in generating avenues of discovery and investigation. The programme will include scenario exercises which will require informed and applied decision-making.

Students will use a range of established techniques to initiate and undertake analysis of information and to propose solutions to individual case studies. They will be encouraged to communicate information effectively to specialists and non-specialists, and to articulate decisions and information in a variety of forms.

Students will have the opportunity to further develop essential skills that are explicitly assessed on the programme.

The essential skills needed during this programme are those that will enable a student to learn and to demonstrate learning through the application of theories and principles tackling climate change.

The overall aim is to use innovative teaching, learning and assessment methods to guide students towards becoming confident and competent in the provision of solutions for a range of climate change scenarios.

1.4 Syllabus:

1. Introduction to water bioengineering
2. Introduction. The hydrological cycle
3. The watershed and the river
4. Hydrological processes
5. Hydraulics applied to open riverbeds
6. Erosive processes
7. The river ecosystems
8. Restoration of watersheds and rivers
9. Water bioengineering techniques.

1.5 Transferable skills development:

Setting personal targets and time management.

Learning skills will be enhanced by use of open-source information and IT skills to research and collate information for case studies.

Communication skills will be enhanced by requiring the use of appropriate language when writing and speaking to fulfil assignments and when making presentations in seminars.

Group-work skills will be developed to address case study problems including the taking of initiative and assuming responsibility in carrying out agreed tasks.

1.6 Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Coursework 1	5	20	50	Framing bioengineering within in the overall fluvial restauration process.
Class test	2	10	50	The correct selection, design and construction of the water bioengineering

				techniques based on the development of the following skills and analyses:
Practical	10	30	50	Ability to interpret and analyse water erosion processes. Establish control measures.
Exam	3	50	50	Ability to use hydrological models for the calculation of runoff and the characterization and alteration of the flow regime.
Total	= 20 hours			

Assessment Strategy

In line with the innovative nature of this Course, the supporting assessment strategy uses a blend of assessment methods. Evidence of the achievement of the learning outcomes will be in the form of:

- Written and practical assignments
- Participation in discussions and scenario exercises
- The production of a portfolio of case studies
- Examination

Both formative and summative assessment methods will be used throughout this programme. Formative assessment creates a point for both students and tutors from which to appraise development, consolidate learning and to plan ahead.

Summative assessment allows recognition for progression to further study, informs those involved of the level of achievement, and validates the learning process.

Students will be expected to apply theoretical understanding in a variety of different scenarios and employ a range of approaches to expression and articulation in assignments.

At the end of this module, students will have developed the knowledge and skills needed for enhanced employability opportunities in the area of climate change.

1.7 Participation:

- Level of participation and interaction
- Interest of the content of works and precision in the presentation
- Punctuality in delivery

- Success and rigor in the results presented
- Interest of the content, understanding of knowledge and ability to synthesize. Application of computer models and applications
- Level of writing and use of technical terminology
- Form of presentation
- Evaluation exams
- Success in the answers to the questions asked
- Clarity in the presentation and correct use of terminology

1.8 Module contacts:

Module leader: Ph. D. José L. García Rodríguez

Module tutor (academic): Ph. D. José Carlos Robredo

Module tutor (industry): Ph. D. Guillermo Tardío and Paola Sangalli

2. INTRODUCTION TO WATER BIOENGINEERING

2.1 Framework, history, limits and scope of application. Necessary analyses for the fluvial restoration case.

Soil and water bioengineering is a discipline that combines technology and biology, making use of plants and plant communities to help protect land uses and infrastructures, and contribute to landscape development (EFIB, 2015).

Water bioengineering is defined as the use of living plant as construction material , used alone or in combination with natural or synthetic support materials, for slope stabilization, erosion control , and revegetation.

The scope of application of bioengineering includes geotechnical interventions and fluvial and coastal environment, forestry and constructive interventions in which the pressures of use have to be compatible with natural systems: extractive activities, linear infrastructures, water depuration, urban environment.

Water bioengineering is an integrated watershed-based technology that uses sound engineering practices in conjunction with integrated ecological principles to assess, design, construct, and maintain living vegetable systems in water environments

Soil and Water bioengineering has a long history with many milestones.

• Tapestries have been found in Chinese emperor's tombs that depict Chinese peasants'using willow bundles for streambank stabilization along the Yellow River in the year 28 B.C.

• In Europe, soil bioengineering techniques were used by Celtic villagers to create walls and fences.

• Romans used wattles and poles for hydro construction.

• The first written record of soil bioengineering was documented by Leonardo Da Vinci (1452–1519), where he recommended using routable,living willow branches to stabilize agricultural irrigation channels, thus creating living streambanks.In the 16th century, streambank soil bioengineering treatments were used throughout Europe.

• In 1791, Woltmann published a soil bioengineering manual illustrating live stake techniques (Stiles 1991). In about 1800, soil bioengineering Austria were using brush trenches to trap silt and reshape channels.

• In the 1900s, European soil and water bioengineers were using in many of the treatments in use today(Stiles 1988).

As these are techniques developed mainly in the countries of the Alpine Arc (Austria, Switzerland, Germany, Italy, etc.) for its development within the Mediterranean ecoregion, it is necessary to adapt them to the specific conditions, based on the first experiences carried out in similar climatic zones, such as Italy or France.

Water bioengineering offers an excellent approach to solving many stream problems.

Projects which are referred to as water bioengineering can range from those that rely almost solely on plant material to those that primarily rely on inert material to provide bank strength. A project that relies primarily on inert or hard material will be less flexible than a project that relies more on plant material for its strength. Thus, the acceptable level of risk, as well as the tolerance for additional movement at the project areas, will generally steer the project and techniques selection.

The limits of soil and water bioengineering are the limits of the abilities of plants and plant communities to fulfill the technical objectives of the intervention (EFIB, 2015).

Success of water bioengineering treatments depends on the initial establishment and long-term development of riparian plant species. The successful establishment and long-term sustainability of herbaceous and woody plants are extremely important to the physical and biological functions of the streams and the connected watershed system.

When selecting the best-suited soil bioengineering techniques, it is important to have a clear understanding of the ecological systems of the adjacent areas.

Because of the use of plants and parts of plants as building materials, the availability of native plant materials and seeds can be a limiting factor n the use of water bioengineering techniques.

The elevation and lateral relationships to the stream can be described in terms of riparian planting zones. Proposed water bioengineering techniques should also be assessed and designed in terms of the location of the plants relative to the stream and water table. These riparian planting zones can be used to determine where riparian species should be planted in relation to the waterline during different periods of flow. For these reasons, both hydrological and hydraulic analysis must be performed for an effective design of a water bioengineering work. Besides, the different water bioengineering techniques have a velocity and boundary shear allowable values. Therefore, each technique is able to withstand a maximum velocity and a maximum shear boundary values. This flow conditions are also determined in the hydraulic analyses performed within the water bioengineering project.

Water bioengineering projects and works follow an integrated approach. Therefore, both engineering and restoration concepts are necessary for an adequate work design. For this reason, in the following sections a presentation of hydrology, hydraulics and river restoration concepts are introduced. Finally, a description of the main water bioengineering techniques is presented.

LINKS

Article: “Introducción a la Bioingeniería o Ingeniería Biológica”. P Sangalli, M Valenzuela. España. 2008.
Source:http://www.caminospaisvasco.com/Actividades/bioingenieria/introduccionbioingenieria
(Bioingeniería definición y finalidades, Antecedentes de la bioingeniería, Funciones de las técnicas de bioingnería, Información necesaria en los proyectos y trabajos de bioingeniería, Materiales de bioingeniería, Principales técnicas y métodos de ingeniería biológica, Técnicas de restauración Fluvial, Situación actual en europa - normativa).

Article:“Bioengineering for Streambank Erosion Control”. Hollis H. Allen, James R. Leech. USA. 1997.

Source:http://www.engr.colostate.edu/~bbledsoe/CIVE413/Bioengineering_for_Streambank_Erosion_Control_report1.pdf
(This report synthesizes information related to bioengineering applications and provides preliminary planning and design guidelines for use of bioengineering treatments on eroded streambanks. It can be used by both planning and design elements, not as a cookbook, but as a guide with tools to accomplish bioengineering projects).

Article:"History of bioengineering techniques for erosion control in rivers in Western Europe"
Source:https://www.researchgate.net/publication/24036109
(This article examines the different forms of bioengineering techniques used in the past to manage rivers and riverbanks, mainly in Europe. We compare techniques using living material according to their strength of protection against erosion).

Article: "Bioengineering for Water Clean upState-of-the-Art Assessment".
Source:https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1102&context=water_rep
(Technical issues, regulatory issues, bioengineering technologies for the accomplishment of bioremediation, current state of knowledge regarding applications and limitations for bioengineering).

Article: "Water bioengineering techniques for efficient water harvesting system".
Source:https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/30274/2/Vasani.pdf
(This paper proposes an alternative to check dam control. An "Eco-friendly flexible check dam – A case study" with Bioengineering techniques has been described. The results are compared with conventional check dams and they indicate that saving on construction cost is approximately 55% with the new alternative suggested, with more water storage).

Video:"Bioengineering techniques create natural-looking and functioning streams in urban headwater channels, Villa Man Creek, Wisconsin freeway reconstruction project".
Source:https://www.youtube.com/watch?v=WHMIE4s_J34
(The video talk about lessons learned for establishing critter-friendly bank vegetation in a stream relocation project).

Article: "History of Bioengineering Techniques for Erosion Control in Rivers in Western Europe".
Source:https://link.springer.com/article/10.1007%2Fs00267-009-9275-y
(Introduction, Streambank Stabilization, Water Channeling, Stabilization of River and Torrent Beds, The Case of the Diois and Baronnies Mountains in the Southern French Prealps).

3. INTRODUCTION. THE HYDROLOGICAL CYCLE

3.1 Introduction to Hydrology. Importance and relationship with other sciences

Water is the most abundant substance on earth, the principal constituent of all living things, and a major force constantly shaping the surface of the earth. It is also a key factor in air-conditioning the earth for human existence and in influencing the progress of civilization.

The hydrosciences deal with the waters of the earth: their distribution and circulation, their physical and chemical properties, and their interaction with the environment, including interaction with living things and, in particular, human beings. Hydrology may be considered to encompass all the hydrosciences, or defined more strictly as the study of the hydrologic cycle, that is, the endless circulation of water between the earth and its atmosphere. Hydrologic knowledge is applied to the use and control of water resources on the land areas of the earth; ocean waters are the domain of ocean engineering and the marine sciences [Chow et al. 1988].

https://www.ethz.ch/content/dam/ethz/special-interest/baug/ifu/hydrology-dam/documents/lectures/hydrologie/lectures/HYI_HS17_Introduction_lecture_complete.pdf

(The relation of hydrology to the botanical sciences:

https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/TR014i001p00023)

3.2 Water on Earth and its current problems

Water is the fundamental ingredient for life on Earth. Looking at our Earth from space, with its vast and deep ocean, it appears as though there is an abundance of water for our use. However, only a small portion of Earth's water is accessible for our needs. How much fresh water exists and where it is stored affects us all.http://earthdata.nasa.gov

NASA:https://www.youtube.com/watch?v=oaDkph9yQBs

Changes in the distribution, circulation, or temperature of the earth's waters can have far-reaching effects; the ice ages, for instance, were a manifestation of such effects. Changes may be caused by human activities. People till the soil, irrigate crops, fertilize land, clear forests, pump groundwater, build dams, dump wastes into rivers and lakes, and do many other constructive or destructive things that affect the circulation and quality of water in nature. (Chow et al. 1988).

(https://www.e-education.psu.edu/earth103/node/720)

Because groundwater systems recover very slowly from human impacts, remediation can be extremely difficult and expensive. (earth 103. EARTH IN THE FUTURE. https://www.e-education.psu.edu/earth103/node/694).

To know more about water resources and climate change, please, visit this web-page: https://www.e-education.psu.edu/earth103/node/694

3.3 The hydrological cycle: Storage levels and water transfer processes on Earth

The hydrological cycle is a conceptual model that has most important processes such as evaporation, transpiration, condensation, and infiltration. Changes in land cover, atmospheric composition and sea surface temperature alter the hydrological cycle both persistently and on a temporary basis. Aerosol particles are an important part of the water cycle as they serve as condensation nuclei for the formation of cloud droplets as well as scattering and absorbing solar radiation. Christopher G. Collier.
https://onlinelibrary.wiley.com/doi/10.1002/9781118414965.ch1

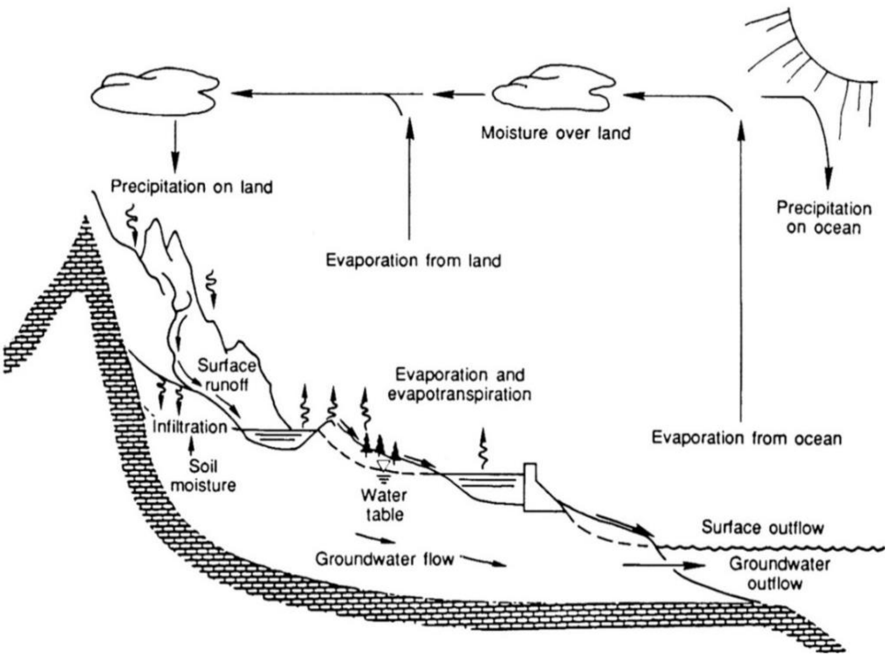


Figure 1 Hydrological cycle with global annual average water balance given in units relative to a value of 100 for the rate of precipitation on land. Chow et al. 1988.

To better understanding of hydrological cycle, please click the link below:

https://www.youtube.com/watch?v=ArBYU1SPZ48

National Science Foundation: This video uses animation, graphics, and video clips to illustrate and explain each of the "flow" and "storage" processes in the Hydrologic Cycle, more commonly known as the Water Cycle: precipitation, interception, runoff, infiltration, percolation, groundwater discharge, evaporation, transpiration, evapotranspiration, and condensation:

https://www.youtube.com/watch?v=al-do-HGulk

LINKS:

Video: “Hydrologic Cycle”. American water college. 2017
https://www.youtube.com/watch?v=ArBYU1SPZ48
(This video is about the Hydrologic Cycle in this excerpt from the Source Water lecture).

Video: “Earth's Water Cycle”. NASA. 2012.
Source: https://www.youtube.com/watch?v=oaDkph9yQBs
(This animation uses Earth science data from a variety of sensors on NASA Earth observing satellites as well as cartoons to describe Earth's water cycle and the continuous movement of water on, above and below the surface of the Earth.).

Article: “Robust Responses of the Hydrological Cycle to Global Warming”. Isaac M. Held, Brian J. Soden. USA. 2005.
Source: https://journals.ametsoc.org/doi/pdf/10.1175/JCLI3990.1
(This study examines some aspects of the changes in the hydrological cycle that are robust across the models. These responses include the decrease in convective mass fluxes, the increase in horizontal moisture transport, the associated enhancement of the pattern of evaporation minus precipitation and its temporal variance, and the decrease in the horizontal sensible heat transport in the extratropics).

Article: “The Hydrologic Cycle”. Conserve-energy-future.
Source:https://www.conserve-energy-future.com/different-steps-of-the-hydrologic-cycle.php
(This article describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and the hydrosphere. Concept of Hydrologic cycle and Different Steps of the Hydrologic Cycle).

Article: “Description of the Hydrologic cycle”. National oceanic and atmospheric administration NOAA- USA.
Source: https://www.nwrfc.noaa.gov/info/water_cycle/hydrology.cgi
(This is an education module about the movement of water on the planet Earth. The module includes a discussion of water movement in the United States, and it also provides specific information about water movement in Oregon).

Article: “Water management: Current and future challenges and research directions”. William J. Cosgrove and Daniel P. Loucks. Canadá. 2015.
Source: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014WR016869
(This paper identifies the issues facing water managers today and future research needed to better informthose who strive to create a more sustainable and desirable future).

Video: “Carbon Cycle, Water Cycle, Nitrogen Cycle, and Phosphorus Cycle”. Andrew Adamson. 2012.
Source:https://prezi.com/od3fg54uk4az/carbon-cycle-water-cycle-nitrogen-cycle-and-phosphorus-cycle/
(This video describes the relationship of the water click with the nitrogen and phosphorus cycle).

4. THE WATERSHED AND THE RIVER

4.1 Parts of a river and the river dimensions (vertical, longitudinal, lateral and temporal dimensions)

As already mentioned, the basic unit of hydrological analysis at an integrated level is the river basin, and within it also has a relevant importance the drainage network that drives the surface water flows to the point of delimitation.

It is important to note that the hydrographic basin is delimited from a point in the drainage network. The object is to know the part of the territory from which they come and circulate the flows that at a certain moment are passing through the aforementioned point. These flows will be conditioned, from a quantitative and qualitative point of view, by the type of soils, relief, vegetation cover, meteorological characteristics, etc., that exist in said area.

Within this territory we can distinguish several zones and characterize them.

4.2 Topographic characteristics

The hydrological characterization of the basins with respect to their topography is structured in three main aspects: size, shape and relief.

For each one of them, different indices or parameters can be determined to obtain information about the behavior of the water in the basin. These indexes are oriented to obtain immediately quantitative values that later allow to qualitatively characterize the basin, being of great utility for analyzing the phenomena that take place in the same.

Among the most outstanding parameters are: surface, hipsographic curve, altitude and maximum relief.

4.3 Geological characteristics, soils characteristics and vegetation cover with hydrological influence

Geology, soil and vegetation cover are three factors with a great influence on the behavior of water in the basin, being also interrelated.

The geology determines to a great extent the typology of the soil of the zone, also conditioning the aquifer properties in the basin according to its porosity and permeability.

As for soil, it is one of the limiting factors, together with the climate, for the establishment of vegetation cover. Its depth, content in organic matter, texture and stoniness are some of its most influential properties in terms of hydrological behavior. In turn, the type of soil greatly influences the susceptibility to erosion.

The vegetation cover plays a very important role in the hydrological behavior of the basin. It acts as soil protection against erosion, both by runoff and by impact of rainfall, and influences the water cycle through the processes of interception, infiltration and evapotranspiration. In addition, it is the basic element of forest hydrological restorations.

4.4 The drainage network

It is defined as the set of water courses (natural or artificial, permanent or temporary) hierarchically organized that participate in the drainage of a basin. The characteristics of it are one of the factors that influence the hydrological behavior of the basin.

Density of drainage, number of order of the rivers and the longitudinal profile of the same, are some of the most important characteristics of a network. These, also with the form, are determining factors for estimating the time of concentration of the basin, being able to vary the form of the resulting hydrographs depending on the type of existing drainage network.

LINKS:
Video: “What is a watershed?”. North Texas Municipal Water District. 2017
Source: https://www.youtube.com/watch?v=QoqgzJAf6LQ
(This video is about concept watershed, how water flows into your primary drinking water source - Lavon Lake. By protecting your watershed and the environment around it, you can help improve the quality of the water you drink).

Video: “Watersheds conservation”. WWF Guatemala / Mesoamerica. 2017
Source: https://www.youtube.com/watch?v=aq_AydC77Gs
(This video is about Watershed conservation that is vital to guarantee water quality and quantity for the future).

Book: “Entering the Watershed: A New Approach To Save America's River Ecosystems”. Robert Doppelt, Mary Scurlock, Chris Frissell, James R. Karr
(Source:https://books.google.es/books?hl=es&lr=&id=_M2gWgcb-hcC&oi=fnd&pg=PR7&dq=The+watershed+and+the+river&ots=dxypL9Q1D5&sig=ygJzVL0U5THPerW9IBWJB2D7SDM#v=onepage&q=The%20watershed%20and%20the%20river&f=false)

Article: “Determination of the drainage structure of a watershed using a digital elevation model and a digital river and lake network”. Author R Turcotte, J.-P Fortin, A.N Rousseau, S Massicotte, J.-P Villeneuve. Canadá. 2001.
Source: https://www.sciencedirect.com/science/article/pii/S0022169400003425
(This video is about distributed hydrological models require a detailed definition of a watershed’s internal drainage structure. The conventional approach to obtain this drainage structure is to use an eight flow direction matrix (D8) which is derived from a raster digital elevation model (DEM). However, this approach leads to a rather coarse drainage structure

when monitoring or gauging stations need to be accurately located within a watershed. This is largely due to limitations of the D8 approach and the lack of information over flat areas and pits).

Article: “Connectivity: Four dimensions”. Department natural resources
Source: https://www.dnr.state.mn.us/whaf/about/5-component/dimensions.html
(This video is about of the connectivity refers to the flow, exchange and pathways that move organisms, energy and matter throughout the watershed system. These interactions create complex, interdependent processes that vary over time. As with hydrology, stream connectivity can be described in four dimensions: longitudinal, lateral, vertical, temporal).

5. HYDROLOGICAL PROCESSES

5.1 Precipitation

Precipitation is water delivered to Earth from the atmosphere in solid or liquid states. It is the major source of water to a watershed system including streams, springs, soil moisture, groundwater, and vegetation. However, not all rains or snows from a storm event will reach the ground. Before reaching the ground, part of precipitation will be intercepted and retained by the aerial portions of vegetation and ground litter. The intercepted precipitation will be either vaporized back to the air or dripped to the ground. This process, called forest interception, can affect precipitation disposition, soil moisture distribution, and the impact energy of raindrops on the soil. The amount of interception loss is determined by storm and forest characteristics (Chang M. 2003).

5.1.1 Origin and types of rainfall. Measurement and characterization. Temporal trends

- Types of rainfall

According to the content explained on pmfias website [https://www.pmfias.com/precipitation-types-rainfall-conventional-rainfall-orographic-rainfall-frontal-rainfall-cyclonic-rainfall-monsoonal-rainfall/], on the basis of origin, rainfall may be classified into three main types – the convectional, orographic or relief and the cyclonic or frontal.

- Rainfall record. Measurement and characterization

The rainfall measurement is made in a timely manner on the ground, and the data refer to the surface unit. The usual unit is "liters / m^2", which is equivalent to 1 mm of water height in an area of 1 m^2.

The relationship between the fallen precipitation and its time interval gives us the Intensity (mm / h). A rainfall intensity value is assumed constant over the time interval with which it has been calculated and, therefore, we speak of average intensity.

- Analysis of a storm from the point of view of its maximum values

If the interest is limited to knowing the amount of precipitation that has fallen in a certain time interval to analyze the data from the point of view of the Water Resource, the study of the variation of the rain corresponding to said interval (normally day, month or year) over time does not require a special previous analysis of the recorded information.

If the focus is on torrential avenues, the intensity of the rain is very important, since these events are closely related to this magnitude. As has been said, to be able to analyze intensity variations, it is necessary to have pluviographic records and the intensity values handled will almost always be average values related to a certain time interval. This time interval, used to calculate the intensity, is variable and will depend on the destination of said data.

In the analysis of torrential events, we are interested in the maximum intensity values that may be arisen, since the maximum flows that can be reached will depend directly on said maximum intensities, modulated by the characteristics of the watershed at the point of the analyzed channel.

5.1.2 Intensity-Duration-Frequency.

To deal with the design of the storm of calculation, when we are going to work with small and medium watersheds, we need to know the possible maximum values of precipitation in "short" time intervals (less than 24 hours). Storms usually last for hours, not days. As we only have the corresponding data for 24 hours, we need to be able to estimate the maximum rainfall for small intervals, hours or even minutes, from said daily data.

For this, we turn to mathematical formulations of height-duration or intensity-duration curves that, duly adjusted to the area in which we work, allow us to work with data associated with small intervals.

Starting from the available data of maximum rainfall in 24 hours for different return periods, we obtain the corresponding maximum daily average intensities

$$d^{T} = \frac{{P_{24h}}^{T}}{24}$$

With these data we can elaborate the Intensity-duration-frequency curves, and their corresponding height-duration-frequency curves (it is enough to multiply by the time interval or divide by it, as appropriate, to move from one to another).

HEIGHT-DURATION-FREQUENCY CURVES

H-D-F

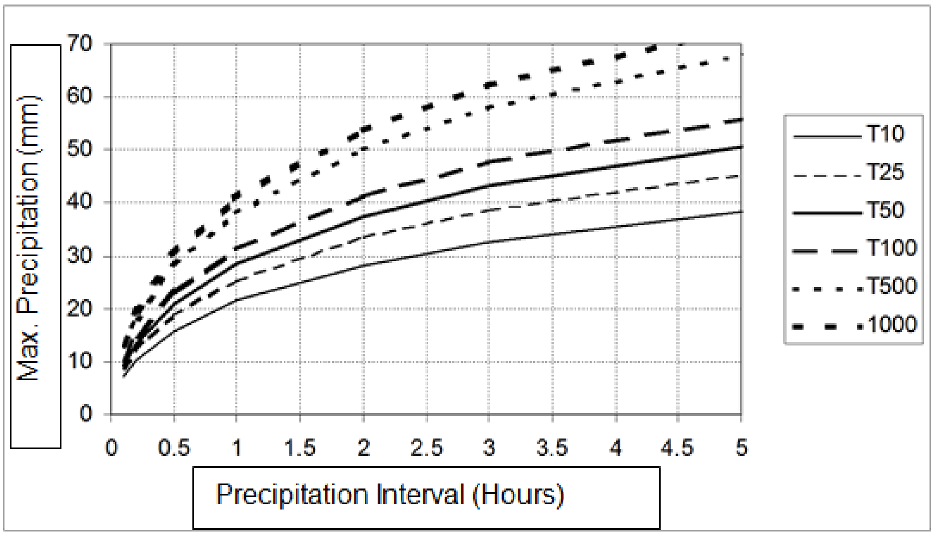


Figure 2 Height-Duration-Frequency curves.

5.1.3 Probabilistic treatment of Hydrologic Data

To perform the statistical study of a certain maximum data, and analyze its probability of occurrence over time, it is necessary to have a more or less large number of records. The broad series, in terms of number of years recorded and spatial distribution correspond mostly to daily records (24 hours of time interval read at a certain time each day, for example at 8:00 a.m.).

To analyze the frequency with which the different values of daily precipitation can be reached, we can discretize the continuous value that is being analyzed in 10 mm intervals, each interval labeling with the corresponding average value. This gives us an idea of the most frequent maximum values, constituting the density function f(x). If we accumulate the maximum events that fall below a certain precipitation value it would give us an idea of the distribution function F(x), and dividing the accumulated event values by the total number of events we would obtain the probability that a certain value of rainfall is not overcome.

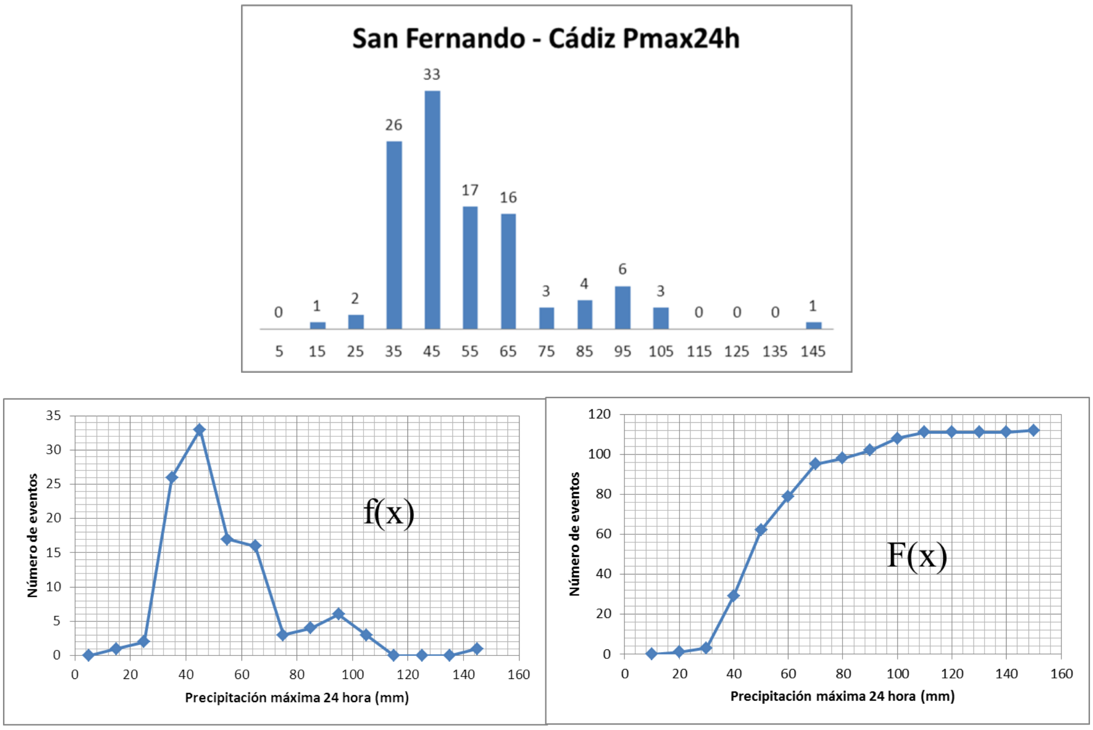


Figure 3. Examples of density function and distribution function of analysed series in San Fernando, Cádiz (Spain).

There are statistical expressions that can represent these distributions. In general the maximum values do not follow a NORMAL distribution, but they have a certain bias towards the highest values. These types of functions are called extreme value functions and are better adapted to the form presented by the series of maximum values such as the one we are analyzing. An example of this type of distribution is the GUMBEL function.

To adjust the different distribution functions available, three values are used:

- The position, associated with the average of the series.
- The scale, associated with the standard deviation
- The asymmetry, associated with the asymmetry coefficient

The distribution functions have a certain number of parameters that allow adjusting the mathematical expression to the values of the series. Normally they usually have two or three parameters. The more parameters you have, the better the adjustment that can be made to the data series, but in return, if the series does not have a large number of data, the inclusion of some new data can cause the adjustment to change, and the results of probability can be modified appreciably. The functions of two parameters are more stable in this regard.

As an example we have (Figure 5):

GUMBEL: It has two parameters and assumes a coefficient of fixed asymmetry equal to 1.14

SQRT: It has two parameters and a coefficient of asymmetry variable depending on the sample, but always higher than 1.14

GEV: It has three parameters.

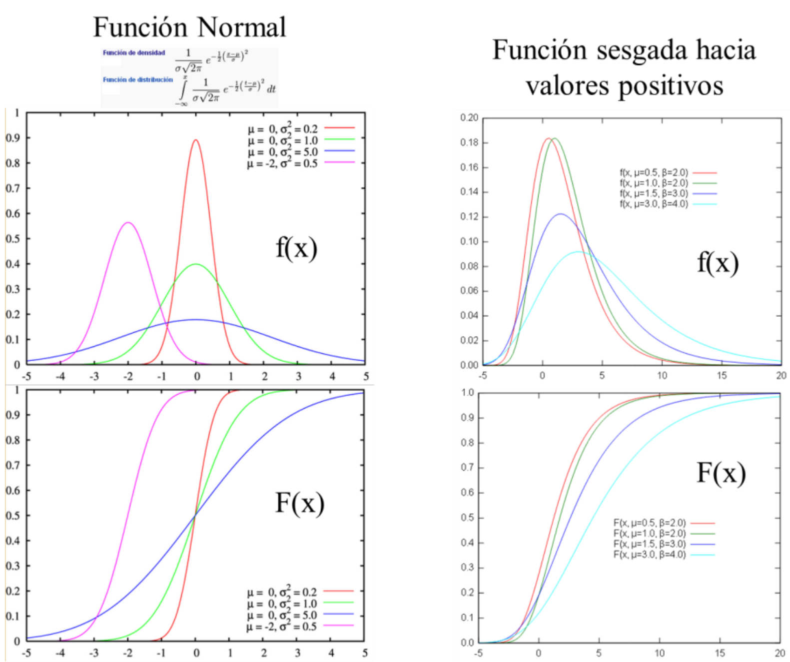


Figure 4. NORMAL function (on the left) and function of extreme values (on the right).

GUMBEL

$$F(x)=e^{\left[-e^{-\left(\frac{x-u}{\alpha}\right)}\right]}$$

$$f(x)=\frac{1}{\alpha}\cdot e^{\left[-\frac{x-u}{\alpha}-e^{-\left(\frac{x-u}{\alpha}\right)}\right]}$$

Coef. Asimetría fijo = 1,14
Dos parámetros: u (posición) , α (escala)

SQRT

$$F(x)=e^{-k\cdot\left[\left(1+\sqrt{\alpha\cdot x}\right)e^{-\sqrt{\alpha\cdot x}}\right]}$$

$$x\geq 0$$

Coef. Asimetría variable en función de la muestra, pero siempre ≥ 1,14
Dos parámetros: u (posición) , α (escala)

GEV

$$F(x)=e^{\left[-\left(1-k\cdot\frac{x-u}{\alpha}\right)^{1/k}\right]}$$

$$f(x)=\frac{1}{\alpha}\left(1-k\cdot\frac{x-u}{\alpha}\right)^{1/k-1}\cdot e^{\left[-\left(1-k\cdot\frac{x-u}{\alpha}\right)^{1/k}\right]}$$

$$k>0,\alpha>0,-\infty\leq x\leq u+\frac{\alpha}{k}$$

Tres parámetros:
u (posición) , α (escala) , k (asimetría)
(Poco robusta)

Figure 5 Different distribution functions of extreme values.

(To know more: https://www.pmfias.com/precipitation-types-rainfall-conventional-rainfall-orographic-rainfall-frontal-rainfall-cyclonic-rainfall-monsoonal-rainfall/)

LINKS:
Video: "Geography-Types of Rainfall". Angel. 2018
Source:https://www.youtube.com/watch?v=LtG5wMjqKZY
(This video is about the behavior of the types of rainfall).

Article: "Winter precipitation over the Iberian peninsula and its relationship to circulation indices". C. Rodríguez, A Encinasand J. Sáenz. España. 2001.
Source: https://www.hydrol-earth-syst-sci.net/5/233/2001/hess-5-233-2001.pdf
(This article is about winter precipitation variability over the Iberian Peninsula was investigated by obtaining the spatial and temporal patterns).

Book: "Hydrology: An Advanced Introduction to Hydrological Processes and Modelling". 2Arved J. Raudkivi.
Source:https://books.google.es/books?hl=es&lr=&id=lu3fBAAAQBAJ&oi=fnd&pg=PP1&dq=Hydrological+processes+precipitation&ots=hs25B4vcmc&sig=Af5_s4e46tDh0x30IVUPmomueUA#v=onepage&q=Hydrological%20processes%20precipitation&f=false
(The text is orientated toward discussion of the hydrological processes and methods of estimation of the various quantities involved).

Article: "Factors Affecting the Response of Small Watersheds to Precipitation in Humid Areas". John D. Hewlett And Alden R. Hibbert. 1966.
Source: http://coweeta.uga.edu/publications/851.pdf
(This video is about the runoff processes in forested headwaters relates quick rises in streamflow to variable source areas and subsurface translatory flow, or the rapid displacement of stored

water by new rain. Because this makes the classification of hydrograph components difficult, if not impossible, a numerical rating system, the response factor, was developed from precipitation and streamflow records for use in classifying the hydrologic response of small watersheds in humid areas.).

Article: "The role of hydrological processes in ocean-atmosphere interactions". Advancing, earth and space science – AGU 100.
Source: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/94RG01873
(This article explains why large-scale convection in the tropical atmosphere is constrained to lie within the 28°C sea surface temperature contour and how hydrological processes are involved in interannual climate variability).

5.2 Evaporation and Interception

5.2.1 Water evaporation. Factors involved

The two main factors influencing evaporation from an open water surface are the supply of energy to provide the latent heat of vaporization and the ability to transport the vapor away from the evaporative surface. Solar radiation is the main source of heat energy. The ability to transport vapor away from the evaporative surface depends on the wind velocity over the surface and the specific humidity gradient in the air above it. (Chow et al. 1988).

Evaporation from the land surface comprises evaporation directly from the soil and vegetation surface, and transpiration through plant leaves, in which water is extracted by the plant's roots, transported upwards through its stem, and diffused into the atmosphere through tiny openings in the leaves called stomata. The processes of evaporation from the land surface and transpiration from vegetation are collectively termed evapotranspiration (ET). (Chow et al. 1988).

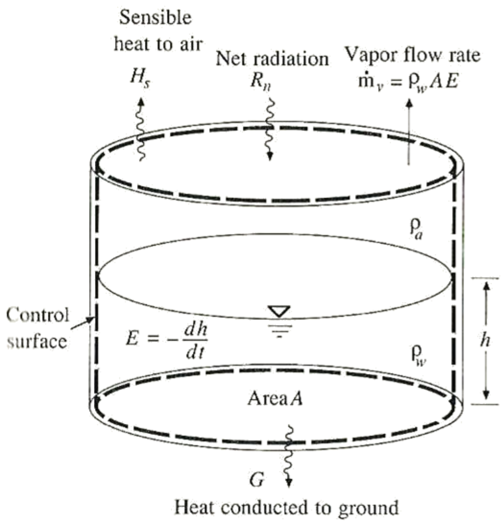


Figure 6.Control volume defined for continuity and energy equation development for an evaporation pan. Source: Chow et al. 1988.

5.2.2 Evapotranspiration. Factors involved. Measurement and estimation

Evapotranspiration is influenced by the two factors described previously for open water evaporation, and also by a third factor, the supply of moisture at the evaporative surface. The potential evapotranspiration is the evapotranspiration that would occur from a well vegetated surface when moisture supply is not limiting, and this is calculated in a way similar to that for open water evaporation. Actual evapotranspiration drops below its potential level as the soil dries out (Chow et al. 1988).

Evapotranspiration may be measured by means of lysimeters. A is a tank of soil in which vegetation is planted that resembles the surrounding ground cover. The amount of evapotranspiration from the lysimeter is measured by means of water balance of all moisture inputs and outputs (Chow et al. 1988).

A. Potential evapotranspiration

The estimate of watershed ET losses is often referred to as the concept of potential evapotranspiration (PE). It is, as defined by Thornthwaite (1948) and Penman (1963), the total water loss in vapor state from the center of an extended surface completely covered by short, even-height green vegetation with no limit on water supply. This definition emphasizes that the advective heat exchanges to and from the surroundings are insignificant, the heat flux from canopy to soil is negligible, water loss is independent of vegetation and soil type, and the solely limiting factor of PE is available energy. Thus, PE is the upper limit of ET under a given climatic condition and cannot exceed free water evaporation. In practice, PE =- ET if water supply to plants is unlimited or if monthly PE is less than monthly precipitation (Chang, M. 2003).

The concept of PE is widely accepted and frequently applied in geographic studies, climate classifications, and water-resources research, planning, and management. However, the PE concept is questionable if it is applied to small, forested watersheds. This is because of the tremendous effects on energy availability of forest density, species composition, the physiological and phenological behavior of woody plants, topography, and advective heat exchange. It also is invalid if it is applied to a body of pure water (Chang, M. 2003).

B. Actual evapotranspiration

When water supply for vaporization is deficient or soil moisture content is below the field capacity, then vaporization cannot proceed at the potential level. Thus, the actual evapotranspiration (AE) is only a fraction of PE, or:

$$AE = a(PE)$$

where the fraction a is affected not only by soil moisture content but also by climate and species. It is the so-called crop coefficient in agricultural irrigation (Chang, M. 2003).

5.2.3 Interception of rainfall. Factors involved. Measurement and estimation

The amount of precipitation captured by vegetation and trees is determined by comparing the precipitation in gages beneath the vegetation with that recorded nearby under the open sky. The precipitation detained by interception is dissipated as stem flow down the trunks of the trees and evaporation from the leaf surface. Stem flow may be measured by catch devices around tree trunks (Chow et al. 1988).

LINKS:
Video: "Interception". H Guan. 2015.
Source: https://www.youtube.com/watch?v=iFNYBHQYxjk
(This presentation is on the hydrological processes occurring when rain falls on canopy vegetation).

Article: "Snow interception evaporation. Review of measurement techniques, processes, and models". A. Lundberg, S. Halldin. Spain. 2001
Source: https://link.springer.com/article/10.1007/s007040170010
(This article is about global warming, primarily affecting wintertime conditions at high latitudes will influence the functioning of the boreal forest and water-balance equation that is evaporation of snow intercepted in forest canopies).

Article: Spatial and temporal characteristics of rainfall in Africa: Summary statistics for temporal downscaling
Source: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014WR015918
(The present study deals with rainfall patterns that are analyzed in the African continent from quarterly estimates of the Tropical Rainfall Measurement Mission (TRMM) of 0.25 ° between 1998 and 2012 to produce monthly statistical summaries).

5.3 Infiltration. Water in the soil

A body of water moving over Earth's surface in a network of channels such creeks, or rivers is called streamflow, a term that is often interchangeable in use with discharge or runoff. Water in stream channels comes from one or all of the four components (Chang, 2003):

(1) Precipitation intercepted by stream channels,
(2) Overland flow (surface runoff)
(3) Interflow (subsurface runoff)
(4) Baseflow (groundwater runoff).

Infiltration is the process of water penetrating from the ground surface into the soil. Many factors influence the infiltration rate, including the condition of the soil surface and its vegetative cover, the properties of the soil, such as its porosity and hydraulic conductivity, and the current moisture content of the soil. Soil strata with different physical properties may overlay each other, forming horizons; for example, a silt soil with relatively high hydraulic conductivity may overlay a clay zone of low conductivity. Also, soils exhibit great spatial variability even within relatively small areas such as a field. As a result of these great spatial variations and the time variations in soil properties that occur as the soil moisture content changes, infiltration is a very complex process that can be described only approximately with mathematical equations (Chang, 2003).

5.3.1 Infiltration of rainfall. Factors involved

Infiltration refers to the entry of water into the soil, a combined process of capillary attraction and gravitation along with the pressure due to water ponding at the ground surface. The infiltration rate is high at the initial stage and declines with time as soil voids such as animal burrows, root tunnels, interstices, and macro- and micropores gradually fill with water. It will eventually decline to a constant at which the infiltration rate is equal to the rate of water drained out through the soil profile by gravity. This process of draining water to deeper layers is called percolation (Chang, 2003).

Water movement into and through soil profiles is affected by a variety of factors reflecting the surface and subsurface conditions and flow characteristics. Surface conditions such as type of vegetation cover, land management practices, roughness, crusting, cracking, surface temperature, slope, and chemicals have a significant impact on surface ponding, overland flow velocity, and ability of the water to enter the soil. Conditions under the ground can include soil texture, structure, organic-matter content, depth, compaction, voids, layering, water content, groundwater table, and root system. These factors affect soil water-holding capacity and ability of water movement. For a given soil, the infiltration in a forest can be many times greater than that over bare ground. Also, infiltration is greater for warmer water containing less sediment (Chang, 2003).

5.3.2 Humidity of the soil. Measurement. Water potential. Characteristic curves of water retention in the soil

The distribution of soil moisture within the soil profile during the downward movement of water is illustrated in the next figure. There are four moisture zones: a saturated zone near the surface, a transmission zone of unsaturated flow and fairly uniform moisture content, a wetting zone in which moisture decreases with depth, and a wetting front where the change of moisture content with depth is so great as to give the appearance of a sharp discontinuity between the wet soil above and the dry soil below. Depending on the amount of infiltration and the physical properties of the soil, the wetting front may penetrate from a few inches to several feet into a soil (Hillel, 1980).

The infiltration rate I. expressed in inches per hour or centimeters per hour, is the rate at which water enters the soil at the surface. If water is ponded on the surface, the infiltration occurs at the potential infiltration rate. If the rate of supply of water at the surface, for example by rainfall, is less than the potential infiltration rate then the actual infiltration rate will also be less than the potential rate. Most infiltration equations describe the potential rate. The cumulative infiltration F is the accumulated depth of water infiltrated during a given time period and is equal to the integral of the infiltration rate over that period:

$$F(t) = \int_0^t f(\tau)\, d\tau$$

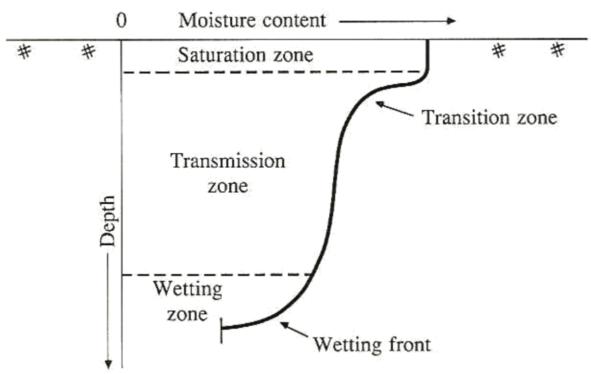


Figure 7 Moisture zones during infiltration

Soil Water Potential

Soil water potential is the driving force behind water movement. The main advantage of the "potential" concept is that it provides a unified measure by which the water state can be evaluated at any time and everywhere within the soil-plant-atmosphere continuum (Hillel, 1980).

Soil water is subject to a number of forces. These forces include gravity, hydraulic pressure, and the attraction of the soil matrix for water, the presence of solutes, and the action of external gas pressure (Hillel, 1980). At any point in the soil, total soil water potential is the sum of all of the contributing forces.

5.3.3 Movement of water inside the ground. Hydraulic conductivity and soil permeability

Hydraulic conductivity

Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement.

Permeability

According to the content explained on USDA website: [https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053573], the term "permeability" has three separate, but related, meanings:

1. In soil science, permeability is defined qualitatively as the ease with which gases, liquids, or plant roots penetrate or pass through a soil mass or layer (SSSA, 2001).

2. "Intrinsic permeability" or permeability (k) is a quantitative property of porous material and is controlled solely by pore geometry (Richards, 1952). Unlike saturated hydraulic conductivity, intrinsic permeability is independent of fluid viscosity and density. It is the soil's hydraulic conductivity after the effect of fluid viscosity and density are removed. It is calculated as hydraulic conductivity (K) multiplied by the fluid viscosity divided by fluid density and the gravitational constant. Permeability (k) has the dimension of area (e.g., cm2). Table 1 provides a comparison of saturated hydraulic conductivity and intrinsic permeability.

3. In some cases, permeability has been used as a synonym for Ks, even though some other quantity was originally used to convey permeability. For example, in the permeability studies by Uhland and O'Neal (1951), flux (under hydraulic gradient greater than one) was the true quantity measured to convey a soil's permeability. Darcy's law demonstrates that flux is numerically equal to Ks only when the hydraulic gradient is equal to one. Therefore, the flux values reported in these studies were not synonymous with Ks. Over time, however, the original flux values from Uhland and O'Neal became misrepresented as Ks without qualification. This misrepresentation has led to confusion and misapplication.

The different meanings for permeability are not scientifically interchangeable. Indeed, the explicit meaning of the term "permeability" may not be discernable from written or verbal context alone. The first of the three meanings carries no quantitative implications, whereas the second and third have specific, quantitative applications. Confusion often arises because the meanings are overlapping. Present scientific convention avoids use of the third meaning entirely and is an important reason for using saturated hydraulic conductivity (Ks).

LINKS:
Article: "Effects of soil water repellency on infiltration rate and flow instability". ZWanga, JWua, LWua, C Ritsemab, L Dekkerb and JFeyenc.
Source: https://www.sciencedirect.com/science/article/pii/S0022169400002006
(he next article is about the infiltration experiments were carried out to quantify the effects of soil water-repellency on infiltration rate and the wetting front instability).

Article: "Relationship between precipitation and the infiltration depth over the middle and lower reaches of the Yellow River and Yangtze-Huaihe River Valley". Z Haoa, Z Quansheng, GXifeng. 2008
Source: https://www.sciencedirect.com/science/article/pii/S1002007108002141
(The purpose of the paper is to extract and make the best use of rainfall information contained in the Chinese historical archives of Qing Dynasty, and reconstruct the precipitation series during 1736–1911. The study followed the Yu-Fen-Cun (rainfall infiltration depth) observation method in Qing Dynasty, to conduct soil infiltration experiment under the natural rainfall conditions during 2004–2006).

Video: "What´s an aquifer?". GeoScience Videos. 2016
Source: https://www.youtube.com/watch?v=g7R0yLX0V9E
(This video describes the basic characteristics of two types of aquifers and identifies four types of geological units that make up many of the aquifers in the US).

Video: "Factors affecting Infiltration. Seth Horowitz. 2016.
Source: https://www.youtube.com/watch?v=86ZKTcooAiY
(This video explores how much of the land, degree of saturation, amount of vegetation, and land use by humans at the rates of runoff and infiltration).

5.4 Runoff

5.4.1 Origin and Types of runoff. Units

Precipitation that reaches the soil surface can be entirely or partly absorbed by the soil in the process of infiltration. The infiltrated water can be lost to the air through evapotranspiration, be retained in the soil as soil moisture storage, become ground water through percolation, or run laterally in the soil profile as interflow or subsurface runoff to reach stream channels. The rate of infiltration processes largely depends on precipitation intensity and soil properties (Chang, 2003).

When precipitation intensity is greater than the infiltration rate of the soil, or precipitation is greater than the soil water-holding capacity, the excess water will run over the ground surface as overland flow or surface runoff to the nearest stream channel. Some of the overland flow can be trapped in concavities of the surface as depression storage. The combination of surface and subsurface runoff is called direct runoff. It is an influent stream if streamflow comes solely from direct runoff. Such streams flow only during storms, after storms, and in wet seasons.
Under the ground, the profile is divided into two zones: the zone of aeration overlying the zone of saturation. The zone of aeration provides soil moisture, air, nutrients, and sites for plants and animals. The zone of saturation provides a natural reservoir to feed springs, streams, and wells. A stream is effluent if its channel intersects with a groundwater table in which water flows all year round (Chang, 2003).

Runoff is considered the residual of the hydrologic system in a drainage basin. Precipitation is first to satisfy the watershed storage and evapotranspiration demands before overland runoff can occur. The runoff process involves translocation, water storage, and the change of the state of water. Since its occurrence is in response to watershed climate, topography, vegetation, soil, human activity, and streamflow quantity and quality provide an effective indicator for watershed management conditions (Chang, 2003).

5.4.2 Runoff coefficients

The rainfall-runoff process should be considered that the physical conditions of a catchment area are not homogenous. Even at the micro level there are a variety of different slopes, soil types, vegetation covers etc. Each catchment has therefore its own runoff response and will respond differently to different rainstorm events (FAO).

The design of water harvesting schemes requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion (percentage) of the rainfall depth.

$$\text{Runoff [mm]} = K\cdot{}^{*}\ \text{Rainfall depth [mm]}$$

In rural catchments where no or only small parts of the area are impervious, the coefficient K, which describes the percentage of runoff resulting from a rainstorm, is however not a constant factor. Instead its value is highly variable and depends on the above described catchment-specific factors and on the rainstorm characteristics (FAO).

5.4.3 Estimation of surface runoff. Curve Number Method

The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall (Hjelmfelt, 1991).

The SCS runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Figure 8 The SCS runoff equation

Where:
Q = runoff (mm)
P = rainfall (mm)
S = potential maximum retention after runoff begins (mm)
Ia = initial abstraction (mm)

This method was developed by U.S. Soil Conservation Service (S.C.S) and is based on the direct estimation of the surface runoff of an isolated rain based on the characteristics of the soil, its use and its vegetation cover.

We assume that each of the ground vegetation complex behaves in a same way to infiltration.

In a completely impermeable soil-vegetation complex (plastic surface) all precipitation becomes surface runoff. This response can be represented graphically as a graphic sample A of the following figure. On the contrary, a completely permeable complex (a strainer) would not give runoff whatever the value of the precipitation (graphic b on the figure 9). Actually, the surface of the land has a certain capacity to retain water. Imagine that this surface is filled with containers of the same capacity that have a height of S mm. Until precipitation does not reach the cumulative value of S, there will be no runoff, Q = 0, but from that accumulated precipitation value all the rain will be transformed into runoff, Q = (P - S). This situation is reflected in graphic C of the following figure.

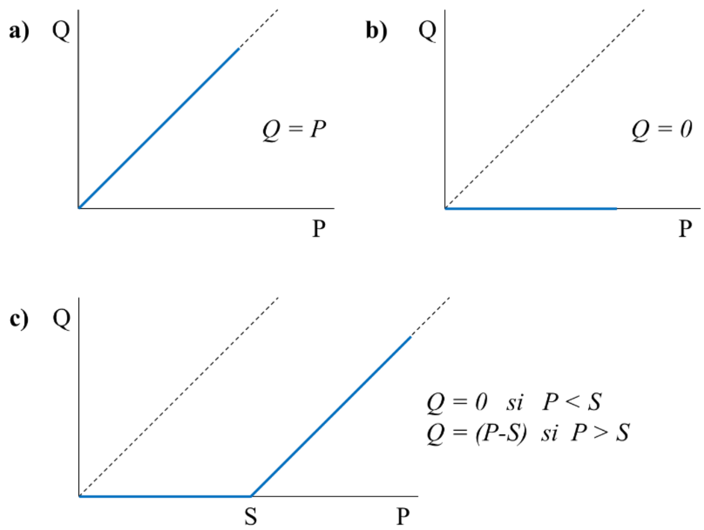


Figure 9 Cumulative runoff response q before the accumulated precipitation value p in different types of surface.

To know more: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

LINKS:

Article: "Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis".
Source: https://www.sciencedirect.com/science/article/pii/S0025326X04004497

Article: "Partial Area Contributions to Storm Runoff in a Small New England Watershed".
Source:https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/WR006i005p01296

Video: Surface Water Runoff of Plaster Creek
Source:https://www.youtube.com/watch?v=aWsnTtT0Uws

5.5 River flow analysis

5.5.1 Flows Origin of the rivers and Types of regime

The stream flow response to rainfall depends on the catchment attributes [1] that include the physiographic, underlying geology, vegetation cover and rainfall amount, intensity, and frequency. The interaction between these attributes and the nature of the response are variable in space and time and induce complexity which cannot yet be predicted in hydrology [2]. River flow regime is one of the means that addresses the complexity of stream flow response through the process of systematically organizing streams, rivers or catchments into groups that are most similar with respect to their flow characteristics [3]. (Berhanu, B. et al. 2015)

Historically, flow regimes have played a vital role in the ecological sciences in understanding river flow variability [4–7], planning conservation efforts for freshwater ecosystems [8,9], exploring the influence of stream flow on living communities and ecological processes [10–14], providing an inventory of hydrologic types for water resource management [15,16], and hydrologic regionalization analyses [17]. Flow regime classification is achieved commonly on the basis of stream flow characteristics using hydrologic indices with five stream flow components; magnitude, frequency, duration, timing, and rate of changes of flows [25,26]. (Berhanu, B. et al. 2015)

There are many different ways of defining flow regime characteristics of rivers using qualitative descriptions, or a wide range of quantitative values. The latter could be based on analyses of time series of flow data at the specific site of interest (either observed, through some method of flow measuring, or simulated by some model or extrapolation procedure), or taken from a regional analysis. The important characteristic that should be defined, regardless of whether qualitative or quantitative descriptors are used, is the degree of variability over different time scales. [http://www.dwa.gov.za/IWQS/rhp/reports/report14/2_flow.pdf]

Some types of Fluvial Regime

Depending on the main source of water contribution to the flow of a river, different types of fluvial regime are usually differentiated:

- Snow Regime: There is a clear increase in the flow of the river in the spring-summer months, due to the snow melting. The winter months have a very low flow because the water is frozen.
- Nivo-pluvial regime: It has a maximum flow in the months of melting and secondary highs related to rainfall.
- Pluvio-nival regime: It presents its maximum flow in the rainiest months, but due to the contribution of the thaw the decrease in flow in the months close to summer is not as marked.
- Oceanic pluvial regime: The flow of the river follows the seasonality of the rains in the zone of oceanic climate. The maximum flow rates occur in winter and spring and there is a decrease in summer. An important feature is that the flow is quite regular. At peak times, the average annual flow is rarely doubled. We can detect this regime in stations located between 1,600 and 2,000 meters of altitude.
- Mediterranean pluvial regime: The flow of the river follows the seasonality of the rains in the zone of Mediterranean climate. It can have its maximum flow in spring, autumn or winter, depending on the area, and summer drought is very marked. An important feature of this regime is the great irregularity. The months of maximum flow usually exceed twice the annual average flow.

5.5.2 Analysis of historical records. Temporary trends

5.5.2.1 Data registry

The hydrological series can be grouped as follows (González, M. 2013):

(1) Daily Average Flow Series: For each day there is a flow data, equivalent to the average flow of the corresponding day
(2) Monthly average flow series: For each month there is a flow data, obtained as the average value of the 30/31 daily average flows of each month
(3) Series of annual average flows: For each year a flow data is available, obtained as the average value of the 12 monthly average flows of that year
(4) Series of Maximum Flows: For each year there is a flow data that corresponds to the maximum daily or instantaneous flow of that year

✓ Monthly module: Average value of monthly average flows, for a consecutive period of years

- ✓ Annual module: Average value of annual average flows, for a consecutive period of years

5.5.2.2 Statistical analysis of hydrological series

In the case of monthly, annual average flow series, it is generally assumed that (González, M. 2013):

- They follow a normal distribution
- Can be characterized through the following descriptors:
    - Medium, Medium
    - Standard deviation, Coefficient of variation
    - Percentiles

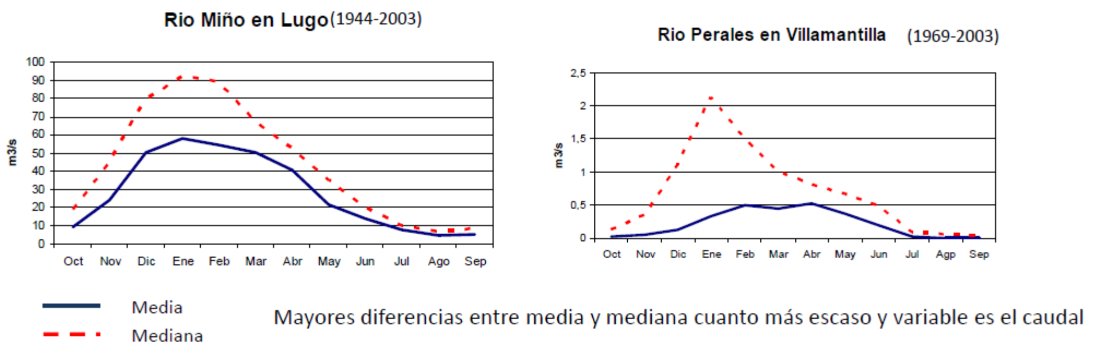


Figure 9. flow comparison of two Spanish rivers. Greater differences between average (Media) and median (mediana) the scarcer and variable is the flow

In the case of the series of maximum flows:

- Adjust to frequency distribution of extreme values (eg Gumbel)
- They are characterized by the maximum flow rates corresponding to the different return periods

Water year	Annual maximum discharge (cfs)	Rank	$(n+1)/m$
1967	2510	8	1.375
1966	4150	1	11.0
1965	2990	5	2.2
1964	2120	10	1.1
1963	3555	2	5.5
1962	2380	9	1.22
1961	2550	7	1.57
1960	2800	6	1.83
1959	3300	3	3.67
1958	3150	4	2.75

$$\text{Frecuencia (Weibull)}: \frac{m}{n+1}$$

$$\text{Periodo de retorno}: \frac{n+1}{m}$$

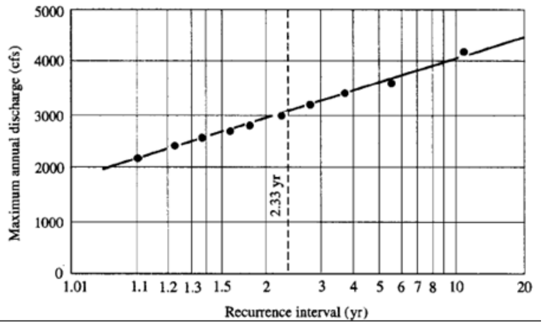


Figure 10. Adjust to frequency distribution of extreme values

In the case of maximum flows with geomorphological meaning:

- Flow that maintains the cross section of the channel (bankfull discharge):
- Permanent, more regular rivers: T = 1.5 - 2 years
- Temporary rivers, p, more irregular: T = 5 - 10 years

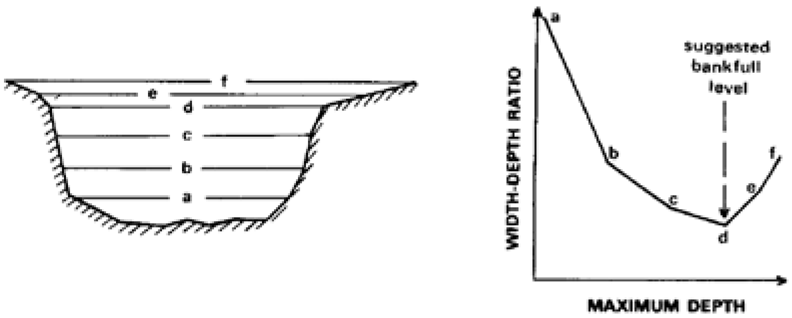


Figure 11. Geomorphological meaning of de maximum flows

5.5.3 Characterization of the flow regime and estimation of its alteration by human activities

The extensive ecological degradation and loss of biological diversity resulting from river exploitation is eliciting widespread concern for conservation and restoration of healthy river ecosystems among scientists and the lay public alike (Allan and Flecker 1993, Hughes and Noss 1992, Kaff et al. 1985, TNC 1996, Williams et a1. 1996).

Society's ability to maintain and res tore the integrity of river ecosystems requires that conservation and management actions be firmly grounded in scientific understanding. However, current management approaches often fail to recognize the fundamental scientific principle that the integrity of flowing water systems depends largely on their natural dynamic character; as a result, these methods frequently prevent successful river conservation or restoration. Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems.

The natural flow of a river varies on time scales of hours, days, seasons, years, and longer. Many years of observation from a streamflow gauge are generally needed to describe the characteristics pattern of a river's flow quantity, timing, and variability that is, its natural flow regime. Components of a natural flow regime can be characterized using various time series (e.g., Fourier and wavelet) and probability analyses of, for example, extremely high or low flows, or of the entire range of flows expressed as average daily discharge (Dunne and Leopold 1978).

Human modification of natural hydrology processes disrupts the dynamic equilibrium between the movement of water and the movement of sediment that exists in free-flowing rivers (Dunne and Leopold 1978). This disruption alters both gross and fine-scale geomorphic features that constitute habitat for aquatic and riparian species (Table 1). After such a disruption, it may take centuries for a new dynamic equilibrium to be attained by channel and floodplain adjustments to the new flow regime (Petts 1985); in some cases, a new equilibrium is never attained, and the channel remains in estate of continuous recovery from the most recent flood event (Woiman and Gerson 1978).

Read More at: LINK

LINKS:

Article: “North Atlantic oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula”
Source:https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.1048

Article: “High resolution mapping of the world's reservoirs and dams for sustainable river flow management”
https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/100125

5.6 Estimation of ordinary flows. Water balances

The water balance consists of estimating the different water flows that connect the storage points of the same within the hydrological cycle. In this way we can know the contribution that can be expected from a watershed at a point in its drainage network based on rainfall, temperatures and morphological characteristics corresponding to that territory. The basic premise is that the continuity equation must be met at the level of a unit of surface

$$[\text{Inputs}] - [\text{Outputs}] = [\text{Storage variation}]$$

In a simple way the elements to consider are:

- Inputs: Precipitation
- Outputs: Real evapotranspiration and aquifer recharge
- Storage: Snow, Soil Moisture and Gravitational Water

One of the most used methods to calculate the balance is Thornhwaite and Matter This uses the month as a time interval and as starting data the average temperature and precipitation. You can consider performing a continuous simulation of all the years registered or work with the average year.

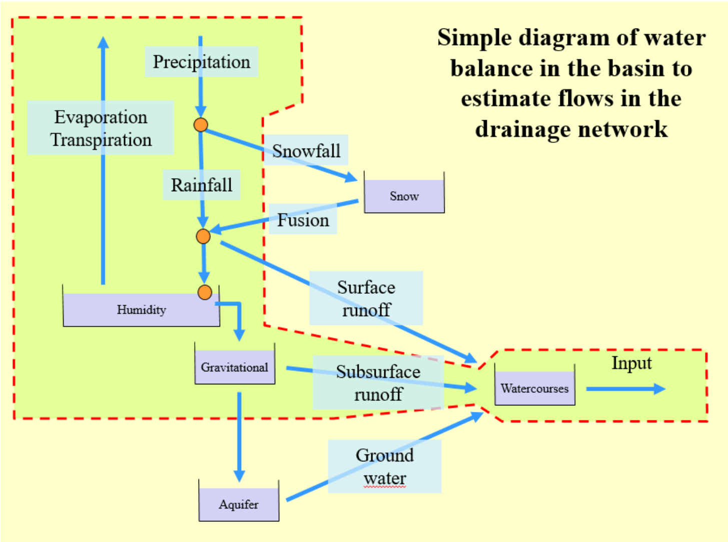


Figure 12Water balance

LINKS:

Article: “GIS-based recharge estimation by coupling surface–subsurface water balances”.
Source:https://www.sciencedirect.com/science/article/pii/S0022169407000765

Article: “Seasonal Variations in the Heat and Water Balances for Nonvegetated Surfaces”
Source:https://journals.ametsoc.org/doi/abs/10.1175/1520-0450(1997)036%3C1676:SVITHA%3E2.0.CO%3B2

5.7 Estimation of extraordinary flows. Flood hydrographs

The floods are a consequence of the elevation of water levels in the riverbeds to unusual values, due to the growth of the flow that circulates through the drainage network. In this section, we intend to reflect some of the tools / methods for the analysis and calculation of the value of these flows.

5.7.1 Rational Formula

This formula allows the calculation of flood flows in small basins, based on rainfall data and runoff conditions in the watershed. Its expression is the following:

$$q = \frac{C * I * A}{3,6}$$

Being:

- q (m^3/s), flood flow for the return period T.
- C, runoff coefficient of the basin, can be estimated by analyzing runoff / precipitation data obtained in basins with similar characteristics to the study.
- I (mm/h): maximum rain intensity in, tc (time of concentration of the basin) for the return period of calculation T.
- A (km^2): surface of the watershed.

The formula is associated with several previous hypotheses that assume the existence of possible sources of error, mainly due to an excessive simplification of processes and the use of empirical factors. Despite this, it is an effective and fast formula, highly indicated for urban hydrology and small and homogeneous basins.

5.7.2 Unit hydrograph

This method was developed by Sherman in 1932, and is currently one of the most used in the case of medium-sized basins. Its foundation is as follows; having an isochronous map, the effective area curve for a duration interval D and constant intensity; if we assume that this interval generates a unit runoff, that is, we have a runoff coefficient and a precipitation intensity such that

$$C \cdot I \cdot D = 1 \text{ mm}$$

The hydrograph generated by said runoff unit will be

$$q(t) = \frac{C \cdot I \cdot A(t)}{3.6} = C \cdot I \cdot \frac{A(t)}{3.6} = \frac{1}{D} \cdot \frac{A(t)}{3.6} = \frac{A(t)}{3.6 \cdot D} = HU(t)$$

Where A(t) is the effective area origin of the water that constitutes the flow that passes through the control point at a given time. This is the so-called unit hydrograph, which does not depend on precipitation, only on the morphological characteristics of the basin, represented by the isochronous map, and the time interval, D, in which the runoff unit has been generated. Once this hydrograph is known and assuming the hypotheses associated with this method, we can estimate the hydrograph generated by any storm for which we have the temporal distribution of intensities.

5.7.3 Computer applications

One of the most used computer applications in this field is HEC-HMS. In this section there is a brief introduction to the bases and foundations of it.

5.7.3.1 HEC-HMS

The HEC-HMS model ("Hydrologic Engineering Center-Hydrologic Modeling System") was designed to simulate rain-runoff processes in dendritic basin systems. It is a free program, public domain and was developed by the Hydrological Engineering Center (HEC) of the United States Army Corps of Engineers (U.S. Army Corps of Engineers-USACE). It is used in studies of water availability, urban drainage, flow forecasts, future urbanizations, flood damage reduction, etc.

The HEC-HMS is used to simulate the hydrological response of a basin. The program creates said simulation, combining the models and specifications. There are four basic modules that define the data entry and the simulation structure of the basin as a whole:

- ✓ Input data
- ✓ Basin model: used to represent the physical part of the basin. The user develops a basin model by adding and connecting hydrological elements. The hydrological elements use mathematical models to describe the physical processes in the basin.
- ✓ Meteorological model: The meteorological model calculates the input of precipitation required by a sub-basin element. The program can use spot or mesh data and can model freezing or liquid rain along with evapotranspiration. Includes several methods of precipitation.
- ✓ Control module: The control specifications set the duration time of each execution of a simulation. The control specifications must include the start date, the end date and the time interval (minutes, hours, days) of the simulation.

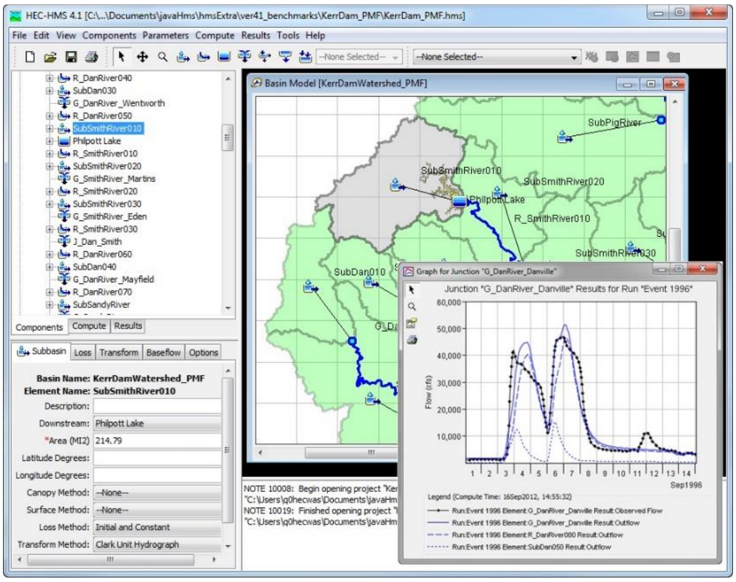


Figure 13. Detail of the interface in HEC-HMS

The results of the simulation can be seen on the map of the basin. Global and element summary tables are generated, which include information about the maximum flow and the total volume.

Also available are a time series table, the element chart, the results of multiple elements and simulations.

Recently, an application has been developed (HEC-GeoHMS, developed for the ArcGIS program) that facilitates the incorporation of spatial information to the HEC-HMS model. All the support on HEC-HMS can be found at http://www.hec.usace.army.mil/software/hec-hms/

LINKS:

Article: "Estimation of flood hydrograph using deterministic modeling and weather radar rainfall".F Magaña, K M. Bâ and VH. Guerra. Mexico.2016.

Source:https://www.researchgate.net/publication/287350493_Estimation_of_flood_hydrograph_using_deterministic_modeling_and_weather_radar_rainfall

(In this study, the importance of using radar-based rainfall estimation for the modeling of peak flow in poorly gauged basin is highlighted. The hydrological modeling with radar estimated rainfall, takes into account, detailedly, the spatial and temporal variability of the rainfall).

Article: "4 Methods to estimate changes in flood flows". Manual for Local Government in New Zealand. New Zealand.

Source: http://www.mfe.govt.nz/publications/climate-change/tools-estimating-effects-climate-change-flood-flow-guidance-manual-loc-5

(This chapter looks at both screening and advanced tools that can be used to help river managers estimate changes in flood flows).

6. HYDRAULICS APPLIED TO OPEN RIVERBEDS

6.1 Introduction to hydrostatics

Hydrostatics is the part of Fluid Mechanics that studies liquids at rest. In the absence of movement, the effects of viscosity do not manifest themselves; therefore, there is no distinction between ideal and real fluids.
Hydrostatic pressure is defined as the force exerted by a liquid at rest on the surface on which it affects.
For further information, please follow the LINK-Section 6.1

6.2 Study of flow in open channels

The open channels are characterized by a free surface (subject to atmospheric pressure) and an impenetrable contour. It is fulfilled by rivers, streams, canals and even pipes if they are not completely full.

Figure 14. Open channel in a headwater area

In them the hydraulic axis is the representative line of the free surface.

a) Channel geometry.

The sections of the natural channels are in general very irregular, however, to deal with the hydraulic calculations in said sections and for the design of channels, simple forms are usually used. The most frequent forms are:

- Trapezoidal: provides lateral slopes for stability.
- Rectangular: it is used when the design material presents no problems in terms of stability.
- Triangular: reserved for small sections, gutters, etc.
- Circular: commonly used in sewage and drainage network

In a section we can define a series of parameters:

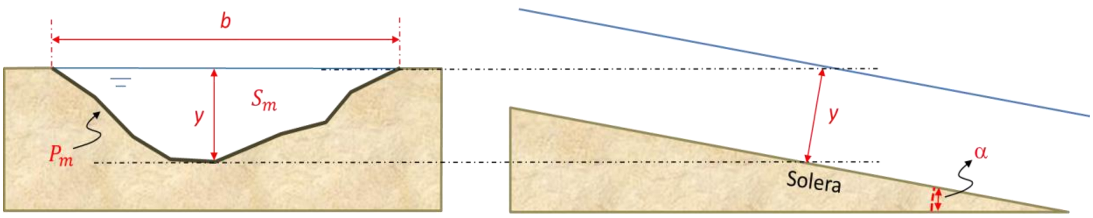


Figure 15. Hydraulic parameters in the cross section

- Draft (y), water sheet height
- Wet section (Sm) = Cross section to the channel
- Wet perimeter (Pm) = Length of the contour line of the wet section
- Hydraulic radius (Sm / Pm)
- Average depth y_m = Sm / b
- Width in the free surface (b)

b) Distribution of pressure in a section

The pressure at any point of the cross section of the flow can be measured by the height of the water column reached in a piezometric tube placed at that point.
In the uniform movement the flow is practically parallel, so that the distribution of the pressure in a section is linear, that is, follows the hydrostatic law, the water will therefore rise to the free surface of the water.
If the current lines presented curvature, rapidly changing movement, a component of the acceleration would appear in the direction of the flow that would disturb the hydrostatic distribution.

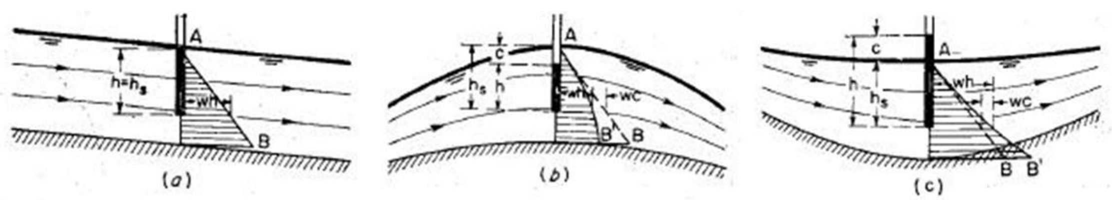


Figure 16. Distribution of pressure in a section

c) Distribution of velocity in a section

In channels, the friction existing against walls and bottom, as well as with the air in the free surface, cause that the velocity varies in each point of a cross section. The velocity vector can have components according to the three coordinate axes, however, the vertical and transverse components are usually small, so only the velocity component will be considered according to the flow direction.

In a uniform movement, it is to be expected and this is the case, the distribution of velocities is substantially equal throughout the entire current.
To determine the velocity at one point, the Pitot tube and the Woltman current meter (Fig. 18) are used.

Figure 17. Woltman current meter.

Experimentally it has been seen that the velocity in a section follows the distribution model as in the figure, where the lines joining points of equal velocity (isotacas) are represented.

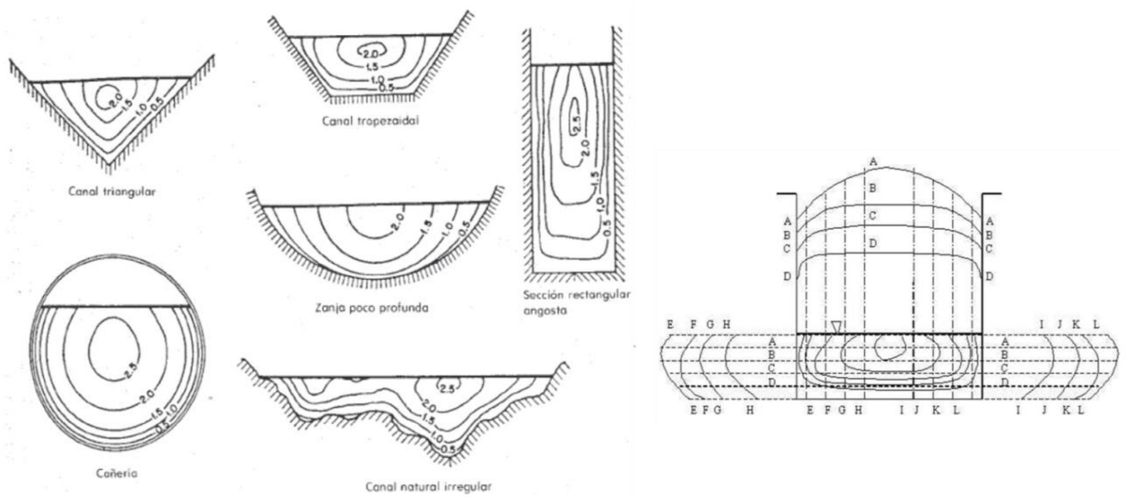


Figure 18 Distribution of velocity in a section (Source: ingenierocivilinfo.com)

Figure below shows a typical distribution of the velocity with the draft. It is observed that the maximum velocity is below the free surface, at a depth between $0{,}95 \cdot y$ - $0{,}75 \cdot y$. ($0{,}05 \cdot y$ – $0{,}25 \cdot y$ if we measure it from the free surface)

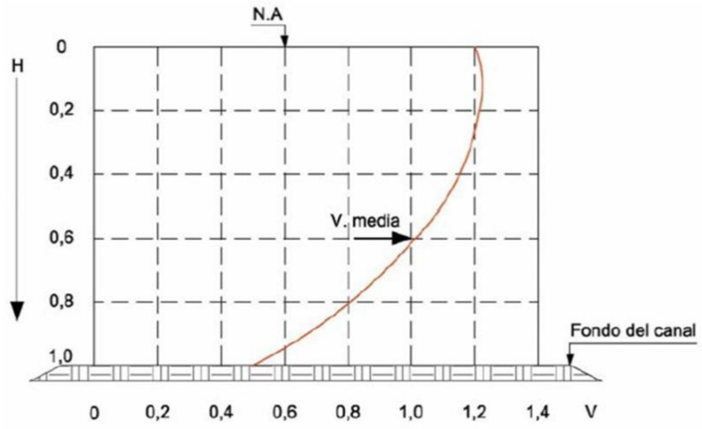


Figure 19 Distribution of velocity (Source: ingenierocivilinfo.com)

d) Froude number.

In the open channels there is no longitudinal pressure gradient and the movement is conditioned by gravity, consequently, the dimensionless number that characterizes it is the Froude number. Froude's number is the dimensionless number that relates the forces of inertia with the forces of weight.

For further information, please follow the LINK-Section 6.2

6.3 Determination of the main hydraulic variables needed in water bioengineering techniques design

Selecting the bioengineering technique to apply in a specific case, it is necessary to calculate or know a series of variables that will allow us to choose the most appropriate technique. These variables are multiple: topographical, biological, climatic ... In this section the hydraulics variables will be treated, differentiating the specific characteristics of the watercourse and those of the materials of the technique to be used, which are associated with hydraulic calculations.

A. Hydraulic variables of the watercourse

- Flow velocity: the flow velocity of a stream is the velocity at which water flows in the channel, expressed in meters per second. The ideal is to know:
    - Minimum flow velocity
    - Average flow velocity
    - Maximum flow velocity
- Flow Shear: the shear of the flow corresponds to the thrust of the water on the riverbed or channel in the direction of flow and is expressed in Newtons per square meter. As with velocity, it is important to know the minimum, medium and maximum. In addition, the ideal would be to be able to distinguish between shear fluxes in the bed and shear fluxes in the slope. As is normal in watercourses, there are numerous curves in the path followed by them, so it would be interesting to also calculate the shear of the flow in curve.

- Slope: is the degree of inclination of a surface that is measured in relation to the horizontal and expressed in degrees. It is interesting to know the maximum and the minimum. Not only the bed, but also the margins and slopes adjacent to the stretch of the watercourse.

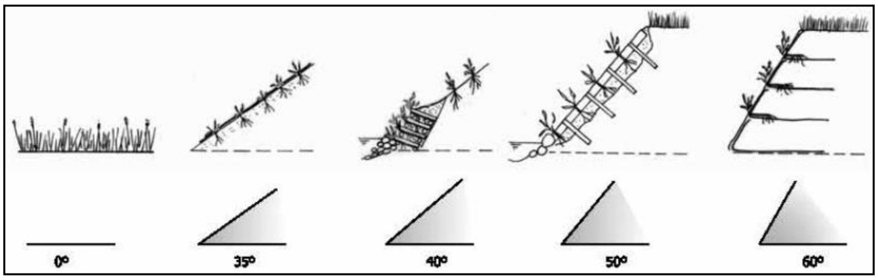


Figure 20Slope as a limiting factor in the Soil bioengineering technique to be used

- Manning roughness coefficient: it is a dimensionless parameter that reflects the degree of resistance offered by the different elements of a water course to the passage of the fluid. It depends on a large number of factors: vegetation, sediments, erosion ... In general, it is determined from tables in which its value is associated with typologies of natural channels.
- Water sheet height
- Hydrostatic thrust

B. Hydraulic variables associated with materials

Manning roughness coefficient: this parameter must not only be taken into account in the typology of the channel, but it is also decisive in the material to be used according to the bioengineering technique to be used. Generally, many of the bioengineering techniques imply the use of vegetation. This, in addition to fixing materials, will greatly influence the resistance to the passage of the fluid. For this reason it is of special importance to know what effect the vegetation can have that is incorporated, as part of the action, on this coefficient of roughness

For further information, please follow the LINK-Section 6.3

6.4 Computer applications

Two of the most used computer applications in this field are HEC-RAS and IBER2D. In this section there is a brief introduction to the bases and foundations of them.

- IBER2D

The IBER2D model is a two-dimensional mathematical model for the simulation of flows in rivers and estuaries, promoted by the CEDEX (Center of Studies and Experimentation of Public Works) and developed in collaboration with the GEAMA (Group of Water and Environmental

Engineering), Grupo Flumen and CIMNE (International Center for Numerical Methods in Engineering) It is free and is constantly updated.

IBER2D is a tool designed for the study of drafts and velocitys that allows solving engineering problems and fluvial dynamics, such as the delimitation of flood zones, the design of channelling and protection works, river restoration, emergency plans for breakage of dams , optimization of the operation of hydraulic works ...

It consists of 3 modules:

- Hydrodynamic module: it is the base of the program, it solves equations of superficial two-dimensional water averaged in depth.
- Turbulence module: it allows to include the turbulent tensions in the hydrodynamic calculation.
- Sediment transport module: solves equations of bottom transport and turbulent transport in suspension, being able to calculate the evolution of the bottom level.

One of the strengths of this computer resource is the possibility of simulating, in 2D, flows of natural channels and the combination of these with regulatory structures. In addition to this, the two-dimensional models are able to simulate with greater adjustment to reality all those situations in which the flow is not exclusively unidirectional, thus vastly expanding its field of use. This is one of your great strengths.

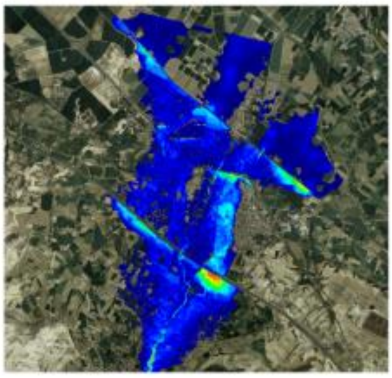


Figure 21 Detail of shallow water flows. Simulation with IBER2D (Source: IBERaula.es)

In IBER2D you can get results of all kinds of hydraulic parameters (drafts, velocitys, Froude number, specific flow, etc.) and has multiple viewing options such as graphics, animations, tables, results by sections ..., but also presents the advantage of being compatible with different Geographic Information Systems since it allows to export the results of each variable in raster format, which facilitates the handling of information and allows us to improve the visual representation.

It also has a strong web support in which in addition to downloading the software and manuals on it, there are tutorials and a help forum;http://www.iberaula.es/

- HEC-RAS

HEC-RAS is designed to perform one and two-dimensional hydraulic calculations for a full network of natural and constructed channels. The following is a description of the major capabilities of HEC-RAS (from: http://www.hec.usace.army.mil/).

The HEC-RAS system contains several river analysis components for: (1) steady flow water surface profile computations; (2) one- and two-dimensional unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is, that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to these river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed (from: http://www.hec.usace.army.mil/).

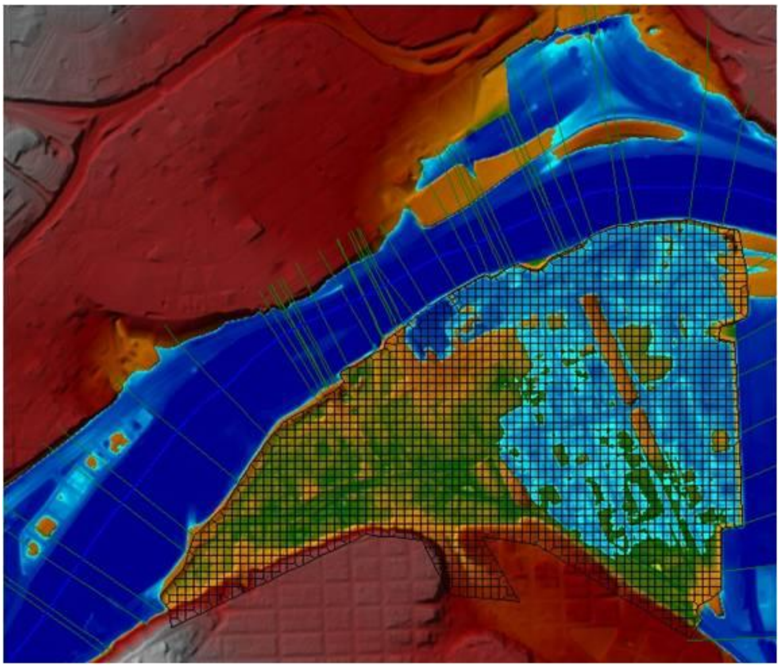


Figure 22 Detail of HEC_RAS. Source: http://www.hec.usace.army.mil/

For further information, please follow the LINK-Section 6.4

LINKS:

Article: "Relationships between hydraulic variables and bedload transport in a subalpine channel, Colorado Rocky Mountains, U.S.A.
Source: https://www.sciencedirect.com/science/article/pii/S0169555X9700055X

Article: "Laws of turbulent flow in open channels".
Source:https://nvlpubs.nist.gov/nistpubs/jres/21/jresv21n6p707_A1b.pdf

Aricle: "Prediction of flow depth and sediment discharge in open channels".

Source:https://authors.library.caltech.edu/25957/

7. EROSIVE PROCESSES

7.1 Soil erosion by water

7.1.1 The hydrological cycle and water erosion. Surface erosion and mass movements

Soil losses are closely related to rainfall, from splash detachment to its contribution to runoff. Thus, the foundation of water erosion rest in the hydrological cycle, That is, in all the paths followed by water from its incidence on the vegetation cover and Its subsequent movement on the surface of the soil.

It is necessary to define the surface water erosion as a result of two phases consistent by the disintegration of the soil in the soil particles by action of the impact of the raindrop (splash) and its transport by runoff. This combined effect is essential to guide an analysis of the mechanisms, factors and forms of erosion.

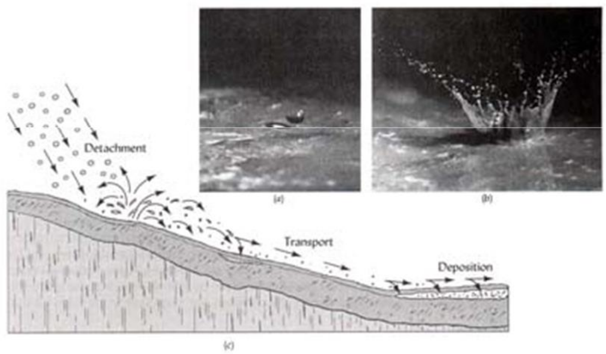


Figure 23. Representation of soil detachment, transport and deposition during water erosion process.

The attack of the water to the ground is carried out superficially or in the depth of its profile. In the first case, the particles of the soil are dragged in isolation while in the second they are mobilized massively. Both, while being a consequence of the action of water, differ in the mechanism. Within these forms we can distinguish the following manifestations:

Surface Erosion.	**Deep erosion (or mass movements)**		
	slow Movements	fast Movements	Landslides
Sheet erosion	Reptation	mudflows	washouts.
Rill erosion	Solifluxionero sion.	Soil flow	detritusLandslides
Gullies Erosion and channels		Landslides	detritus fall

			rockslides
			Rockslide

7.1.1.1 Sheet erosion

It consists of a removal of thin layers of soil spread more or less evenly over an entire surface. It results from the disintegration of soil elements by the impact of raindrops and the action of draining. The formation of a homogeneous surface flow transports soil particles previously disintegrated.

Sheet erosion is the cause of large sediment inputs to watercourses and, in addition, a significant loss of soil fertility by affecting finer soil particles.

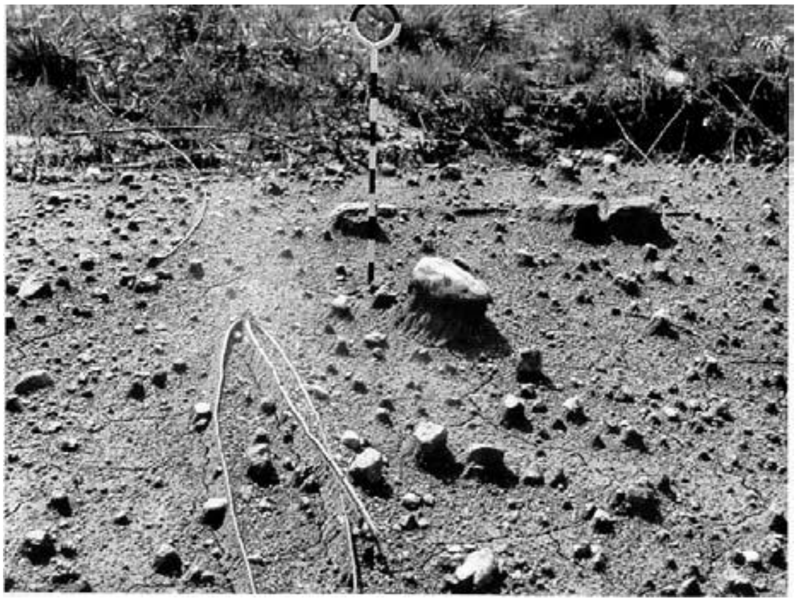


Figure 24. Example of sheet erosion

7.1.1.2 Rill erosion

Rills are longitudinal incisions in the ground, usually temporary and not hierarchical, that appear as a consequence of the local concentration of the water flow, channelled by the local characteristics of microrelief (Riou, 1990). The concentration of the flow implies the increase of the draft and the consequent increase of the erosive capacity.

The concentration of the waters when draining on the surface is mainly due to irregularities and surface unevenness. The presence of an obstacle in the middle of the stream (stones, rocks, isolated bushes, etc.) causes a separation and concentration of the water flow.

The formation of rills occurs especially during heavy rainfalls, the damage being serious, however, to appear well manifested, can act in due time and make appropriate mechanical corrections.

Figure 25. Example of rill erosion. (Source: José L. García)

7.1.1.3 Gully/ ravine erosion

In water courses, with permanent or temporary flow, erosion processes occur, unlike those considered above, located on the surface that defines the channel itself. It is consists of deep incisions in the terrain usually originated when there is a high concentration of runoff in a certain area. Once the formation of the ravine begins, its shape evolves according to the relative consistency offered by the different layers of soil and subsoil.

In the permanent watercourses, riparian vegetation plays a significant role in two aspects: on one hand, and fundamentally for its radical systems, it stabilizes the banks effectively controlling the processes of erosion of margins; on the other hand, thanks to the reduction of the velocity of the flow that the aerial organs impose and the consequent diminution of the erosive capacity of the water, it protects the soil of the flood plains that it occupies of the erosive phenomena that accompany the extraordinary avenues, time that favours the lamination in the course of the flood wave (López Cadenas de Llano, 1988).

In gullies and ravines, the radical systems provide the soil with a remarkable resistance both to the drag of its materials and to the collapse or mass movement, these latter effects are associated with mass movements induced in the formation of the channel. The progression of the gully, either longitudinally, upward progression, or transversally, may be limited by the presence of vegetation, although generally this is not enough to control the process and should be used engineering works such as consolidation dams and ditches in its head, which help to stabilize these erosive phenomena in a definitive way.

The erosion in ravines is much more striking than the sheet erosion and in rills, for this reason, it is attributed a greater importance, however, it is the sheet erosion that has the greatest repercussions, since apart from being more extended and hidden, its existence creates a propitious situation for the formation of deeper rills and erosions.

Figure 26 Gully erosion in Puebla de Valles. Source: José L. García

7.1.2 Deep Erosion.

There are other forms of erosion, not so widespread, that obey other types of mechanisms. It is the case in which the displacements of soil are made in mass, the action of the waters consisting in creating favourable conditions in the soil so that it moves by the action of gravity.

As explained in module 2 'Soil bioengineering and geological engineering', the saturation of the soil is a favourable circumstance for mass movements. When this occurs on steep slopes and not subject to vegetation, it is possible that soil movements will occur by gravity, either on the surface or internally.

Another circumstance favourable to this type of movement occurs when the water reaches a horizon of the soil over an impermeable layer. This, by the action of the water, is lubricated and, if it is sloping, it can create a line of imbalance in the whole area of the soil located above. This fact will be favoured when the roots of the plants cannot penetrate the impermeable layer, and therefore, do not contribute to hold or prevent the movement from occurring.

Know more about type of mass movement:

https://www.youtube.com/watch?v=WyGw1pk9YWo

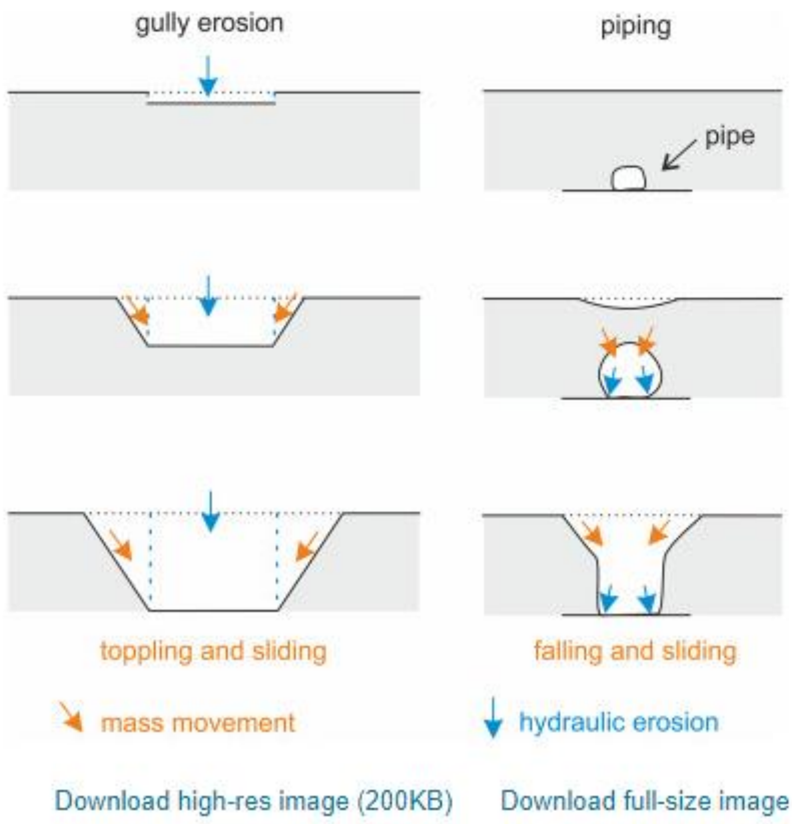


Figure 27 Formation of Piping erosion (Source: Bernateck and Poesen, 2018)

LINKS:

Video: "Water Erosion".
Source: https://www.youtube.com/watch?v=ofhQvAu_L1I

Video: "Erosion, Weathering, and Mass Movement"
Source:https://www.youtube.com/watch?v=w-w-pAtRRTU

7.2 Erosive processes in riverbeds

7.2.1 Erosion, transport and sedimentation in riverbeds. Basic principles

7.2.1.1 Fluvial erosion

Erosion in a river occurs when the energy (or gross power) of a river current is greater than the sum of power friction (that used to save friction) and transport power (the one used to transport materials).

This takes three modalities: vertical, recessive or headward, and lateral.

7.2.1.2 Vertical Erosion

Vertical erosion is the result of a summation of processes:

a) Abrasion; exerted by the bottom charge transported by the river. Thus, the helical rotary movement that the current can take at some point due to the roughness of the bed rotates the edges it transports. The result is the formation of deep buckets with a circular shape at the bottom of the channel, which are called giant pots or pilancones.
b) Hydraulic action; due to the velocity of the current, which deepens more and more in the channel.
c) Dissolution in soluble materials (plasters, salts, limestones, etc.); which can produce intense chemical erosion.

7.2.1.3 Headward erosion

Rivers and streams tend to expand their watersheds due to the continuous erosion of their waters. The hydrographic divisions are not, therefore, static, but tend to move upstream.

7.2.1.4 Lateral Erosion (meanders)

The river also tends to widen its valley, for which it exerts lateral erosion. The clearest proof of the existence of this erosion is the formation and evolution of the meanders. The meanders are originated as a consequence of a balance between topographic slope, and different factors: velocity, load, flow, etc. They are usually formed in the middle or lower sections of the rivers. The accentuation of the curve is due to the active erosion in the concave bank, while in the convex there is sedimentation, which gives rise to small fluvial beaches. The flow of water when entering the curve hits the concave shore, eroding it.

The existence of the currents causes the materials to be transported from the concave to the convex edge. As this phenomenon occurs both at the entrance and exit of the curve, the meander tends to strangle and leaves the river channel, in which case it receives the name of abandoned meander.

There are two main types of meanders:

a) Wondering meandering of alluvial plain; They are the free meanders installed in extensive alluvial plains. They do not have a fixed position and suffer the three processes described in their evolution.
b) Embedded meanders; They are of fixed position and receive their name because they are deeply embedded in the bottom of a valley with abrupt walls.

7.2.1.5 Fluvial Transport

Transportation is carried out by the river in different ways: dissolution, suspension, saltation and rotation. The transport by dissolution and suspension can take place simultaneously in all the body of water. The fluvial transport supposes a great wear of the clasts, which show surfaces polished when it has acted enough time. In general, the load that a river can carry is proportional to the flow, and is made up of the volume of materials that it sets in motion or evacuates.

7.2.1.6 River sedimentation

The sedimentation and formation of deposits of a river takes place when the energy of the river diminishes and becomes insufficient to transport all the load; then part of it is deposited. The manifestations of these depositions mainly constitute the current alluvial plains and the fluvial terraces.

7.2.2 Shear stress, velocity, critical shear stress and critical velocity

The force exerted by flowing water on the bed or banks of a stream is called available shear stress that is directly proportional to water density, gravitational acceleration, hydraulic radius and slope of the water surface (Du Boys 1879). The amount of energy needed to entrain the sediment grain (incipient motion) of a particular size is the critical shear stress. Dey (1999) mentioned that if flow velocity continues to increase over the loose sedimentary bed, the sediments start moving when the bed shear stress (available shear stress) generated by the flow exceeds a critical value of shear stress.

The particles move in different ways in a stream as the flow characteristics, size of sediment, fluid and sediment densities and the channel conditions vary spatially and temporally. Hjulstrom (1935) derived an empirical curve relating mean velocity to grain size from experiments with sand-size particles and extrapolating to larger and smaller sizes. The critical shear stress required for the entrainment of individual sediment particles for non-cohesive sedimentary bed in unidirectional channel was described by Shields (1936). After that, large numbers of scientists and researchers have triggered their research to determine critical shear stress of sediment erosion (Ahmad et al. 2011).

They understood and explained that the critical shear stress of finer sediment particles are dependent on both particle size and bulk density but in larger particles the critical shear stress is dependent only on particle size (Ahmad et al. 2011). Torfs (1995) indicated that conventional non-cohesive formulation for sand fractions could be applicable for the mixture with less than around 3–15% mud content. Erosion behaviour changes dramatically when a small amount of mud is added to a sand bed (Mitchener and Torfs 1996; Williamson and Ockenden 1992). The formula of critical shear stress separately for sand and mud mixture to describe the erosion behavior of sediment was proposed by Van Ledden (2003). Sand-mud mixture will exhibit the cohesive property when the proportion of mud reaches 20–30% (all sediment less than 0.05 mm in diameter) and below it the mixture is non-cohesive in nature (Van Rijn 1993; Ahmad et al. 2011). Charlton (2007) and Clayton (2010) mentioned that patterns such as sheltering, imbrications, armoring, and variations in sorting can also affect resistance, and in turn the critical shear stress required to entrain the sediment (Mayoral 2011).

LINKS:

Article: Riverbed sediment classification using multi-beam echo-sounder backscatter data
Source: https://asa.scitation.org/doi/abs/10.1121/1.3205397

Video: River erosion processes
Source:https://www.youtube.com/watch?v=hAaHwU3vhlE

Video: River Erosion, Transport and Deposition
Source:https://www.youtube.com/watch?v=E6sWiPAu708

8. THE RIVER ECOSYSTEMS

The river is the paradigm of connectivity. Connectivity is the degree to which water, organisms, and suspended elements and compounds can move across the fluvial system landscape. The degree of connectivity is based on the presence or absence of barriers. Barriers are features which interrupt connectivity. They may be natural or human induced. Human induced barriers can be hydrologic or structural. Barriers can also be natural. Barriers tend to reduce the ecological functions provided by the fluvial system, especially aquatic organism habitat functions. The number and health of fish and other aquatic organisms existing in the system is reduced when their opportunity to move freely is interrupted by a barrier.

As with hydrology, stream connectivity can be described in four dimensions:

- longitudinal – linear connectivity
- lateral – floodplain connectivity
- vertical – hyporheic (below the stream bed)
- temporal (time) – many scales; seasonal, multiyear, generational

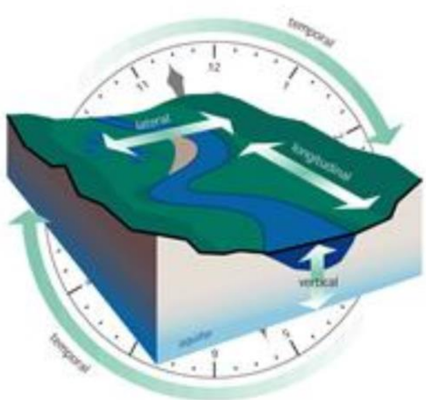


Figure 28 Longitudinal connectivity(Source: Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG))

Longitudinal connectivity: longitudinal connectivity describes the degree of connection along the main direction of flow for water, sediment, aquatic organisms, and other elements in the system, both living and inert. Its direction can normally be described as upstream and downstream. *Lateral connectivity* allows the stream access to its floodplain during high water events. This access is critical for the healthy ecosystem function. Nutrients and organic matter are transported to the stream from the floodplain, plant and wildlife species flourish in the diverse successional stages of inundated areas, and aquatic species gain access to seasonal habitats essential to their life cycles.

Figure 29 Lateral connectivity (USDA, NRCS, 2012; Technical Note No. 2)

Lateral connectivity refers to the periodic inundation of the floodplain and the resulting exchange of water, sediment, organic matter, nutrients, and organisms. Lateral connectivity becomes especially important in large rivers with broad floodplains.

Access to floodplain is also important for small streams that can experience dramatic episodic flooding. Heavy, localized rains can cause small streams to rise several feet in a few hours. This flashiness is largely a result of more overland flow and less infiltration following the conversion of native land cover to row crops and human communities. Large amounts of sediment are mobilized by these events, impacting all trophic levels and altering biological communities in the stream and the adjacent floodplain.

Lateral connectivity allows the stream access to its floodplain during high water events. This access is critical for the healthy ecosystem function. Nutrients and organic matter are transported to the stream from the floodplain, plant and wildlife species flourish in the diverse successional stages of inundated areas, and aquatic species gain access to seasonal habitats essential to their life cycles.

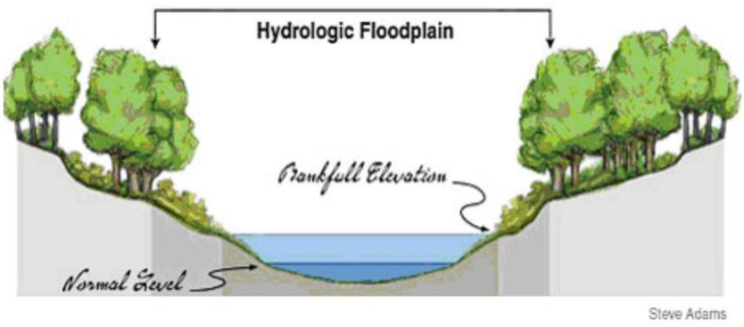


Figure 30 Vertical connectivity (source: How rivers run; Instream Flow Council; Annear et al., 2002)

Vertical connectivity is represented by the connection between the atmosphere and groundwater. The ability of water to cycle through soil, river, and air as liquid, vapor, or ice is important in storing and replenishing water. This exchange is usually visualized as unidirectional–precipitation falling onto land and then flowing over land or percolating through the ground to the stream.

Mixing of surface water and ground water occur in the hyporheic zone. This biologically active zone contains water percolating through the permeable soils adjacent to the open streambed. Important microbial activity and chemical transformations are enhanced in this area (Stream Corridor, FISRWG).

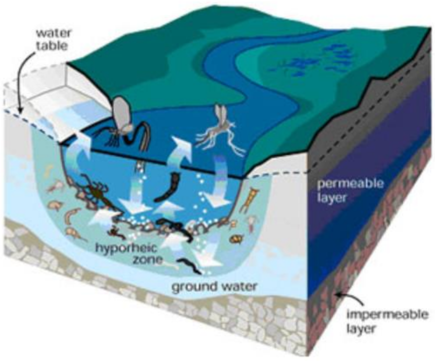


Figure 31 Vertical connectivity (source: Stream Corridor, FISRWG)

Temporal

A stream exhibits temporal connectivity of continuous physical, chemical, and biological interactions over time, according to a rather predictable pattern. These patterns and continuity are important to the functioning of the ecosystem. Over time, sediment shifts, meanders form, bends erode, oxbows break off from the main channel, channels shift and braid. A stream rises and falls according to seasonal patterns, depending on rain and snowmelt. Watersheds are adjusted to these normal fluctuations, and many organisms have evolved to depend on them.

The integrated approach followed by water bioengineering gives answers to the complexity of river systems.

8.1 The morphological role of vegetation and the fluvial space

It long has been recognized that vegetation plays an important control on river form and activity. The literature is of two basic types: that dealing with the indirect relations among vegetation-water / sediment yield-river morphology, and that dealing with the direct impact of boundary vegetation on channel morphology.

Vegetation exerts significant control over fluvial processes and morphology through five important mechanisms: resistance to flow, bank strength, nucleus for bar sedimentation, construction and breaching of log-jams, and concave-bank bench deposition.

The role of vegetation as an influence on channel form and process in larger rivers is less important, though it may still be quite significant.

The interaction between vegetation and river channel dynamics can be expressed in terms of:

Resistance to flow: It has long been recognized that channel and foodplain vegetation, as part of the boundary roughness elements, may exert a considerable influence on the resistance to flow. Indeed, the Cowan method includes a vegetation correction factor in the estimation of the Manning n magnitude.

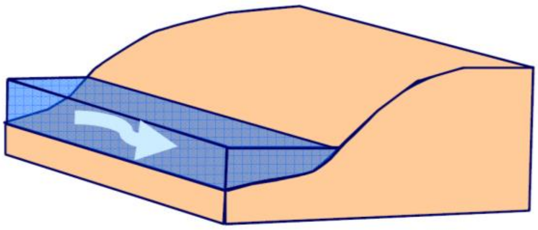


*Figure 32*The river flow exerts forces on the riparian soils

This empirically based procedure indicates that, with other factors constant, variation in bank vegetation in small channels can easily produce an order of magnitude variation in Manning n. In larger channels, bank vegetation will have a relatively smaller but nevertheless significant influence on flow resistance.

Bank strength: Channel form and the lateral stability of a river, depending as they do on the strength of the bank materials, may be influenced significantly by the binding properties of vegetation growing on and near the river banks. Since vegetation binds sediment and increases its strength, and since critical tractive force theory implies that bank slope is proportional to shear strength, physical reasoning would suggest that well-vegetated banks will be associated with lower ratios of width to depth than will poorly vegetated banks.

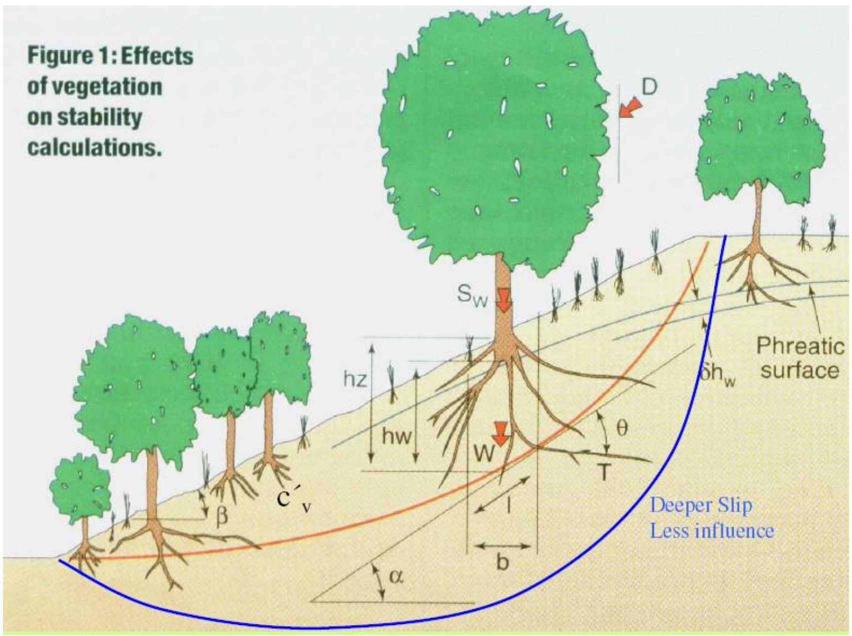


*Figure 33*Plants reinforces the soil mechanical strengths (Greenwood, 2004)

8.2 River ecosystems and aquatic fauna.

River systems facilitate the gravitational transport of water, dissolved substances, and large and small particulate materials downstream through a diversity of types of drainage networks from relatively simple channels to highly complicated "braided" channels, both above and below ground (Allan and Castillo, 2007).

Rivers and streams are far more than channels transporting water, chemicals and sediments downstream. They function as ecosystems with all of the varied and complicated activities and interactions that occur among their abiotic and biotic components, which are characteristics of all ecosystems.

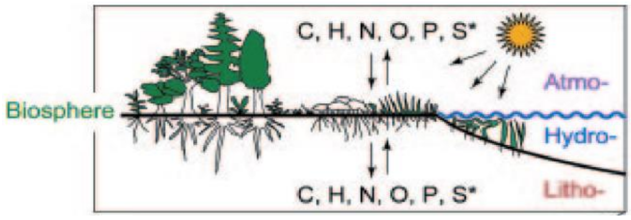


*Figure 34*Fluvial system processes

Species inhabiting rivers face challenges imposed by the unidirectional flowing nature of their environment. Strategies include current avoidance in sheltered areas (along channel margins, behind debris dams or in interstitial spaces), and specialized adaptations such as attachment to hard substrates. Riverine species also share the benefits provided by water flow which supplies particulate matter to filter-feeding organisms, replenishes nutrients and oxygen at the cell boundary layer, and, during floods, allows periodic access to floodplain habitats (Likens, 2010).

Primary producers

Attached algae, phytoplankton, and macrophytes contribute to autotrophic production in rivers: their relative importance varies in accordance with river hydrogeomorphology. In shallow, fast flowing rivers, benthic algae predominate particularly where rocks and woody debris provide stable substrate fro colonization. Benthic algal abundance is determined by the light conditions, and flow regime. In deep, slow-moving rivers, phytoplankton are often the dominant primary producers. Their abundance is mainly limited by light availability.

Constricted and channelized rivers have steep shoreline areas, which provide little suitable habitats, whereas floodplain and low-gradient rivers allow for greater colonization in shallow-water areas.

Invertebrates

Invertebrates are important to trophic energetic because they link primary sources of energy to higher trophic levels such as fish. Pelagic invertebrates (zooplankton) are commonly found in regulated and deep rivers. River zooplankton assemblages are dominated by rotifers and cladocerans, whereas larger zooplankters are generally associated with lentic environments.

Benthic invertebrates are important components of river food webs and are widely used in habitat assessment owing their sensitivity to water quality conditions. These include crustaceans, molluscs, and a great variety of insects.

Invertebrates may be grouped according to their feeding habits as predators, filtering and gathering collectors, deposit feeders, scrapers, and shredders. Productivity is determined by water temperature, food quantity and the presence of suitable habitat.

Fishes

Fish are typically the top predators in river food webs and, like macroinvertebrates, are often used as 'bioindicators' for habitat assessment. Anthropogenic influences generally act to make fish assemblages more similar within and among basins and lead to loss of biodiversity. In many rivers, the presence of water regulation structures has had a negative impact on species that prefer flowing conditions and in some cases, has restricted their ability to access former spawning areas. As for other river biota, discharge is the key environmental factor structuring communities. In floodplains, fish seek refuge from current velocities and utilize food resources in inundated areas. In levied and naturally constricted rivers, high discharge may cause high mortality, particularly of larval stages, due to elevated current velocities in the channel (Likens, 2010).

Water bioengineering techniques can enhance and protect the fluvial ecosystems by:

- Triggering physical and chemical processes
- Creating a diversified set of habitats
- River self-regeneration capacity
- Developing the riparian vegetation
- Recovering system connectivity. The four dimensions of a river: longitudinal, vertical, lateral/floodplain and temporal (river connectivity).
- Protecting the riparian soils from erosion and slope instabilities.

The preceding aims can be included at the design stage of water bioengineering works and throughout the monitoring stage, design feed-back loops and calibration actions can be determined.

LINKS:
Video: "River ecosystem".
Source: https://www.youtube.com/watch?v=yn18PPqLSUY

Video: "Water Ecosystems: Rivers".
Source: https://www.youtube.com/watch?v=Wgog5KY5Mb0

"The Role of Riparian Corridors in Maintaining Regional Biodiversity"
Source:https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.2307/1941822

9. RESTORATION OF WATERSHEDS AND RIVERS

River restoration is the process of managing rivers to reinstate natural processes to restore biodiversity, providing benefits to both people and wildlife. Reintroducing natural processes can reshape rivers to provide the diversity of habitats required for a healthy river ecosystem and ensure their long-term recovery by addressing the root cause of the issue.

The concepts explained in the river system section, reflect the main points to be included in the river restoration strategy and approach.

River restoration is also the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas).

The character of river landscapes is largely a function of fluvial processes. Temporal and spatial variability in disturbance by river flows, and the erosion and deposition of sediments, structure riparian vegetation patterns; resulting in close associations between vegetation composition and age, and geomorphological features (Bendix and Hupp, 2000).

There are three distinct influences of riparian vegetation on hydrological processes: (i) the physical impact of living and dead plants on flow patterns (hydraulics); (ii) the impact of plant physiology on water cycling; and (iii) the impact of riparian vegetation on water quality.

A key element in the physical impact of riparian vegetation on fluvial processes is the first of these influences. Vegetation stands vary greatly in their hydraulic resistance and root strength, and thus the degree to which they can resist erosion and induce sedimentation.

There are four types of mechanisms by which riparian vegetation actively influences fluvial processes. Two of these are abiotic mechanisms: the flow resistance of the vegetation canopy; and the impact of root systems on the erodibility of sediments. In addition two groups of biotic mechanisms also play an important role: the reproductive strategies adopted by the plant species, and the nature, magnitude and timing of propagule dispersal. These biotic mechanisms are extremely important in influencing the potential distribution and establishment rates of riparian vegetation (Bennet et al., 2004).

Vegetation also reflects the impact of floods in creating the conditions for seedling establishment. This may occur where floods have deposited fresh alluvial surfaces or have removed the vegetation from pre-existing surfaces (McBride and Strahan, 1984).

Water bioengineering works trigger the before mentioned biotic and abiotic mechanisms by fostering the riparian vegetation development. Hence, soil and water bioengineering techniques represent a very powerful tool in the overall river restoration scheme and strategy.

9.1 Identification of pressures and impacts and location of critical areas.European Directives and Environmental assessment of watershed restoration.

The 1992 European Commission (EC) Habitats Directive and the 2000 EC Water Framework Directive (WFD) made river restoration a fundamental part of river management in the UK and Europe by requiring countries to improve the ecological status of their rivers.

The WFD establishes a framework for the protection of all waters (including inland surface waters, transitional waters, coastal waters and groundwater) which, according to Article 1:

- Prevents further deterioration of, protects and enhances the status of water resources;
- Promotes sustainable water use based on long-term protection of water resources;
- Aims at enhancing protection and improvement of the aquatic environment through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;
- Ensures the progressive reduction of pollution of groundwater and prevents its further pollution; and
- Contributes to mitigating the effects of floods and droughts.

9.2 Definition of the restoration intervention targets (level of the intervention ambition)

River managers face significant challenges in restoring river ecosystems. These challenges include:

1. Returning rivers to a natural state is not feasible in most situations. Traditional approaches to river restoration have relied on the use of natural rivers as a benchmark. The degree of change in river basins around the world means that in many cases returning rivers to a pre-development condition is now physically or economically impractical.
2. Balancing the multiple roles of a river. River restoration is now often required to achieve multiple objectives, by balancing the natural functions of the river with specific human needs, which can require trade-offs in the planning process.
3. Complexity and scale. Many restoration projects have failed as a result of tackling issues at the wrong spatial scale, often failing to consider basin-level processes. Operating at a larger scale requires consideration of a greater number of issues, engagement with a wider range of stakeholders and linking to a wider range of planning and management instruments.
4. Increasing uncertainty over future conditions. The gross uncertainty over the future of river basins makes it challenging to ensure that restored rivers are suited to the future world. Among other factors, uncertainty exists around changes in climate, land use, population growth and urban development.

A restoration strategy should identify a long-term vision for the river basin, the desired outcome of the strategy over the planning horizon (goals), and specific, measurable targets to be achieved over the short to medium term (objectives). Goals and objectives should be framed, as much as possible, in terms of measurable changes to ecosystem function, the provision of ecosystem services, and desired socio-economic benefits.

Developing a strategy for action requires an iterative process of considering potential goals together with options for action (see Figure below). This requires a consideration of:

- The current condition of the river system, its historical trajectory, and the likely future state of the system priorities for, and demands on, the basin, including those related to socio-economic development and ecosystem conservation
- Feasibility of different options and potential constraints, such as limitations as a result of budget, capacity, political will, or institutional mandate
- The appropriate scale at which to intervene
- The effectiveness of different measures
- The efficiency of different measures
- The approaches more likely to be sustainable over the medium to long term.

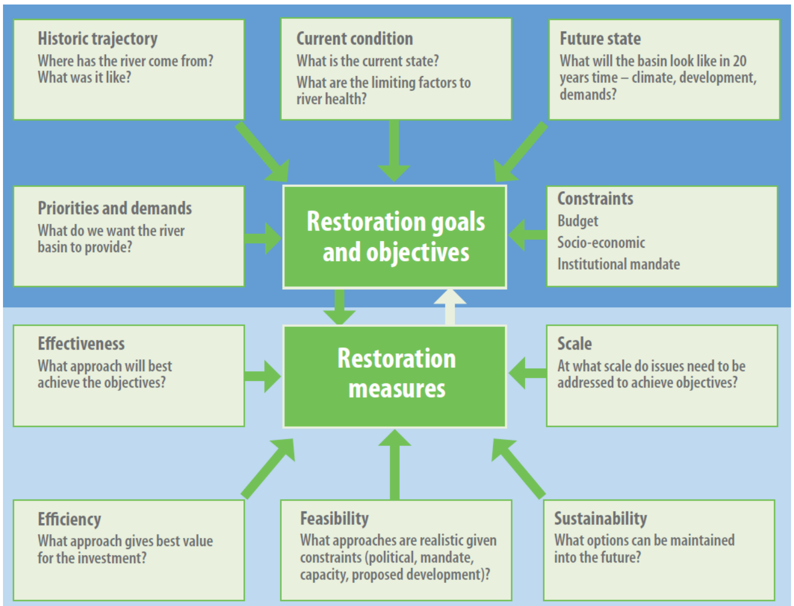


Figure 35 Considerations in selecting restoration goals, objectives and measures (source: UNESCO, 2016)

The preceding iterative scheme, necessary for defining the river restoration goals and aims, matches with the intrinsic adaptive management scheme necessary in water bioengineering actions and works. This highlights the importance of the monitoring stage in river restoration projects.

9.3 Assessment indexes for determining the functional and ecological state of a river

A critical part of improving river health is accurate assessment of the current ecological state of river ecosystems so that causes of poor health, or the success of rehabilitation efforts, can be measured. River health monitoring, which has traditionally concentrated on the use of structural measurements (such as water quality or taxonomic composition of aquatic organisms), should be complemented by functional indicators, such as rates of primary productivity and community respiration or organic matter decomposition, to provide a more complete and accurate assessment of the state of these environments.

Functional indicators are measures of the rate, or relative importance, of a particular process happening in an ecosystem, while structural indicators focus on patterns of abiotic resources or biological community composition (Matthews et al., 1982). In other words, functional indicators measure the services or functions provided by ecosystems, while structural indicators measure what lives in an ecosystem.

An advantage of including functional indicators in regular biomonitoring is the fact that these measurements provide a truly integrated measure of stream health because 1) they are affected by such a wide range of biotic and abiotic controlling variables, 2) they integrate environmental conditions over a moderate time period, and 3) they integrate across a variety of habitat types in a reach.

The use of fluvial functionality index (FFI) (Siligardi, 2007) is recommended for the overall assessment of the river functionality and state. The objectives of the FFI is to evaluate the whole river ecosystem with particular attention to its functionality in terms of retention and cycling capacity of the fine and coarse particulate organic matter (short FPOM and CPOM) (Elwood et al., 1983), of buffer potential of the riparian ecotones (Negri, 1997) as well as of morphological structure able to support and sustain well diversified and stable biological communities (Sansoni, 1987). The FFI results can also be used in order to plan, forecast and verify the policy and strategy applicable for the river and land management.

The results of the FFI method can be directly displayed on maps using a GS siftware. For each river stretch, two lines are drawn corresponding the left and right bank and representing the functionality level according to this method.

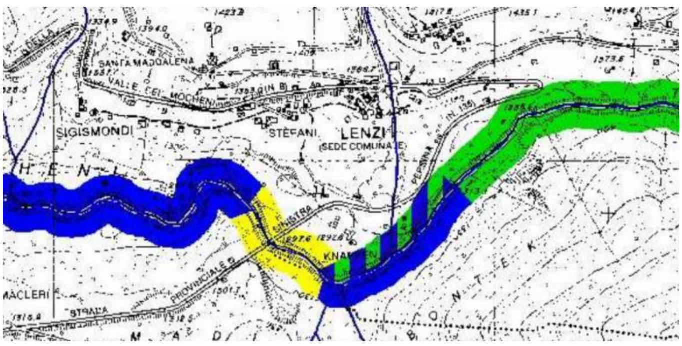


Figure 36 An example of map with the FFI functionality level expressed with different coloured stretches (Siligardi, 2007).

By means of this type of indexes it is possible to:

- Indicate the fragility of the river ecosystem ad therefore underlie which river features (i.e., vegetation, bed, sinuosity, etc.) may cause a decrease of the functionality
- Be used to verify which water course areas are most suitable for river restoration schemes (Negri et al., 2004)
- Foresee the possible effects of river works

It is also possible to use the FFI for assessing the performance and beneficial effects of water bioengineering interventions.

9.4 Improvement of hydrological conditions: infiltration, runoff control, improvement of vegetation cover, improvement of flow regime

Periodic flooding may allow certain riparian communities to persist through time with consistent composition because repeated disturbance holds successional change in abeyance. Characteristic variation in riparian forest composition is maintained by periodic flooding (Hosner and Minckler, 1963). The plant distributions are at least in part controlled by inundation frequency and susceptibility of plants to damage by floods. Vegetation growing on the flood-prone channel shelf tends to have a shrub growth form with small, highly resilient stems and the ability to sprout rapidly from flood-damaged stumps (Hupp, 1983). Floodplain species are less tolerant of destructive flooding than channel-shelf species but are tolerant to periods of inundation. Terrace species may be intolerant of repeated flood damage or inundation (Cowell, 1993).

In arid, bedload-laden streams, an increase in gradient is often associated with a shift to a braided channel pattern (Graf, 1988). The result is that a higher proportion of the valley floor is occupied by relatively unstable, shifting islands and bars, relative to the more permanent floodplain surface. The potential for disturbance is magnified, since powerful floods are combined with an unstable substrate. The vegetation influences the river pattern by limiting the braided patterns and hence, improving the preceding situation.

The simultaneous action and interactions of different-scaled variables affecting riparian vegetation reflect the multidimensional context of fluvial systems. In analysing vegetation, it is common to think in two dimensions how far is it from the channel horizontally, and how far is it above the channel, vertically. Other dimensional may be critical: the longitudinal position in the watershed, the characteristic of the watershed itself, and the site history. The actual species composition reflects the unique intersection of environmental influences acting at varied scales (Bendix, 1994).

In comparison with traditional engineering techniques, the non-technical benefits of plants are often stressed along with the usual technical advantages. Four general groups of benefits of biotechnical methods can be outlined:

1. Technical advantages: - protection against surface erosion - an increase of slope stability by root reinforcement and draining of the soil - protection against rock fall and wind
2. Ecological advantages: - regulation of temperature and humidity close to the surface, thus promoting growth - improvement of the soil water regime via interception, evapotranspiration and storage - soil improvement and top soil formation - improvement of and provision for habitat – improvement of soil infiltration capacity
3. Economic advantages: - reduction of construction and maintenance costs - creation of areas for agricultural and recreational use
4. Aesthetic advantages: - structures fit into the landscape - landscape is more appealing

These advantages make soil and water bioengineering techniques a worthwhile consideration in stream and bank rehabilitation.

LINKS:
"Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners".
Source:https://onlinelibrary.wiley.com/doi/full/10.1111/j.1526-100X.2007.00244.x

Video: "Case Studies of river restoration".
Source:https://www.youtube.com/watch?v=-E-OkMrQVv0&list=PL3eoaBdiC8XQagTbgKxEGksx3UhHED-Lc

Article: "Restoration of wetlands in the Mississippi–Ohio–Missouri (MOM) River Basin: Experience and needed research".
Source:https://www.sciencedirect.com/science/article/pii/S0925857405001916

Article: "Restoration of degraded lands in the interior Columbia River basin: passive vs. active approaches".
Source:https://www.sciencedirect.com/science/article/pii/S0378112701004510

Artice: "Riverbank Stabilisation"
Source:https://www.youtube.com/watch?v=mS87csAFCKI

10. WATER BIOENGINEERING TECHNIQUES.

10.1 The techniques

Soil and Water Bioengineering techniques can be classified in different ways:

1- The main element involved in their design

- Soil Bioengineering: When the techniques are related with the earh
- Water Bioengineering: when the techniques are related wit the water environment, fluvial, lake or costal

2-The role of the plant and the technical function it provide

- **Coating techniques**: techniques, whose purpose is the control of erosion and superficial stabilization or revegetation of the soil.
  Sowings, hydroseeding, hydromatt, organic mats, Transplantation of rhizomes and stolon's, division of turf and grasses, Plantation of reed stalks, stake of cane stalks.
- **Stabilization techniques**: techniques, in which certain woody species or their fragments are used as principal elements to stabilize a slope or a river margin until a depth of 60-150 cm.
  Riparian stakes, live brushes,live combs, fascine, fascine of helophytes, brush layers, brush mattress, living braided…
- **Mixed or combined techniques:** techniques based on the joint use of living plant components and other materials that act as coating or stabilization elements until the plant has the capacity to exercise these functions.
  Simply River log cribwall, double living log cribwall, live palisade, vegetated rip rap, vegetated gabions
- **Complementary techniques:** Each of the techniques which, although they do not act directly on surface protection or stabilization of the earth contribute to achieve other objectives of the techniques, such as ecological or landscaping objectives
  fish ramps, fords for fauna, dykes…

3- The part of the river Water bioengineering techniques can be classified according to the following categories (TS 14I; NRCS, 2007):

- Toe treatments
- Bank treatments
- Flow changing techniques

In the following paragraphs the main water bioengineering techniques are presented. For detailed information about each one, including construction stages and processes, installation details, utilized materials, etc, please refer to the following references:

- NTJ 12S PARTE 5 and 6
- Construction type manual EFIB Verein Fúr Ingenieurbiologie (Zeh, 2007)
- Bernard Lachat. "Génie Biologique" (PowerPoint slides). BIOTEC, March 20, 2009

- Technical supplement 14I (TS14I), Engineering handbook of the NRCS (Natural Resources Conservation Service) of the USDA (United States Department of Agriculture), 2007.ç
- Manuale Lazio Ingegnieria Naturalistica in ámbito fluviale

TOE TREATMENT TECHNIQUES:

Coir fascines- Stabilisation technique

Coir fascines consist of coconut husk fibers boundtogether in a cylindrical bundle by natural or syntheticnetting and are manufactured in a variety of standardlengths, diameters, and fill densities for different energy scenarios.

Figure 37 Installation of coir fascines (source: Robbin B. Sotir and Associates Inc.)

Aquatic species rolls and single rolls, stabilisation technique

Rolls or clumps of aquatic species with single poles are used to protect the toe of an eroding streambank. The aquatic rolls may consist of suitable native species. There is an alternative in which the roll is constructed using coir mesh.

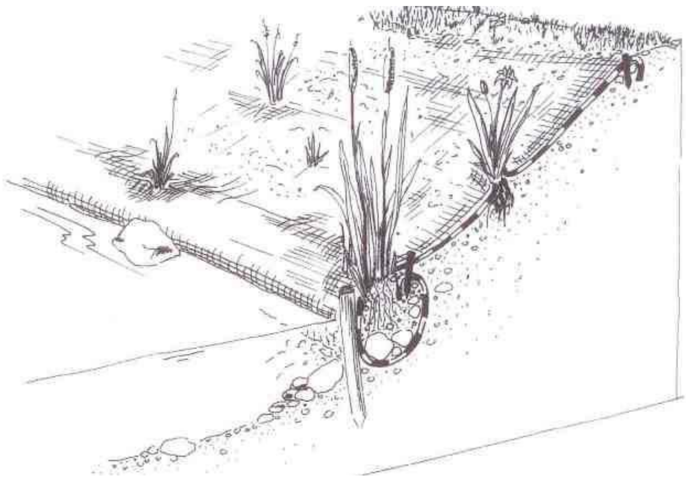


Figure 38. Aquatic species rolls constructed of coir mesh (source: HelgardZeh, Soil Bioengineering Construction Type Manual, Zurich: European Federation for Soil Bioengineering, 2007,pp 322)

Fascines with double poles, stabilisation technique

Fascines with double willow (or balsam poplar) poles are used to protect the toe of an erodingstreambank. Fascines are live cuttings from branches and stems of suitable native shrubsand trees which have properties of vegetative propagation.

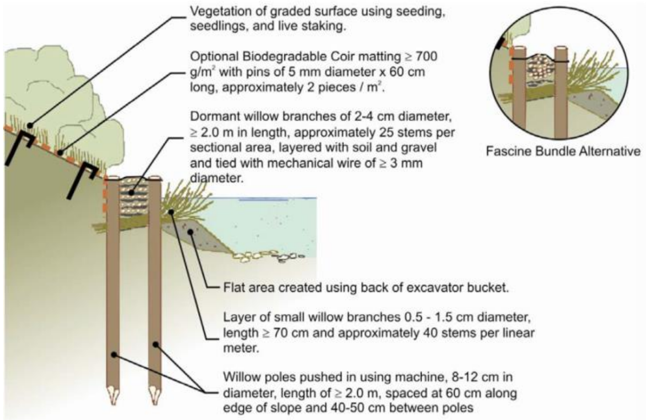


Figure 39. Fascines with double poles detail (adapted from Bernard Lachat. GénieBiologique, March 20, 2009-PowerPoint slides. BIOTEC)

Rock toe with one or multiple brush layer row- Stabilisation technique

A rock toe is placed along shorelines to provide erosion protection and a brush layer is installedabove the rock toe. The brush layer consists of a row of live cuttings (native willow, balsampoplar and red osier dogwood) placed in a criss-cross or overlapping manner in between layersof soil, with tips protruding beyond the face of the fill.

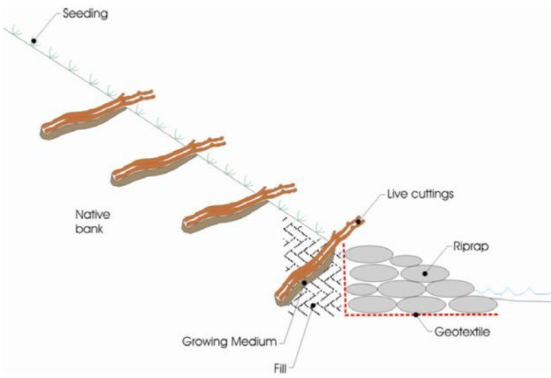


Figure 40. Rock toe with multiple brush layer rows (source: Terra Erosion Control Ltd. drawing)

Vegetated crib wall-Mixed technique

Vegetated log crib walls consist of multiple courses of logs, drainage material, geotextiles, backfill and live vegetation.

Figure 41. Log crib wall after first growing season (source; TS14I, NRCS, 2007)

Live palisade or bank pile wall-Mixed technique

The pile wall or live palisade is a helpful structure to consolidate unstable slopes and road embankments. The front is protected against erosion during flood by means of live fascines. The transverse elements are working as an anchoring system.

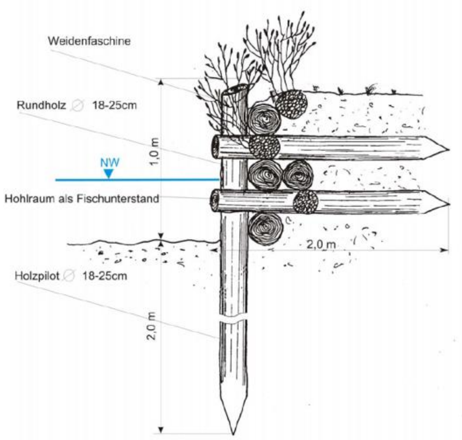


Figure 42. Source: Hans Peter Rauch, 2008

Fascine wall-Mixed technique

A fascine wall is a vertical bioengineering element. Several fascines vertically positioned are mounted with wire on wooden poles with a diameter of 20 – 25 cm. The length of the wooden poles are 3 m, two thirds of the poles are driven into the ground.

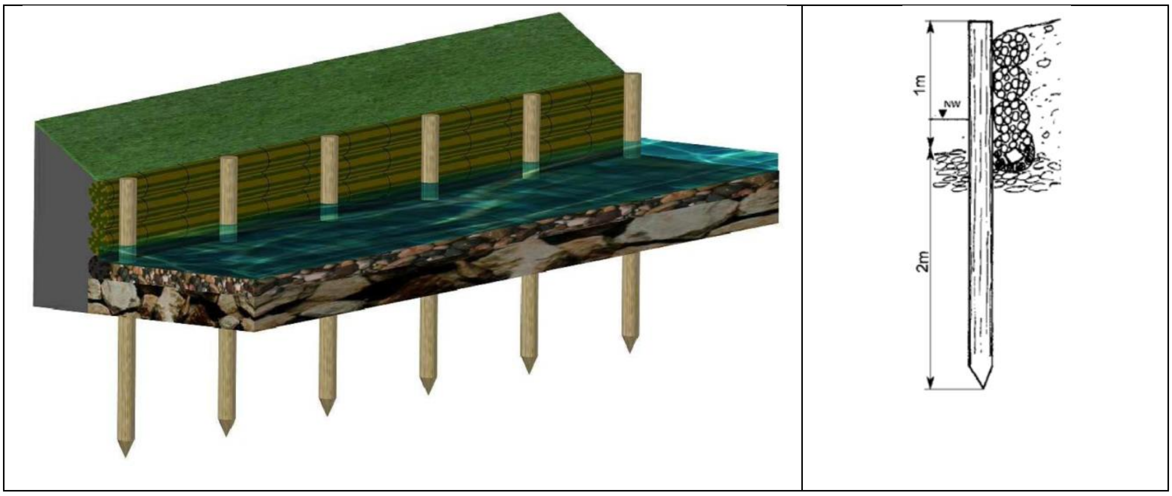


Figure 43. Source: Hans Peter Rauch, 2008

Vegetated gabion wall/vegetated rock wall- Mixed technique

Gabions are rectangular shaped containers made from twisted wire mesh or welded wire meshthat are filled with stone. When live materials are combined with the gabion baskets they arecalled vegetated or green gabions.

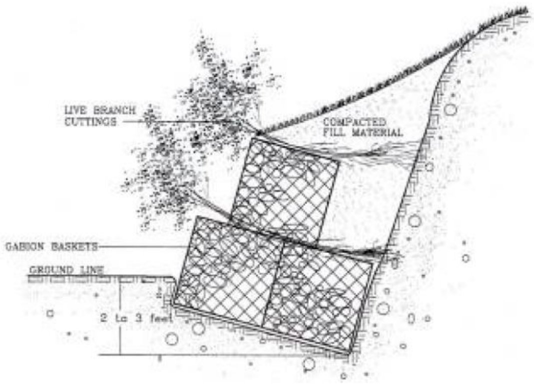


Figure 42. Live branches placed between gabion baskets (source: D.H. Gray and R. B. Sotir, Biotechnical and Soil Bioengineering Slope Stabilization. A Practical Guide for Erosion Control (New York: John Wiley & Sons, Inc., 1996), 290.)

<u>BANK TREATMENTS</u>

Live pole cuttings or live stakes, Stabilisation technique

Live pole cuttings are dormant stems, branches, or trunks of live, woody plant material inserted into the ground with the purpose of getting them to grow.

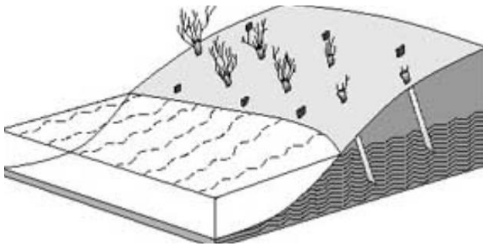


Figure 43. Live stakes. Source: Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG).

Live pole cuttings are dormant stems, branches, or trunks of live, woody plant material inserted into the ground.

Brush layers, Stabilisation technique

A brush layer consists of a row of live cuttings (willow spp., poplar spp., etc.) placed in a criss-cross or overlapping manner in between layers of soil with tips protruding beyond the face of the fill.

Suitable for bank stabilization and erosion control of steep eroded banks in conjunction with / or above constructed toe protection structures.

Figure 44. Brush layers installation (source:Terra Erosion Control Ltd. photos.)

Contour fascine, Stabilisation Technique

Contour fascines are another use of fascines to assist in controlling overland flow by breaking long banks into a series of shorter banks
The structure provides immediate protection against surface erosion, due to its orientation (approximately perpendicular, even at an angle) to the slope face and its porous barrier-like installation.

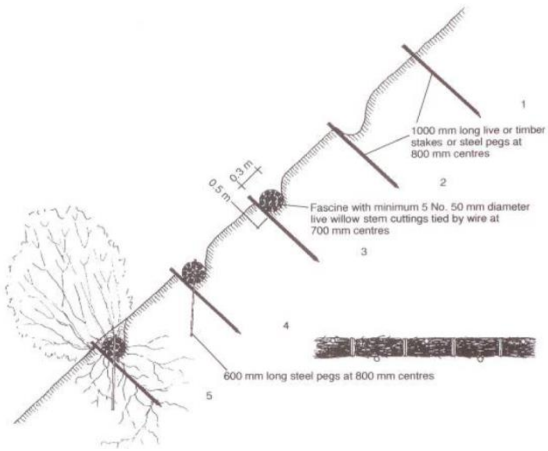


Figure 45. Fascine construction (siurce : H.M. Schiechtl and R. Stern, Ground Bioengineering Techniques for Slope Protection and Erosion Control (Cambridge: Wiley-Blackwell, 1996, 70.)

Brush mattress, Stabilisation technique

A brush mattress is a layer of live cuttings placed flat against the sloped face of the bank (fig. TS14l–28).
Dead stout stakes and string are used to anchor the cutting material to the bank. This measure is often constructed using a fascine, joint planting, or riprap at the toe, with live cuttings in the upper mattress area.

Figure 46.Brush mattress installation (source: TS14l)

Vegetated reinforced soil. Stabilization technique
A vegetated reinforced soil slope (VRSS) system is made up of layers of soil wrapped in synthetic geogrid or geotextile with live cuttings or rooted plants installed in between the wrapped soil layers. As with brush layering or branch packing, the branches or rooted plants protrude beyond the face of the bank. The live cuttings contribute to soil reinforcement along with the geogrid.

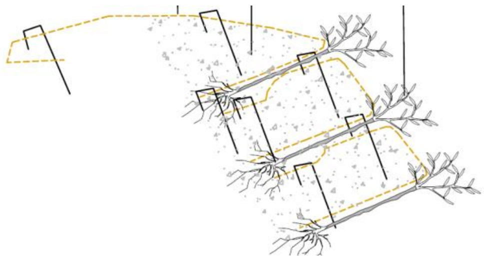


Figure 47. Vegetated reinforced soil (source: drawing by Paola Sangalli)

Brush wattle fence, Stabilisation technique

Treatments are intended to promote sediment deposition and protect the bed from erosion. They are typically installed in multiple rows along flood plains and areas adjacent to banks. Wattle fences are rows of live stakes or poles with live wattling materials woven in a basket-like fashion.

Figure 48.Wattle fence after installation (source: TS14I)

For a more comprehensive list of water bioengineering techniques please, use the before mentioned references.

<u>FLOW CHANGING TECHNIQUES</u>

Bioengineering groynes:

Ecological groynes influence the flow at low water level conditions. The deflection of the flow enables different fields of flow velocities and consequently sedimentation and erosive processes are activated giving place to an enriched hydrodynamic situation within the riverflow. A wide range of different flow velocities improves the aquatic habitats for the fauna. The classification of groynes is based on material, height of the structure and the technique alignment.

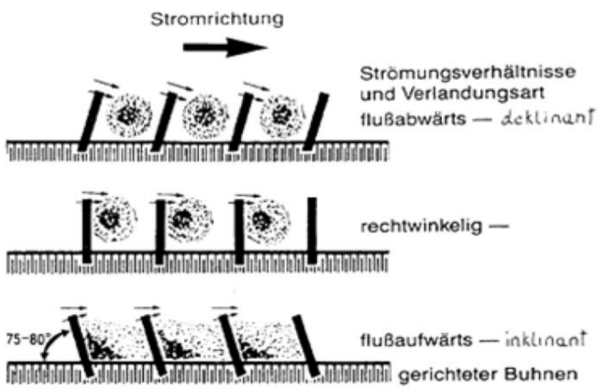


Figure 49. Groynes with different alignment: declinant, transverse and inclinant. Source: Hans Peter Rauch, 2008

Examples of bioengineering groynes are the following: palisade groyne, rock groyne, wattle fence groyne, wooden structure groyne and rough tree.

Figure 50. Example of bioengineering groyne. The wooden structure groyne. Source: Hans Peter Rauch, 2008

10.2 Materials and plant biotechnical traits

The typical materials used in water bioengineering works can be classified as (NTJ 12S parte 6):
Living material: e.g., Plants and part of plants, seeds, live stakes, live branches, etc.
Inert biodegradable materials: logs, timber, organic mats, geoproducts made of natural fibres, organic amendments, etc.
Inert natural materials: rocks, earth, aggregates, etc.
Manufactured materials: geogrids, geotextiles, wires, nails, bolts, wire nets, gabions, etc.
For the particular use of the preceding materials in each technique can be found in technical details drawings and schemes such as those included in:

- NTJ 12S PARTE 5 and 6
- Construction type manual EFIB (Zeh, 2007)
- Bernard Lachat. “Génie Biologique” (PowerPoint slides). BIOTEC, March 20, 2009

The use of plants in structural and civil engineering is based on knowledge and observations of their properties, which often date back centuries. Thanks to their different properties, plants can respond flexibly to their environment and are therefore employed to perform engineering functions (EFIB, 2015). The plant biotechnical properties are:
-Their capacity to reproduce and develop in different ways trough seeds and/or trough vegetative forms,
-Their regeneration capacity following damage and adverse environmental changes,
-Their extraction capacity water from the soil and release it to the atmosphere (evapotranspiration),
- Their capacity to consolidate and strengthen soils. The main plant properties related to this biotechnical trait is the plant capacity to generate deep and well distributed roots. Root tensile strength, root depth and root architecture are the main factors defining this capacity.
-Their capacity to connect and interlink different materials and structures,
-Their capacity to cover surfaces,
-Their capacity to intercept /retain / moving solid materials, dissolved substances and water,
-their capacity to tolerate burying or submersion by developing sprouting roots,
-their ability to adapt to changes in local conditions like the variation on the velocity of the water flow in a channel.

10.3 Hydrology and hydraulics applied to water bioengineering

As explained before, the determination of the discharge values for the different period of return is essential for determining the flooding areas and the main hydraulic variables values.

Bankfull discharge is the flow that reaches the transition between the channel and its flood plain and is thus morphologically significant (Leopold and others, 1964). Bankfull may be functionally defined and identified as the stage or flow at which the stream is about to overtop its banks (Leopold and others, 1964; Leopold, 1994) and is reported to occur every 1 to 2 years. In soil and water bioengineering works, bankfull discharge values are used to determine the different plantation zones and to locate the changing flow techniques position and orientation.

The main hydraulic values to be determined are the following:

Water level determination: The elevation and lateral relationships to the stream can be described in terms of riparian planting zones. For this definition, the water level must be determined. These riparian planting zones can be used to determine where riparian species should be planted in relation to the waterline during periods of flow.

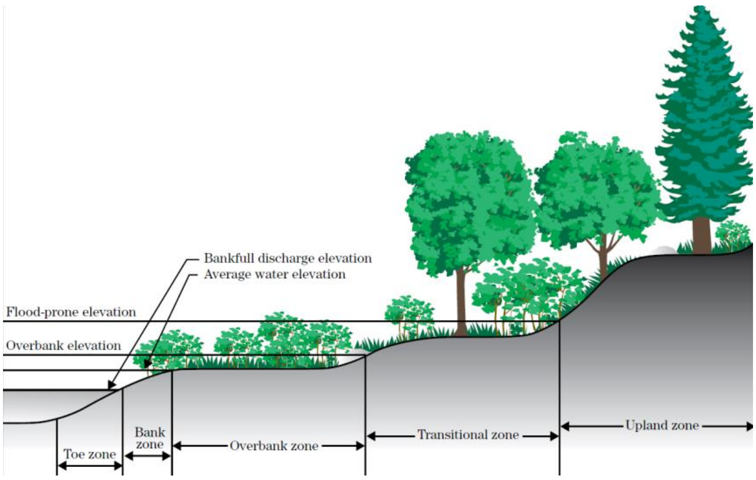


Figure 49.Source: Technical supplement 14I "Stream Soil Bioengineering", NRCS

Velocity and shear values: the effect of the water current on the stability of any streambank protection treatment must be considered. This evaluation includes the full range of flow conditions that can be expected during the design life of the project. Two approaches that are commonly used to express the tolerances are allowable velocity and allowable velocity and allowable shear stress. For these methods to be applied, a hydraulic simulation is necessary for assessing the hydraulic conditions in the intervention area.

The combination of hydraulic and geotechnical variables can also be used to assess the evolution of the fluvial slope in rapid draw down scenario.

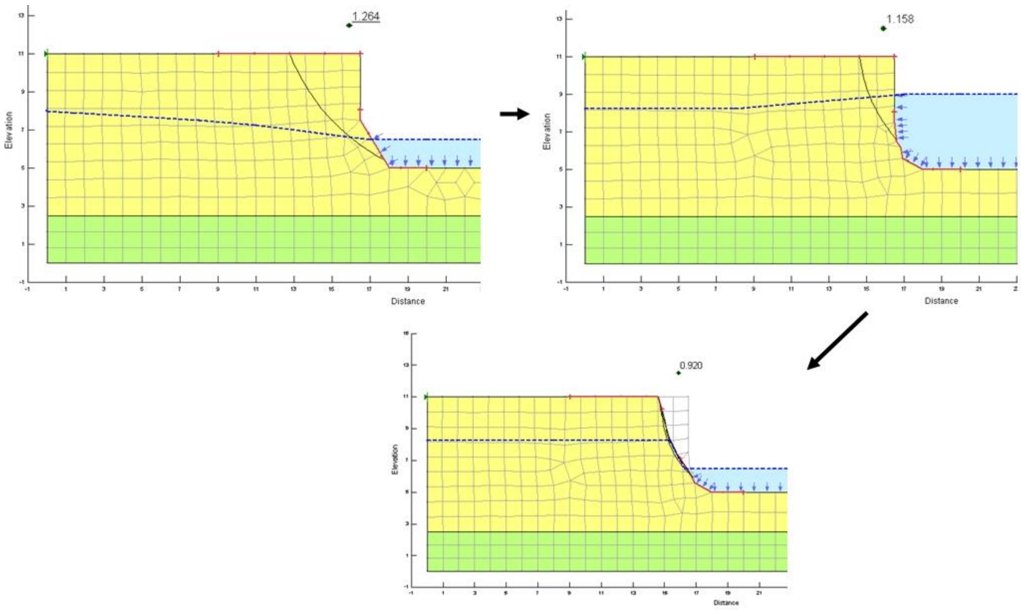


Figure 502.Rapid draw down effect on a fluvial slope

A methodology and freeware for assessing the preceding situation was developed by the Laboratory of the USDA. As a result of this research the BSTEM (Bank stability and Toe Erosion Model) software was produced (Pollen and Simon, 2005).

The design parameters of a water bioengineering action depend on the number of data on flood events. Minor stabilization measure of an embankment, for example in agriculture and horticultural areas, may consider a recurrence period of the 5 year flood is normally sufficient. Regarding important transport infrastructures and buildings a 100 annual flood should be taken as a basis (EFIB, 2015).

Vegetation influences on the main hydraulic variables:

The main influences of the vegetation on the main hydraulic variables can be expressed in terms of:

Roughness: vegetation plays a key role for estimating the roughness of a channel and consequently for the morphology.

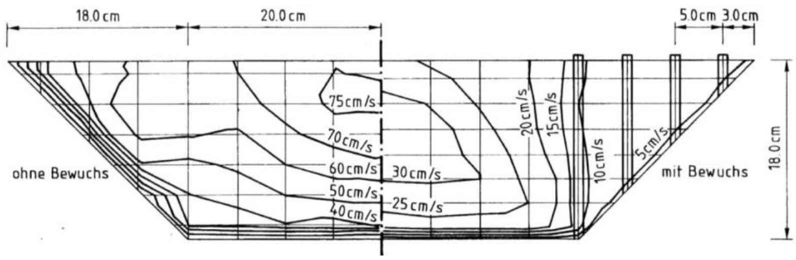


Figure 53. Distribution of velocities with and without vegetation (source: DVWK, 1991)

In the preceding figure the vegetation effects on the velocity fields are depicted. In the left side of the figure there are no vegetation influences. On the right side of the figure there are clear vegetation effects.

Bed shear stress: the vegetation protects the river bed from flow drag forces. The hydraulic stress on a plant with elastic behaviour leads to longitudinal and transverse contraction. The following figure shows the behaviour of a plant by different velocities.

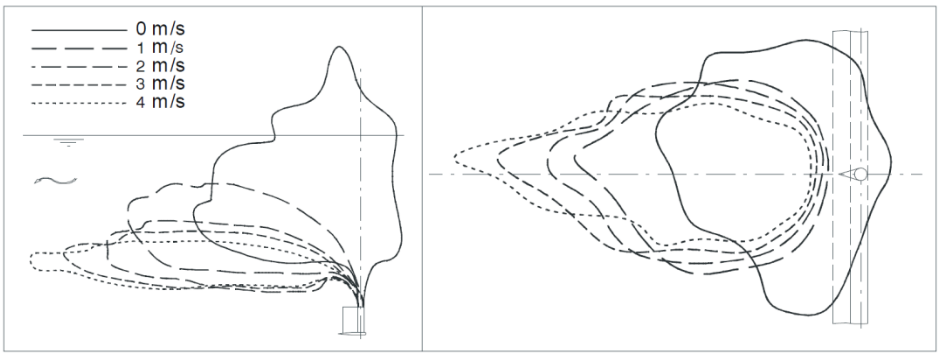


Figure 54. Deflection of Salix sp. at different velocities. Left: profile view; right: plan view (Oplatka, 1998)

The preceding effect release the river bed from the river flow boundary shear stresses.

The protective functions of the vegetation depend on the vegetation mechanical behaviour during flood events. Different types of behaviours can be distinguished:

- Elastic vegetation
- Rigid and dense vegetation
- Rigid and isolated plants (e.g. isolated trees)

Left: flexible vegetation; center: rigid and dense vegetation; right: isolated rigid vegetation (isolated trees)

Flexible vegetation bends down over the riparian soil protecting them against the erosion processes. In this case, the vegetation decreases the flow velocity values.

The vegetation effects on the flow velocity can be assessed according to the following approaches:

By using the **Gauckler-Manning-Strickler (GMS)** flow formula:

$$v_m = k_{st} \cdot R^{2/3} \cdot J^{1/2} = \frac{1}{n} \cdot R^{2/3} \cdot J^{1/2}$$

Where:

v_m = average velocity

K_{st} = Strickler coefficient

R = Hydraulic radious

J= energy line slope

The values of the Strickler coefficient for the different vegetation types are the following:

K_{st} = 30-40 $m^{1/3}$ s^{-1} for the submerged herbaceous vegetation

K_{st} = 15-25 $m^{1/3}$ s^{-1} for the submerged shrubs case (flexible woody vegetation)

K_{st} = 3-4 $m^{1/3}$ s^{-1} for trees and rigid shrubs case (rigid woody vegetation)

The factors

By using the **Felkel** formula:

$$v_m = \frac{k_o \cdot L_o + k_p \cdot L_p}{u} \cdot R^{2/3} \cdot J^{1/2}$$

Where:

k_o = Strickler coefficient without vegetation

L_o = length of the cross-section without vegetation

k_p = Strickler coefficient with vegetation

L_p = length of the cross-section with vegetation

According to **Coolebrook-White** logarithmic flow formula:

$$v_m = \left(\frac{8 \cdot g}{\lambda}\right)^{1/2} \cdot R^{1/2} \cdot J^{1/2}$$

Where:

g = gravity acceleration (9.81 m/s^2)

λ = coefficient of roughness = $\lambda_p + \lambda_{So}$

λ_p = resistance coefficient expressing the plant effects

λ_{So} = resistance coefficient for the riverbed or riverbanks (no vegetation effects included)

In the vegetated part of the river cross-section, the strength coefficient (λ_v) can be estimated as follows:

λ_v = resistance coefficient in the vegetated part of the river cross-section= $\lambda_p + \lambda_{So}$

λ_p = resistance coefficient expressing the plant effects

λ_{So} = resistance coefficient for the riverbed or riverbanks (no vegetation effects included)

A method for calculating the λ_p (part of the resistance coefficient expressing the plant effects) is the following:

$$\lambda_p = \frac{4 \cdot h_p \cdot d_p \cdot \cos\alpha}{a_x \cdot a_y} \cdot C_p = \frac{4 \cdot A_p \cdot \cos\alpha}{a_x \cdot a_y} \cdot C_p$$

Where:

h_p = plant height (m)

d_p = plant diameter (m)

a_x = distance between tha plants in the flow direction (m)

a_y = distance between plants trasverse to the flow (m)

α = slope angle (°)

C_p = coefficient of a single plant

A_p = area of the submerged plant (m^2)

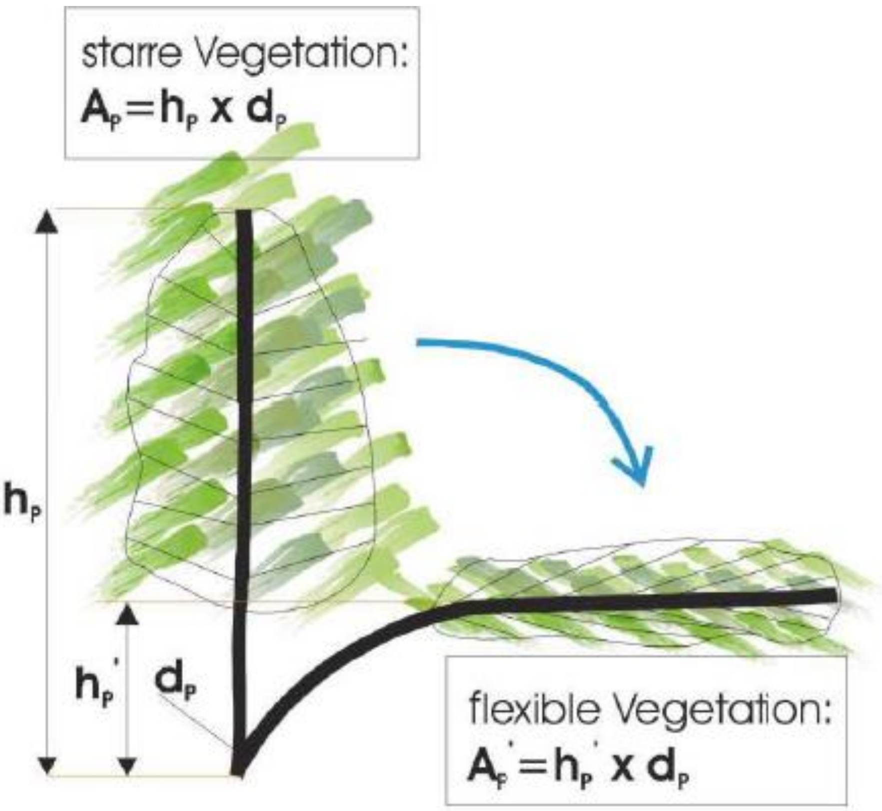


Image showing the way to calculate the term A_p (source: Rauch, 2005)

Unlike the flexible vegetation, rigid vegetation both reduces the effective hydraulic cross sectional area and generates local erosion processes. The hydrodynamic resistance offered by the rigid vegetation can be assessed according to:

$$F_p = \rho_w \cdot \frac{v^2}{2} \cdot C_p \cdot A_p$$

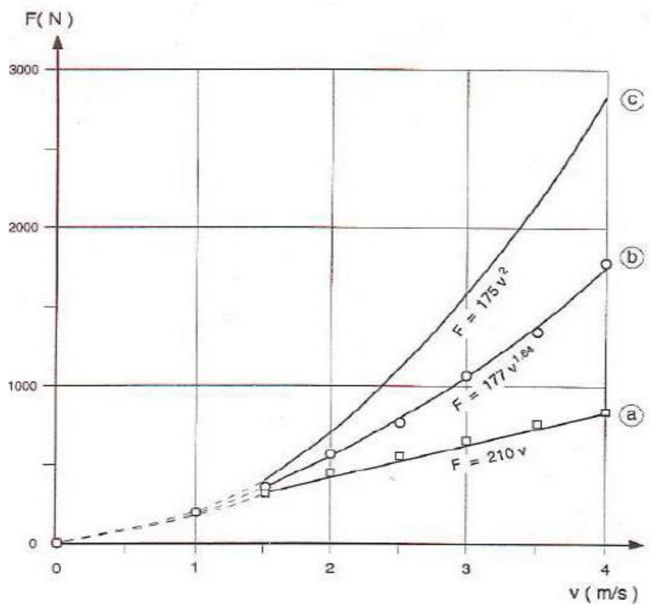
Where:

ρ_w = water density (Kg/m³)

The other terms have already been defined in preceding formula.

The flexible vegetation also offers hydrodynamic resistance although its effect is lower than the rigid vegetation case. In the flexible vegetation case, the following formula can be used:

$$. \ F_p = \rho_w \cdot \frac{v}{2} \cdot C_p \cdot A_p$$



Variation of the hydrodynamic resistance with the vegetation rigidity and the flow velocity. Plot a) flexible vegetation, plot b) middle rigidity, plot c) rigid vegetation (source: Vischer and Oplatka, 1998)

On general terms, the effects of the different vegetation types are the following:

Rigid and dense vegetation effects:

- Reduction of the effective hydraulic cross sectional area,
- flow velocity decrease,
- good protection against erosion processes,
- an increase in the water level, it may cause flood in the nearby areas

Isolated and rigid woody vegetation (isolated trees):

- Water deflection,
- Low water velocity reduction
- generation of turbulence processes,
- Local erosive processes,
- dragged trees can block bridge spans

According to the preceding analysis, an effective protection of the riverbanks can be achieved by combining flexible vegetation and dense and rigid woody vegetation. Ideally, flexible vegetation should be placed at the toe and lower part of the riverbanks and trees should be placed at the top of the banks.

Currently, there are research lines contributing with new information and approaches for assessing the vegetation effects on both the river flow and the riverbanks protection. For further readings please refer to H P Rauch (2008).

10.4 Project, construction, maintenance and monitoring-brief introduction

The water bioengineering project should follow the “minimum intervention” principle. It should include the analysis of the living material availability, the average construction time required, a monitoring plan or schedule and the maintenance costs.

Detailed construction drawings are very helpful for an adequate construction of the bioengineering techniques.

Throughout the construction stage a quality control of the utilised materials (living and inert materials) is essential.

The initial maintenance costs of biotechnical structures are higher than those of conventional structures but they become much lower, and also more steady later on. Maintenance of wood vegetation depends on (Anselm, 1976):

- maintenance frequency
- age of the riparian thicket, density of growth
- successional stage (pioneer stage up to climax)
- accessibility and width of growth
- species (willows are more effective in bank securing but need more care)
- water quality (increase of submerse plants when water quality drops)
- size of the stream
- density of stream network
- stream region (upper, medium and lower reaches)
- debris and sediment transport

For the monitoring programme, vegetation plots can be used (e.g., 100 m2 circular plots, 1m2 plots on shoreline trench). Analysis of the plant survival rates will be very useful for proposing improvement for future works.

The main purposes of the monitoring plans will be:

- Evaluate and verify success of revegetation
- Establish a framework and protocols to assess revegetation overtime

Within the performance analysis of the bioengineering intervention, both the ecological and social benefits must be part of the overall assessment and evaluation of the works.

The protocols generated throughout the ECOMED project could be used for:

- Defining the field work variables and procedures associated to the monitoring plan
- Generating the work analysis report
- Generating the bioengineering work performance analysis
- Proposing improvements at the design, construction, maintenance, and monitoring levels. Generate lessons learned for future works.

LINKS:
Video: "Bioengineering"
Source:https://www.youtube.com/watch?v=EDZYMaSu9Tk

Video: "Restoring Shorelands with Bioengineering"
Source:https://www.youtube.com/watch?v=GCHt1v6sOeY

Video: "Restoring Shorelands through Bioengineering".
Source:https://www.youtube.com/watch?v=taHUhD0OXsw

"Soil bioengineering techniques for riparian restoration"
Source:https://cvc.ca/wp-content/uploads/2011/02/2002-polster.pdf
"Bioengineering techniques for streambank restoration"
Source:http://www.env.gov.bc.ca/wld/documents/wrp/wrpr_2.pdf

11. REFERENCES

Chang, M. 2003. Forest Hydrology. An introduction to water and forests. CRC Press, 373 pp.

Chow, V.T.; Maidment, D. and Mays L. 1988. Applied Hydrology. McGraw Hill., 224 pp.

Dunne, T. & Leopold, L.B.1978. Water in Environmental Planning. W. H. Freeman Co., San Francisco, 818 pp.

Morgan, R.P.C. 2004. Soil Erosión and Conservation. Blackwell Publ.

Musy, A. & C. Higy, 2011. Hydrology. A Science of Nature. CRC Press. 346 pp.

Ponce, V.M. 1994. Engineering Hydrology. Principles and Practices. Prentice-Hall. 640 pp.

Belete Berhanu, Yilma Seleshi, Solomon S. Demisse, and Assefa M. Melesse, 2015. Flow Regime Classification and Hydrological Characterization: A Case Study of Ethiopian Rivers. Water 2015, 7, 3149-3165.

Gonzalez, M. 2013. HIDROLOGÍA. RESTAURACIÓN HIDROLÓGICO-FORESTAL. Régimen de caudales.

Leopold, L.B., 1994, A view of the river: Cambridge, Mass., Harvard University Press, 290 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, Calif., W.H. Freeman and Co., 522 p

Norris, J.E.; Stokes, A.; Mickovski, S.B.; Cammeraat, E.; van Beek, R.; Nicoll, B.C.; Achim, A. (Eds.) Slope Stability and Erosion Control: Ecotechnological Solutions. 2008, VI, 290 pp., Springer.

Schiechtl, H. M., Stern, R. 1996. Ground Bioengineering Techniques: For Slope Protection and Erosion Control. Wiley-Blackwell, ISBN 10: 0632040610, ISBN 13: 9780632040612.

Schiechtl, H. M., Stern, R. 1997. Water Bioengineering Techniques: for Watercourse Bank and Shoreline Protection. Wiley-Blackwell , ISBN 10: 0632040661, ISBN 13: 9780632040667.

Studer, R, Zeh, H., De Cesare, G. 2014. Soil bioengineering – construction type manual. vdf Hochschulverlag AG der ETH Zürich, ISBN: 978-3-7281-3642-8

Allan, J.D., Catillo, M.M., 2007. Stream ecology: Structure and Function of Running Waters, 2nd edn,. P. 436. Dordrecht, The Netherlands; Springer.

Anselm, H., 1976. Analyse der Ausbauverfahren, Schäden und Unterhaltungskosten von Gewässern. Mitteilungen des Instituts für Wasserwirtschaft, Hydrologie und Landwirtschaftlichen Wasserbau, TU Hannover, Report 36:11-191.

Bendix, J., 1994. Scale, direction and pattern in riparian vegetation-environment relationships. Annals of the Association of American Geographers 84: 652-665

Bendix, J., Hupp, C.R., 2000. Hydrological processes, 14. 2977-2990.

Cowell CM. 1993. Ecological restoration and environmental ethics. Environmental Ethics 15: 19-32.

Elwood, J.W., Newbold, J.D., O'Neil, R.V., Van Winkle, W., 1983. Resource spiraling: an operational paradigm for analyzing lotic ecosystem. Fontaine, T.D., Bartell, S.M. (eds.)- "Dynamics of lotic ecosystems", Ann Arbor, Michigan, USA pp 3-27.

Hosner, J.F., Minckler, L.S., 1963. Bottomland hardwood forests of southern Illinois. Ecology 44: 29-41.

Hupp CR. 1983. Vegetation pattern on channel features in the Passage Creek Gorge, Virginia. Castanea 48: 62-72.

Likens, G.E. (Editor), 2010. River Ecosystem Ecology: A Global Perspective. Academic Press. ISBN: 9780128102138.

Matthews, R. A., Buikema, A. L., Cairns, J., Rodgers, J. H. 1982: Biological monitoring Part IIA - Receiving system functional methods, relationships and indices. Water Research 16: 129-139.

McBride, J.R., Strahan, J., 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. American Midland Naturalist 112: 235-245.

Negri, P., 1997. Ruolo delle zona riparia di una roggia di fondovalle in Valsugana, Trentino. Unpublised bachelor thesis. Universitá Ca' Foscari Venezia, Italia. In Italian.

Negri, P., Siligardi, S., Francescon, M., Fuganti, A., Monauni, C., Pozzi, S., 2004. The fluvial fuctioning index: an ecological assessment applied for river restoraion. Proceedings of the 3rd European Conference on River Restoration, "River Restoration" Zagreb, Croatia pp 223-227.

Pollen, N., Simon, A., 2005. Estimating the mechanical effects of riparian vegetation on streambank stability using a fiber bundle model. Water Resources Research, 41, W07025.

Sansoni, G., 1987. Efeti biologici delle arginature e delle escavazioni fluviali. Notizie Cisba 2: 11-16. In Italian.

Siligardi, M (coordinator of the study group). 2007. "IFF Indice di Funzionalità Fluviale - Manuale di applicazione. ISPRA, Roma (Italy), ISBN 978-88-448-0318-6

Simon, A., Bennet, S.J., Neary, V.S. , 2004. Riparian vegetation ad flucvial geomorphology. Waterscience and Application. American Geophysical Union.

W Mays, L. (1999). Hydraulic Design Handbook. McGraw-Hill.

Altarejos García, L., 2010. Estudio hidrodinámico del río Linares. Proyecto de I+D+I para la optimización de técnicas de bioingeniería. TRAGSA. CPS Ingenieros.

Bentrup, G., & Hoag, J. C., 1998. The Practical Streambank Bioengineering Guide. USDA NRCS Aberdeen Plant Materials Center.

Faber, R., 2004. New techniques for urban river rehabilitation. Specifications for new materials and techniques Improve instream morphology Soil-bioengineering. Vienna: Urban River Basin Enhancement Methods.

Martínez, A. (2015). Aplicación informática para la selección de técnicas de bioingeniería en actuaciones de restauración fluvial. UPM.

Foster, G.R. y Meyer, L.D. (1975) "Mathematical simulation of upland erosion using fundamental erosion mechanics". En "Present and Predictive Technology for Predicting Sediment Yields and Sources", Report No. ARS-S-40, U.S.Dept. of Agric., Agric. Res. Serv., Washington, DC, pp 177-189.

Foster,G.R. y Lane, L.J. (1987) "User requirements: USDA-Water Erosion Prediction Project (WEPP). NSERL Report No. 1, National Soil Research Laboratory, USDA-ARS, W. Lafayette, IN.

Foster, G.R.; Lane, L.J.; Nowlin, J.D.; Laflen, J.M. y Young, R.A. (1981) "Estimating erosion and sediment yield on field-sized areas. Trans. ASAE. 24, pp 1253-1262.

Kirkby, M.J. y Morgan, R.P.C. (1984). Erosión de suelos. Ed. Limusa. Mexico. D.C.

López Cadenas de Llano, F. et al. (1994) Restauración HIdrológico-Forestal de Cuencas y Control de la Erosión. 902 pp. Coedición TRAGSA, TRAGSATEC y MUNDI-PRENSA.

Williams, J.R. 1975 Sediment routing for agricultural watersheds". Water Resources B.A.R.A.

Wischmeier, W.H and Smith, D.D. 1978 Predicting rainfall erosion losses, USDA Agr. Res. Serv. Handbook 537.

Flow Regimes. Aquatic Biomonitoring – Hydrological Data. [on line: http://www.dwa.gov.za/IWQS/rhp/reports/report14/2_flow.pdf]

Junta de Andalucía. [on line: http://agrega.juntadeandalucia.es/repositorio/13122010/ff/es-an_2010121313_9170018/ODE-5ea32056-57b3-3c38-823c-3c0ee3359298/11tipos_de_rgimen_fluvial_en_espaa.html]

HEC-RAS: [on line: from: http://www.hec.usace.army.mil/]

DVWK. Merkblatt 220 (1991): Hydraulische Berechnung von Fließgewässern, Verl. Paul Parey, Hamburg.

Oplatka, M., 1998. Stabilität von Weidenverbauungen an Flussufern. Dissertation, ETH-Zürich.

Hans Peter Rauch, 2008. Application of Soil Bioengineering Techniques for river engineering projects with special focus on hydraulics and morphological issues. Bilateral agreement for the academic year 2007/2008. Lifelong Learning Programme: Higher Education ERASMUS between Universidade de Evora and University of Natural Resources and Applied Life Sciences (BOKU).

11.1 Computer applications

11.1.1 HEC-HMS:

- HEC-HMS (2010). Hydrologic Modeling System HEC-HMS User's Manual Version 3.5, August 2010. U.S. Army Corps of Engineers, Hydrologic Engineering Center. Davis, California.
- HEC, 2003. Geospatial Hydrologic Modeling Extension: HEC-GeoHMS User's Manual, Version 1.1, December 2003. US Army Corps of Engineers, Hydrologic Engineering Center.

- Scaini, A. et al. (2011). Análisis del modelo HEC-HMS para la simulación de las avenidas del río Arga en Pamplona. (C.- Agua y ciudad).
- Figura x: http://www.hec.usace.army.mil/software/hec-hms/images/hec-hms_main.jpg

11.1.2 IBER2D:

- Cea, L., Bermúdez, M., Puertas, J., Bladé, E., Corestein, G., Escolano, E., Conde, A., Bockelmann-Evans, B., Ahmadian, R. (2016). IberWQ - New simulation tool for 2D water quality modelling in rivers and shallow estuaries. Journal of Hydroinformatics, 18(5), 816-830. DOI: 10.2166/hydro.2016.235
- Cea, L., Blade, E. (2015). A simple and efficient unstructured finite volume scheme for solving the shallow water equations in overland flow applications. Water Resources Research, 51(7), 5464–5486.
- Bladé, E., Cea, L., Corestein, G., Escolano, E., Puertas, J., Vázquez-Cendón, M.E., Dolz, J., Coll, A. (2014). Iber: herramienta de simulación numérica del flujo en ríos. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería, 30(1), 1-10.

11.2 Useful links

www.tuik.gov.tr (accessed 03.04.2014)

www.worldclim.org/download (accessed 09.08.2015)

http://www.fao.org/docrep/u3160e/u3160e05.htm#3.5.3%20runoff%20coefficients

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053573

https://www.pmfias.com/precipitation-types-rainfall-conventional-rainfall-orographic-rainfall-frontal-rainfall-cyclonic-rainfall-monsoonal-rainfall/

http://www.professorpatel.com/curve-number-introduction.html

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

12. EXERCISES

12.1 Exercise 1. Sizing the stone diameter for the slope toe protection of a fluvial slope.

In the framework of a integrated restoration actions

A hydraulic simulation was performed and the values of the main hydraulic variables were obtained. Assume that the average velocity and average boundary shear stress in the intervention river stretch are the following:

v = 3,0 m/s

t = 125 N/m^2

Determine a adequate stone size for protecting the slope toe and for complementing the water bioengineering techniques.

Solution:

Two different methods will be used:

Method 1: Lowe (1996). Fish Habitat Enhancement Structures - Typical Designs, (Edmonton, AB: Alberta Environmental Protection, Water Resources Management Services

Method: U.S. Bureau of Reclamation (USBR EM-25) method

According to the first method, for a water velocity of 3 m/s, the stone sizing gradation is the following:

Stone size	% passing
450 mm	0
350mm	20
300 mm	50
200 mm	80

The formula used in the second method is:

$D_{50}=0.0122V_a^{2.06}$

Where:

D_{50}=Stone size in feets (1 m = 3,2808 feets)

V_a =average velocity in feet/s

Applying the formula we get:

D_{50}= 1,35 pies = 0,41 m.

We will use the biggest size obtained in both methods. Therefore, we will use stones with 0.41 m of diameter.

12.2 Exercise 2. Selecting the water bioengineering technique given a certain average velocity and average boundary shear stress

Water bioengineering techniques are going to be used in a river stretch. There is a high erosion rate affecting the riparian soils and an adequate protection is needed to be designed.

A hydraulic simulation was performed and the values of the main hydraulic variables were obtained. Assume that the average velocity and average boundary shear stress in the intervention river stretch are the following:

v = 2.0 m/s

t = 125 N/m^2

Determine which water bioengineering techniques could be used with the preceding hydraulic conditions.

Solution:

Two different techniques election criteria will be used: maximum velocity allowable and maximum boundary shear stress allowable.

The selected techniques will have to withstand the hydraulic conditions present in the intervention area both at the end of construction stage and at the mid-long term.

At the end of construction stage, the vegetation renforcement effects cannot play a role in the riparian soil conservation strategy. It takes a year for the vegetation to develop and reinforce both the soils and the used soil and watre bioengineering techniques.

The period of return selected for the design is 10 years. During this time, the vegetation will have enough time for developing and offer their stabilising role.

The allowable velocity and boundary shear stress for the different soil and water bioengineering techniques are shown in the following techniques (without including the vegetation role) (*Note: please note that these values could be different in other conditions*):

Table 1 Sources: NRCS, 1996; Hoag and Fripp, 2002; Fischenich, 2001; Gerstgrasser, 1999; Nunnally and Sotir, 1996; Gray and Sotir, 1996; Schiechtl and Stern, 1994; USACE, 1997; Florineth, 1982; Schoklisch, 1937

Water bioengineering techniques	Allowable boundary stress (N/m^2)	Allowable velcity (m/s)
Live log crib wall (double wall)	200	2,5-3,0

Palisade (simple log crib wall)	200	2,5-3,0
Brush mattress	150	1,2
Live brush wattle fence	100	1,0
Live poles	100	1,0

The preceding values do not include the vegetation reinforcement effects and therefore, correspond to the end of construction stage. Once the vegetation is well developed and able to reinforce the riparian soil and the water bioengineering technique, the allowable strength values are presented in the following table:

Table 2 Sources: NRCS, 1996; Hoag and Fripp, 2002; Fischenich, 2001; Gerstgrasser, 1999; Nunnally and Sotir, 1996; Gray and Sotir, 1996; Schiechtl and Stern, 1994; USACE, 1997; Florineth, 1982; Schoklisch, 1937

Water bioengieering techniques	Allowable boundary stress (N/m²)	Allowable velcity (m/s)
Live log crib wall (double wall)	300	3,0-4,0
Palisade (simple log crib wall)	300	3,0-4,0
Brush mattress	400	3,0
Live brush wattle fence	250	3,0
Live poles	250	3,0

Using the first table, according to the velocity criteria, the techniques to be selected are the following: live log crib wall and live palisade.

According to the shear stress criteria, the selected techniques are the following: Live log crib wall, live palisade and brush mattress.

Therefore, combining both criteria, the selected water bioengineering techniques are the following: live log crib wall and live palisade.

If we were to use other techniques such as live brush wattle fence, an extra reinforcement would be necessary (e.g., rip rap).

13. CASE STUDY ANALYSIS

A case study analysis throughout the project, construction and monitoring stages is presented. The assessment of the intervention performance, conclusions and improvements are also shown.

<u>The intervention area description:</u>

The Artia channel renaturalization project was one of the first soil and water bioengineering project done in the Basque Country and in Spain.

The Artia creek was channelized to prevent the frequent floods that were affecting the nearby neighbourhoods. The pre-operational scenario is a channelized creek (the Artia creek) with a trapezoidal cross-sectional shape made of concrete.

<u>Main problems to be addressed in the intervention:</u>

The river dimensions were not functional. There was no connection between the floodplains (no lateral connection) and there was no vertical connexion either (the riverbed made of concrete). The longitudinal dimension was also much altered. There were no natural transport dynamics and the hydrodynamic of the Artia creek was not functional. There was no riparian vegetation.

Figure 51 Pre-operational situation (initial situation). The channel was formed by a trapezoidal cross section made of concrete

<u>Main information for the project description:</u>

The project consists of the demolition of the concrete channel and the construction of the new renaturalized creek using soil and water bioengineering techniques.

The project included the following actions:

- Elimination of the left hand side concrete wall.
- Demolition of the river bed concrete
- Construction of wider banks. Grading the slopes. Softening the creek fluvial slopes
- Establishment of a riparian vegetation buffer

Main strategy followed within the project:

The main objectives of the project were the following:

- Restoration of the river system functionality
- Restoration of the creek fluvial dimensions (lateral, vertical, longitudinal and temporal)
- Restoration of the riparian vegetation by implementing a phytosociological approach.
- Triggering ecosystem services and improving ecosystem functionalities
- Improvement of flora and fauna habitats
- Implementing the soil and water bioengineering approach which includes the development over time of the stabilizing role transferring processes between the inert materials and the plant communities.

Main results and calculation obtained in the project:

At the design stage, the following variables were calculated:

The maximum shear boundary stress was lower than 100 N/m^2.

Rock size was calculated for both the fluvial slope and the riverbed positions. The methods used for each case are the following:

- Rock size over the fluvial slope: Hallmarte method, Pilarczyk formula, Maynord formula.
- Rock size at the riverbed: RIP-RAP software.

Both the grain size curve and the rock wall thickness were also calculated.

Main soil and water bioengineering techniques used:

At the right river banks the water bioengineering techniques were the following:

Double log crib walls (with live branches of *Salix atrocinerea* and *Salix alba*), vegetated rock walls (with *Tamarix gallica* and *Salix* sp live branches).

At the leftriver banks the water bioengineering techniques were the following:

Brush mattresses (with *Tamarix gallica* live branches and *Salix* sp live stakes), and gabion mattress (with hydroseedling or *Phragmites* sp transplantation).

Tree plantation along the river banks (*Fraxinus excelsior*, *Alnus glutinosa* and *Acer platanoides*).

Plantation of shrubs (*Hedera helix*, *Coryllus avellana*, *Cornus sanguinea* and *Eounymus europaeus*).

The living materials used were: *Tamarix gallica* live stakes, *Salix* sp live branches.

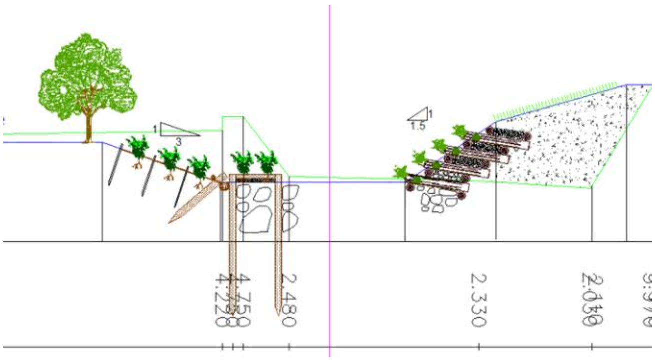


Figure 52 Example of a project cross sectional view (a brush mattress on the left riverbank and a double crib wall on the right riverbank)

Figure 53 Construction of the Artía River and 6 months later – Irun -Spain – Basque Gouvernement Picture P. Sangalli

Construction stage analysis. Main conclusions.

The live stakes were not classified per plant species. This explains the inverse distribution of riparian plant species in some stretches of the Artia creek. For instance, one can find the *Fraxinus excelsior* right by the river and the *Salix* sp in a further position form the river.

The work force lack of experience in soil and water bioengineering works was another limitation of the construction stage.

Ensuring that the work force is well trained in the construction of soil and water bioengineering techniques is a crucial factor for an adequate development of the construction stage. By including a course before the beginning of the construction stage a minimum training level of the workforce would be ensured.

Monitoring stage analysis:

There was a monitoring after the construction stage, it was visited in several times during the first 5 years and the vegetation was maintained by thinning.

The outcomes of the maintenance actions are satisfactory.

Performance analysis:

For the performance analysis, according to the Ecomed project protocols (www.bioecomed.eu), a field work was carried out in order to characterize the water bioengineering techniques performance.

Both vegetation and the current state of the wooden elements were analysed. For the vegetation characterization, different dendrometric variables were measured (e.g., diameters, heights, basometric area, etc). For the wooden elements (logs) characterization, resistograph tests were carried out.

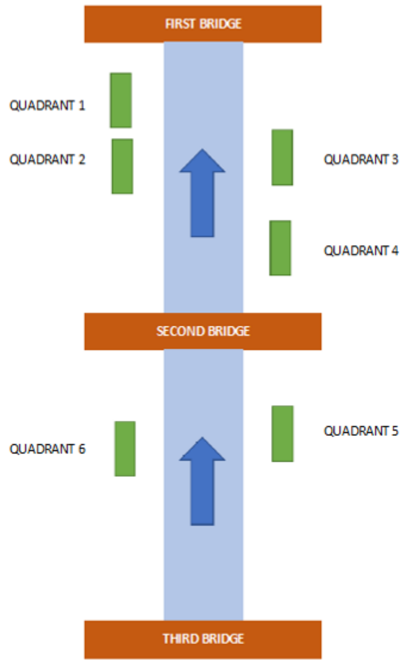


Figure 54 Quadrants localization (sampling spots) selected for the field work

After analysing the field work collected information, the following conclusions were reached:

The bioengineering work has fulfilled the pursued objectives. The Artia creek renaturalization process is fully developed. Compared to other reaches where the Artia creek is still channelized, the fluvial scenario is completely different. Many fluvial processes are present within this reach of the Artia creek. Ecosystem services are now offered to the citizenship of the surrounding areas.

The river dimensions have been restored (longitudinal, vertical, lateral and temporal).

The main limiting factors are the following:

The width limitations of the right riverbank

The mowing of the adjacent meadows is negatively affecting the development of the riparian zone in terms of its structure and plant composition.

A completely new dynamic was generated after the implementation of the soil and water bioengineering approach and methodology. A riparian buffer area was developed. The stabilization role transfer between the initial inert element (the logs) and the evolving vegetation has been fully developed. The soil and water bioengineering strategy has been successfully accomplished.

The fluvial hydrodynamic processes have also been activated. Riffles and slow water areas are present now in the Artia creek.

The trunks in ground contact are much deteriorated. The logs are no longer fulfilling any stabilising function. The remaining function is the fertilisation of the surrounding soil. Actually, nowadays the logs just work as a slow release organic fertilizer. The vegetation has already taken over the stabilization function. The volume occupied by the logs is now occupied by the roots and by the formed soil. The soil and water bioengineering approach and strategy has been successfully developed.

<u>Proposals of improvements for future soil and water bioengineering works:</u>

At the design stage, the following parameters should have been calculated:

The diameters of the wooden elements used in the soil and water bioengineering techniques.

The ramming depths of the vertical elements.

Plant selection: *Tamarix* sp. was proposed to be used in all the log crib walls regardless sea tidal influence. The use of *Tamarix* sp. live branches is adequate for the stretch under the tidal influence. Outside that influence, the *Salix* sp live branches option is more adequate.

Strategy implementation: more explanations about the soil and water bioengineering approach would improve the project contents.

Bioengineering techniques selection. A justification of both the techniques selection and the techniques localization is lacking in the project.

Plantation schemes or drawings showing the distribution of the different plant species over the intervention area would have been very useful for the construction stage. Above all because of the limited experience the companies had in the Basque Country by that time.

The selection of the bioengineering techniques and their distribution over the riverbanks is correct, but it seems to be oversized.

Improvements at the construction stage:

The wooden material utilised during the construction stage were green and barked logs. Because of this situation, the logs had a high water content level and the moisture loss process was very low. Hence, the logs were very vulnerable to the fungi attack from the very beginning of the bioengineering work service life. A minimum seasoning is recommendable to decrease the log water contents before their use in bioengineering works.

The live stakes were not classified per plant species. This explains the inverse distribution of riparian plant species in some stretches of the Artia creek. For instance, one can find the *Fraxinus excelsior* right by the river and the *Salix* sp in a further position form the river.

The work force lack of experience in soil and water bioengineering works was another limitation of the construction stage.

Ensuring that the work force is well trained in the construction of soil and water bioengineering techniques is a crucial factor for an adequate development of the construction stage. By including a course before the beginning of the construction stage a minimum training level of the workforce would be ensured.

Improvements regarding the performance analysis:

The mowing of the adjacent meadows is negatively affecting the development of the riparian zone in terms of its structure and plant composition. A good coordination with the existing green zone maintenance actions would improve the overall performance and ecological development of the intervention area.

Figure 55 Artia Channer – Before the works and nowadays Basque Government and P.Sangalli

14. LEARNING AND TEACHING ACTIVITIES

The delivery of this module is web-based. It is essential that the student works through the reading materials and exercises provided on the virtual learning platform (VLP). Formal lectures are enhanced with tutorial/seminar sessions which allow for discussion. The delivery of this module is also via flexible learning (i.e. self-study). All the material are provided on VLP and presented in the form of course units and reading and self-study materials. It is the responsibility of the student to study in his/her own time. The student should also take the responsibility to seek clarification and/or guidance from the theme-specific Module Tutor or Module Leader.

The module is underpinned by assessment activities based on two courseworks. Students are encouraged to apply knowledge and insight gained from the tutorial/seminar sessions in their courseworks.

You will be expected to attend and to take notes at the tutorial/seminar sessions. For some (but not all) of the sessions you will be given an access to the lesson plan and/or miniature copies of the slides used during the presentation as support notes. Handouts will also be issued from time to time at the sessions. Spare copies of issued materials will be available at the discretion of the lecturer responsible for that section of the course. You will have regular opportunities for face to face contact with your tutor at these sessions.

15. ASSESSMENT AND FEEDBACK

This module is continuously assessed during the course of the semester. The assessment comprises a case study evaluation, a practical case and multiple choice questionnaire. The pass mark for this module is 50% - you must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above.

Full details of the course works are contained in the Coursework Briefs which will be issued in due course.

Note: Failure to submit the coursework for the appropriate deadline without 'good cause' will be regarded as a non-submission, and hence will result in failure in this module. If you have a good reason for needing an extension to the deadline, you must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date.

To help you guide your development you will be provided with feedback on your performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort's overall performance will be provided. You will be given an opportunity to individually review your marked work to help you understand which aspects of your studies you are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. You are entitled to keep marked submissions for your review - however, you must return these when asked by the Module Leader or Module Tutor.

16. DIRECTED LEARNING AND PRIVATE STUDY

As you are expected to 'read' for your degree, you will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect you to be up to date with the current theme.

The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and you will be expected to demonstrate evidence of having sourced information from these in your coursework activities.

You should also make use of web-based materials and visit appropriate sites to develop a wider knowledge of the key issues and activities of not only your chosen discipline, but also in other related fields.

Please refer to the Module Descriptor for a detailed reading list. However, you may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section.

17. MODULE DIFFICULTIES AND EVALUATION

If you have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, you should speak with your employer or Academic tutor.

A module evaluation form will be made available to you on-line after the module is complete and you will be asked to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms are analysed (anonymously) and the findings considered by the appropriate professional organisation as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that you may have about the module in the first instance.

17.1 General Notes on Coursework Requirements

It is not easy to give hard and fast rules about criteria for marking either written reports, particularly those for which a specific answer is not appropriate. However, it is important that you first study carefully the coursework brief to make sure that you know what is expected. Please refer also to the General Marking Criteria in your Programme Handbook, which give you an idea what we are looking for in grading work at Masters level. You may then consider the following as universal marking criteria for written reports.

The following constitute positive criteria for marking and will be rewarded:

- Work that is planned and structured
- Work which embodies an argument and is rigorous, logical and sustained
- Work that is concise and precise
- Work that is clearly presented
- Work that is fully referenced
- Text which embodies a balance of explanation and analysis
- Text in which specific claims made in the narrative are supported by evidence
- Work which consistently engages with the question and is relevant to the topic

The following constitute negative criteria for marking and marks will be deducted for:

- Work that is deficient in planning and structure
- Work that is poorly argued
- Work that is poorly presented
- Work that is poorly referenced
- Text in which claims are made in the narrative that are unsupported and which lapse into opinion and anecdote
- Text which is deficient in explanation and analysis
- Text which is simply a reproduction of lecture notes or in which originality, innovation and imagination are conspicuous in their absence
- Text which does not relate to the terms of reference

And one other thought:

It is important that your courseworks are properly referenced as you will be submitting your courseworks via the plagiarism detection software facility on the VLP.

Plagiarism is defined as: "to use another person's idea or a part of their work and pretend that it is your own" (http://dictionary.cambridge.org/)

- This definition is straightforward - note it well and remember it. Plagiarism is a form of scientific misconduct and it may result in 'the suspension of the student from the university' as it is a serious offence. (see the university regulations regarding cheating and plagiarism, clause 8)
- Remember that each of the assignment activities is to be the student's own individual attempt - no student should collude with others or use someone else's work.

18. PERSONAL DEVELOPMENT PLANNING (PDP)

PDP is embedded within ECOMED to assist you to develop as an independent and confident learner, not only during your time with us, but throughout your future career. It also allows more effective monitoring of your progress while undertaking your degree programme studies. The process has been described as

“A structured & supported process undertaken by individuals to reflect upon their own learning and performance, and/or achievement, and to plan for their personal education and career development.”

As a member of a professional graduate community, you will be required to undertake Continuing Professional Development throughout your career. Learning therefore must be seen as a lifetime activity, and the introduction of PDP at the early stages of your career prepares you for these future requirements. PDP provides an opportunity for you to develop your capacity for learning by getting you to reflect on why and how you are learning, and to become more capable of reviewing, planning and taking responsibility for your studies. All of the foregoing will of course be supported by staff, in particular your Academic Tutor. The key objectives of the PDP process can be summarised as follows:

- To help you become a more effective, independent and confident self-directed learner
- To understand how you are learning and be able to relate that learning to a wider context
- To improve your general skills for study and career management
- To articulate your personal goals and evaluate your progress towards these
- To encourage you to develop a positive attitude to learning throughout your professional life.

19. OPEN ACCESS TO RESOURCES

Access to a wide range of services, information and software can be made through the ECOMED homepage page: http://www.ecomedbio.eu. You will be automatically given access to the virtual learning platform (VLP ; e.g. Moodle) when you register with ECOMED. VLP is the basic gateway to all other software and electronic resources on the ECOMED webpage. VLP is an instructional software package which you are expected to use to read announcements, access resources and communicate with staff associated with the module.

You will be updated on progress with any upgrades and new palpitations of the software and resources. All software and related problems are dealt with by the ECOMED Helpdesk.

QUESTIONS FOR THE VIRTUAL LEARNING PLATFORM (VLP):

1. A river has four different dimensions:
    a. Yes
    b. No. A river has three dimensions: the lateral, the vertical and the temporal dimension
    c. The number of dimensions varies depending on the river connectivity.
2. The Intensity-Duration-Frequency curves are used for
    a. Calculating the design storm in large watersheds
    b. Calculating discharge values when data are scarce
    c. Calculating maximum precipitation values in short time intervals.
3. The soil intrinsic permeability depends on:
    a. Soil density
    b. Soil viscosity
    c. Soil pore geometry
4. The rational formula is used for:
    a. Calculating the soil water content
    b. Calculating the erosion rate
    c. Calculating extraordinary flood flows in small basins
5. In water bioengineering works it is essential to know:
    a. Velocity, shear stress and water level values
    b. Only the water level values
    c. Soil properties and the slope safety factors
6. There are three modalities of fluvial erosion which are:
    a. Rill, sheet and gully erosion
    b. Rill, sheet and mass waste movements
    c. Vertical, headward and lateral erosion.

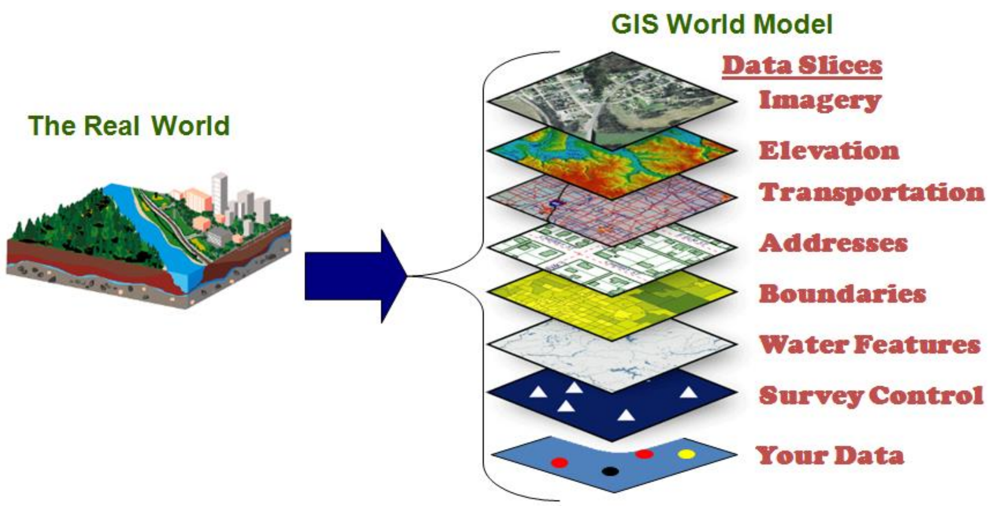
7. Critical shear stress values of the riverbanks can be increased by:
    a. The soil moisture content
    b. Using appropriate software such as Hec Ras or Iber
    c. The development of the riparian vegetation
8. The FFI index is used for:
    a. Assessing the riverbank stability
    b. Characterizing, in a detailed fashion, the fauna and flora of a river system
    c. Assessing the overall river functionality and state
9. The fascines with double poles can be classified as a:
    a. Stabilization technique
    b. Mixed technique
    c. Coating technique
10. An effective protection of riverbanks can be achieved:
    a. By using only dense rigid woody vegetation (mainly shrubs)
    b. By combining rigid trees and dense rigid woody vegetation
    c. By combining flexible and dense rigid woody vegetation

MODULE 4.

GEOGRAPHIC INFORMATION SYSTEMS (GIS) FOR SOIL AND WATER BIOENGINEERING

Module
4

SPECIALIZATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT



Module 4 — Geographic Information Systems (GIS) for Soil and Water Bioengineering

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

Module 4: Geographıc Informatıon Systems for Soıl and Water Bıoengıneerıng

Editors:

George N. ZAIMES and Valasia IAKOVOGLOU

Department of Forestry and Natural Environment Management - Eastern Macedonia and Thrace Institute of Technology (EMaTTech)

September, 2018

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FIGURES

Module 4 | GIS for Bioengineering

1. MODULE DESCRIPTOR

Status: Core

Credit Points (ECTS): 3

Pre-requisite knowledge: NA

Module structure:

Activity	Total Hours
Lectures	20
Tutorials	10
Seminars	2
Practical	10
Independent learning	30
Assessment	3
Total	3 ECTS - (1ECTS=25hrs)

Table 1 Module structure

Summary of module content:

Geographic Information Systems (GIS):

Today, GIS is being used to map and analyze data in numerous scientific fields including environmental studies. This part of the module will introduce students to the basics of Geographical Information Systems (GIS) and how to utilize GIS tools in soil and water bioengineering. Environmental applications require utilizing a specific set of skills of the GIS science. Specifically, the students will be expected to manage real-world scenarios by learning foundation concepts such as digital data, scale and map projections, afterwards utilizing operations such as inputting and storing data, creating maps and analyzing geographic problems, and finally effectively communicating these results. Through this knowledge and exercises, students will understand and appreciate how utilizing GIS toolsets can help in the more effective development and implementation of soil and water bioengineering (SWB) techniques in the field.

LEARNING OUTCOMES:

On successful completion of this module students should be able to:

Geographic Information Systems (GIS) outcomes:

LO1. Learn the theory behind cartographic mapping and modeling.

LO2. Knowledge on some of the most important tools in GIS.

LO3. Become competent in the use of one GIS software program.

LO4. Complete a hands-on mapping project.

LO5. Analyze and critically interpret primary and secondary data.

LO6. Understand GIS concepts in an interdisciplinary setting.

LO7. Implement methods used to analyze remotely sensed SWB data.

LO8. Demonstrate ability to utilize GIS to design and implement more efficient soil and water bioengineering works

Other General outcomes:

LO9. Communicate: participate in group discussion, undertake and present scientific writing

LO10. Manage: safe and effective project planning and execution; time management

LO11. Work in group and learn to utilize each member's skills

LO12. Develop problem-solving abilities, practical competencies, critical appraisal and written and oral communication skills.

Teaching/Learning strategy:

Teaching will follow novel methods derived through the ECOMED project: lectures for imparting fundamentals of module and tutorials and practicals for the application of the fundamentals. These will be supplemented with virtual learning content, case study analysis, site visits and work placements.

Other learning and teaching strategies will be developed and implemented, appropriate to student needs to enable all students to participate fully in the module.

Module 4 | **GIS for Bioengineering**

Syllabus:

TOPIC 1 - GEOGRAPHIC INFORMATION SYSTEMS (GIS)

1.1. GIS Basics and Principles

1.2. Structure of Geographical Data

1.3. QGIS – A free and open-source cross-platform

1.4. Find and Share Environmental Data

1.5. Utilizing GPS data

1.6. Design maps to communicate analysis results

1.7. Soil and Water Bioengineering scenario using GIS

1.8. Project presentation

Indicative reading:

Geographic Information Systems (GIS)

Scally, R. 2006. GIS for Environmental Management, ESRI Press, pp. 156.

Wegmann, M.,Leutner, B., Dech, S. (Eds). 2016. Remote Sensing and GIS for Ecologists (Data in the Wild). Pelagic Publishing, pp. 324.

Rosenberg, M.J. 2015. GIS For Biologists: A Practical Introduction for Undergraduates. Pictish Beast Publications, pp. 352.

Zhu, X. 2016. GIS for Environmental Applications: A practical approach. Routledge, pp.490.

Wise, S. 2013. GIS Fundamentals. Routledge, pp.338.

Bruy, A., Svidzinska, D. 2016. QGIS By Example. Packt Publishing, pp.316.

McCartney M.T., Freeman, N. 2014. Getting Started With GIS Using QGIS. CreateSpace Independent Publishing Platform, pp. 134.

Menke, K., Smith R.Jr., Pirelli L., Van Hoesen, J., 2016. Mastering QGIS. Packt Publishing, pp.486.

Transferable skills development:

Setting personal targets and time management will help student become more organized and efficient.

Learning skills will be enhanced by use of open-source information and IT skills to research and collate information for actual case studies.

Communication skills will be enhanced by requiring the use of appropriate language when writing and speaking to fulfill assignments and when making presentations in seminars.

Group-work skills will be developed to address case study problems including the taking of initiative and assuming responsibility in carrying out agreed tasks.

Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Coursework	40	10	50	Attendance, in class exercises
Homework	12	30	50	Weekly Homework Assignments
Practical	20	30	50	Team Project (write up and presentation)
Exam	3	30	50	Final Exam
Total	75	100	50	

Table 2 Assessment methods

Module contacts:

Module leader: George N. Zaimes

Module tutor (academic): Valasia IAKOVOGLOU, Dimitrios EMMANOULOUDIS

Module tutor (industry): Michael XINOGALOS

2. GEOGRAPHIC INFORMATION SYSTEMS

A geographic information system (GIS) is a spatial framework to gather, manage, and analyze data. It originates from the scientific field of geography. GIS has the ability to analyze spatial locations and organize layers of information into visualizations using maps and 3D scenes while integrating many types of data. T his unique capability, allows a user to better understand the data, by seeing patterns, relationships, and situations. This way, smarter and science based decisions can be made in regard to environmental management including soil and water bioengineering. The user-friendly visual representation also makes it attractive to decision makers, stakeholders and the general public. In general GIS can be used to: a) identify problems, b) monitor changes, c) manage and respond to events, d) perform forecasting, e) set priorities and f) understand trends.

The main components of a GIS are the:

- **Digital Data** — the geographical information that will be viewed and analysed using computer hardware and software.
- **Computer Hardware** — computers used for storing data, displaying graphics and processing data.
- **Computer Software** — computer programs that run on the computer hardware and allow you to work with digital data. A software program that forms part of the GIS is called a GIS Application.

With a GIS application you can open digital maps on your computer, create new spatial information to add to a map, create printed maps customised to your needs and perform spatial analysis.

2.1 Vector data, raster data, projection systems

2.1.1 Vector data

Vector data can represent real world features within the GIS environment. A feature is anything you can identify on the landscape. For example you are looking down from the top of a hill. From this location you can see rivers, roads, houses, trees and other characteristics (see Figure 1.1). Each one of these objects would be a feature when represented in a GIS Application. Vector features typically consist of text or numerical information that describe these features that are called attributes.

To represent a vector feature as a shape, geometry is utilized. The geometry is made up of one or more interconnected vertices. A vertex describes a position in space utilzing typically a X, Y and optionally Z axis. When the vertices also include a Z axis their geometries are often referred to as 2.5D. The reason is because they describe height or depth at each vertex, but not both.

When a feature's geometry consists of only one single vertex, it is referred to as a point feature (see Figure 1.2). Where the geometry consists of two or more vertices and the first and the last vertex are not equal, a polyline feature is formed (see Figure 1.2). Where three or more vertices are present, and the last vertex is equal to the first, an enclosed polygon feature is formed (see Figure 1.3).

Figure 2.1 Landscape picture

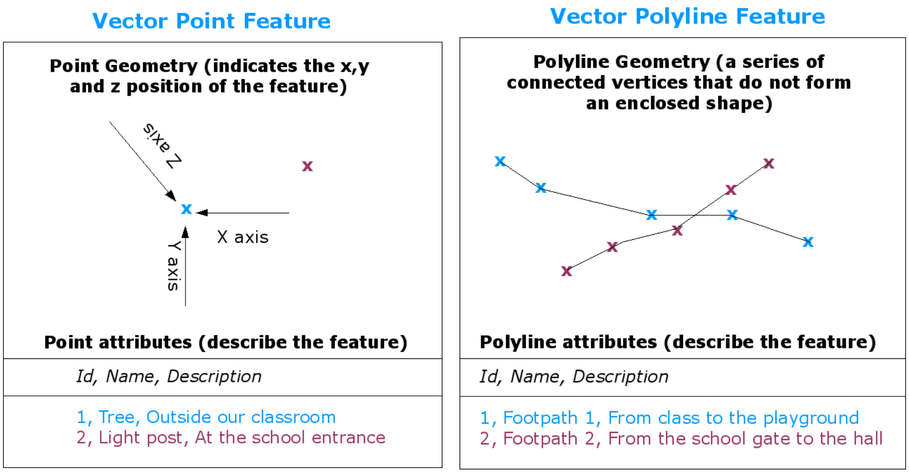


Figure 2.2 Vector Geometries – Points and Lines
(source: https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/vector_data.html)

A point feature is described by its X, Y and optionally Z coordinate. The point attributes describe the point that can be a tree, shrub, sign or lamp post. A polyline is a sequence of joined vertices. Each vertex has an X, Y (and optionally Z) coordinates. Attributes describe the polyline. A polygon, like a polyline, is a sequence of vertices. However in a polygon, the first and last vertices are always at the same position. Looking back at the landscape picture

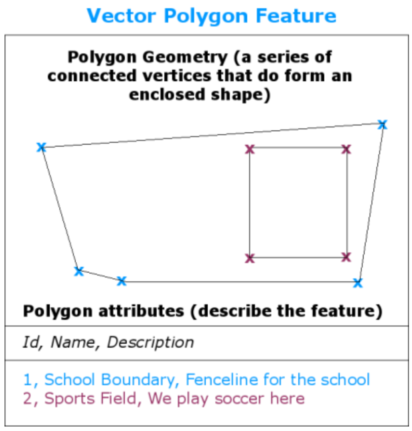


Figure 2.3 Vector Geometries – Polygon Features
(source: https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/vector_data.html)

presented earlier, you should be able to see the different types of features in the way that a GIS represents them now (see Figure 1.4). In this new image the featurs of the landscape can be seen as presented in a GIS environment. Specifically the rivers (blue) and roads (green) can be represented as polylines, trees as points (red) and houses as polygons (white).

The scale plays a very important role in what we describe as a point feature in GIS while in many cases it is also a matter of opinion. For example on a small scale map (covers a large area), a city can be represented as a point feature with GIS. However if you increase the scale

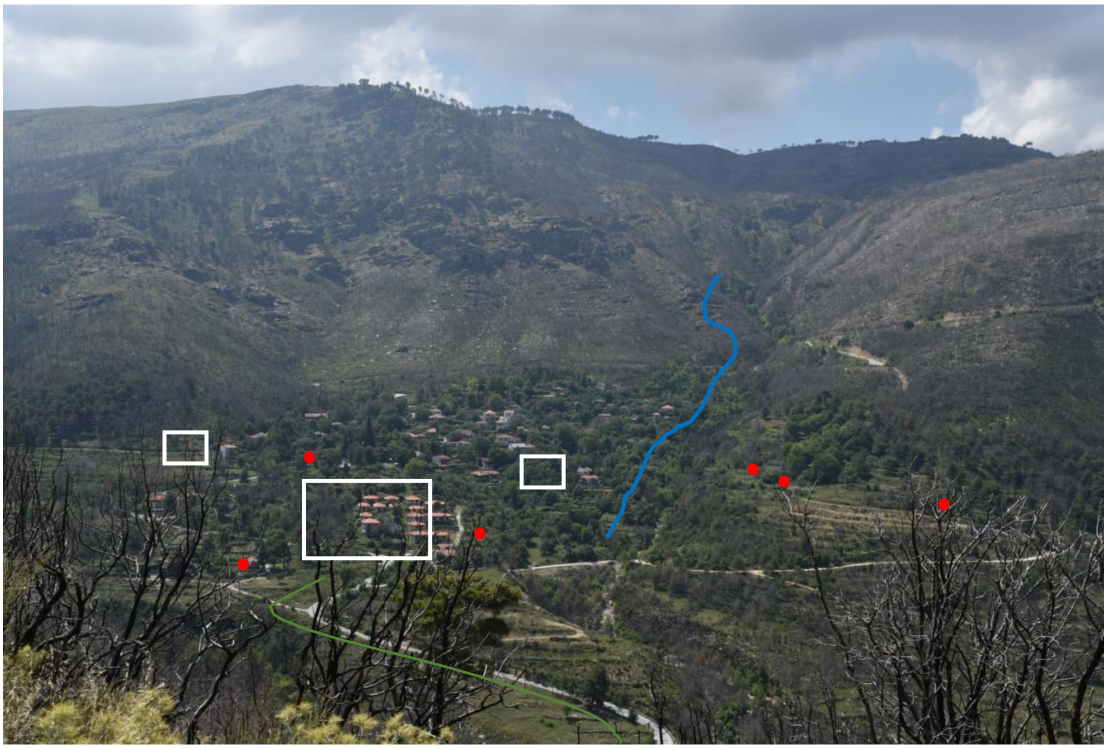

1.4

Figure 2.4 Landscape picture through a GIS perspective, points (red dots – trees), lines (blue line river, red line – road) and polygons (white rectangle – house) (zooming in onto the map), it is more likely to represent the city limits as a polygon. If you zoom in even more (increase more the scale) the houses could be represented as a polygon. Overall when choosing to use points to represent a feature it is mostly a matter of scale (how far away are you from the feature), convenience (it takes less time and effort to create point features than polygon features), and the type of feature (some things like telephone poles or tree just don't make sense to be stored as polygons). A point feature has an X, Y and optionally, Z value. The X and Y values will depend on the Coordinate Reference System (CRS) being used. One of the most common reference systems is Longitude and Latitude. Lines of Longitude run from the North Pole to the South Pole. Lines of Latitude run from the East to West. You can describe precisely where you are at any place on the earth by giving someone your Longitude (X) and Latitude (Y). If you make a similar measurement for a tree or a telephone pole and marked it on a map, you will have created a point feature. Finally, the Z value is important to add in a point feature since the earth is not flat and describes the elevation above sea level.

The main difference of a polyline feature with a point feature (single vertex) is that it has two or more vertices. The polyline is a continuous path drawn through each vertex (see Figures 1.2 and 1.4). When two vertices are joined a line is created. When more than two vertices are joined, they form a 'line of lines', or polyline. A polyline is used to show the geometry of linear features such as roads, rivers, contours, footpaths, flight paths and so on. Sometimes we have special rules for certain polylines in addition to their basic geometry. For example contour lines may touch (e.g. at a cliff face) but should never cross over each other. In contrast, polylines used to represent a road or a river network should be connected at intersections. In some GIS applications you can set these special rules for a feature type (e.g. roads) and the GIS will ensure that these polylines always comply with these rules. If a curved polyline has very large distances between vertices, it may appear angular or jagged, depending on the scale at which it is viewed (see Figure 1.5). Because of this it is important that polylines are digitized (captured into the computer) with distances between vertices that are small enough for the scale at which you want to use the data. In Figure 1.5 the polylines viewed at a smaller scale (1:20 000 to the left) appear smooth and curved while the same polylines when viewed at larger scale (1:500 to the right) look very angular. Depending on the accuracy you need for your project, the polyline feature you can digitize these lines at different scales. The attributes of a polyline describe its properties or characteristics. For example a road polyline may have

Figure 2.5 Jagged Polyline
(source: https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/vector_data.html)

attributes that describe whether it is surfaced with gravel or tar, how many lanes it has, whether it is a one way street, and so on. The GIS can use these attributes to symbolize the polyline feature with a suitable color or line style.

Polygon features are enclosed areas like dams, forest stands, lakes, islands, and town, prefect and country boundaries and so on. Like polyline features, polygons are created from a series of vertices that are connected with a continuous line. The polygon always describes an enclosed area that means that the first and last vertices are always at the same place (they meet). Polygons often have shared geometry/boundaries that are in common with a neighboring polygon (e.g. neighboring countries or counties). There are GIS applications that can ensure that the boundaries of neighboring polygons exactly coincide. Finally polygons also have attributes similar to points and polylines. The attributes describe each polygon and provide additional useful information. For example a dam may have attributes for depth and water quality while a forest stand on what type of vegetation it has.

Following we will study how vector data are managed and used in a GIS environment. Most GIS applications group vector features into layers. Features in a layer have the same geometry type (e.g. they will all be points) and the same kinds of attributes (e.g. information about what species a tree is for a trees layer). For example if you have recorded the positions of all the footpaths in your school, they will usually be stored together on the computer hard disk and shown in the GIS as a single layer. This is convenient because it allows you to hide or show all of the features for that layer in your GIS application with a single mouse click.

The vector data are stored in GIS as a layer. The process that allows you to create and/or modify the geometry data of a layer is called digitizing. If a layer contains polygons (e.g. forests, dams) the GIS application will only allow you to create new polygons in that layer. Similarly if you want to change the shape of a feature, the application will only allow you to do it if the changed shape is correct. For example it won't allow you to edit a line in such a way that it has only one vertex.

Overall, creating and editing vector data is an important function of a GIS since it is one of the main ways in which you can create personal data for things you are interested in. Say for example you are monitoring pollution in a river. You could use the GIS to digitize all storm water drains (as point features) that end in the river. You could also digitize the river itself (as a polyline feature). Finally you could take readings of pH levels along the course of the river and digitize the places where you made these readings (as a point layer) and indicate the different levels of pH along the river course.

Map scale is an important issue to consider when working with vector data in a GIS. When data is captured, it is usually digitized from existing maps, or by taking information from surveyor records and global positioning system (GPS) devices. Maps have different scales depending on the area of interest, so if you import vector data from a map into a GIS environment (for example by digitizing paper maps), the digital vector data will have the same scale issues as the original map. This effect can be seen in Figures 1.6 and 1.7. Many issues can arise from making a poor choice of map scale. For example using the vector data in Figure 1.5 to plan a wetland conservation area could result in important parts of the wetland being left out of the reserve! On the other hand if you are trying to create a regional map, using data captured at 1:1,000,000 might be just fine and will save you a lot of time and effort for capturing the data that eventually you not utilize. Digitizing can be very time consuming at large scale maps.

The vector layers you create or add to the map view in a GIS application will be drawn with random colors and basic symbols. One of the great advantages of using a GIS is that you can create personalized maps very easily. Specifically the GIS program will let you choose colors to suite the feature type (e.g. you can tell it to draw water bodies vector layer in blue). The GIS will also let you adjust the symbol used. So if you have a tree as a point layer, you can show each tree position with a small picture of a tree, rather than the basic circle marker that the GIS uses when you first load the layer (see Figure 1.8). This symbology is a powerful feature, which makes maps come to life and the data in your GIS easier to understand for policy-makers, stakeholders and the general public.

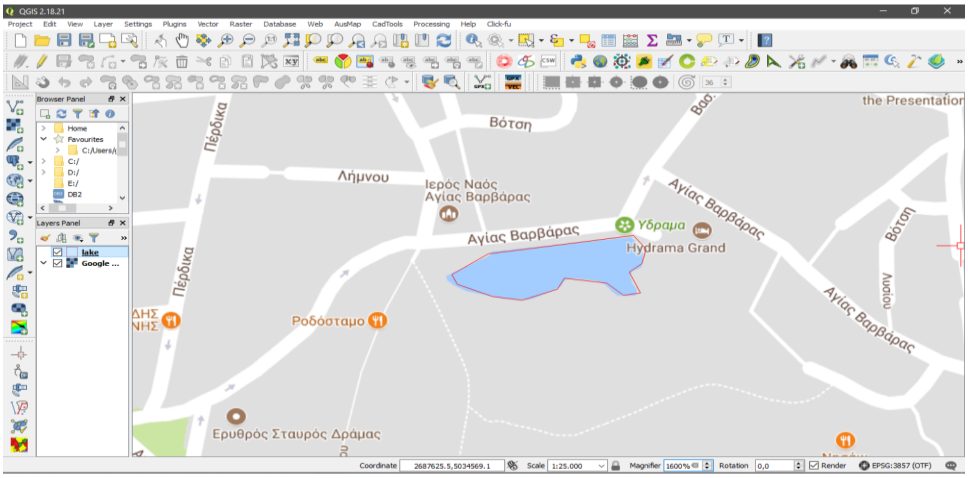


Figure 2.6 Digitized Vector at a small scale. In this case the vector data (red lines) was digitized from a small scale (1:1000 000)

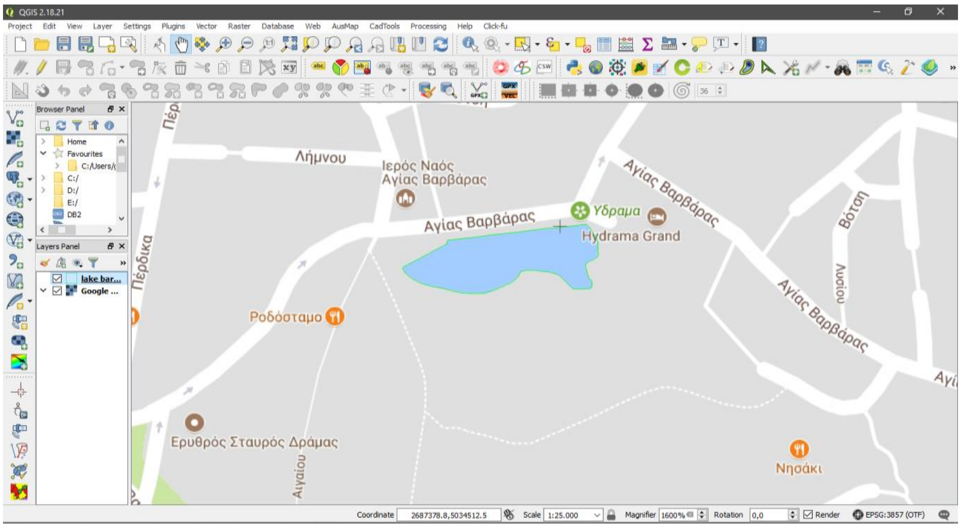


Figure 2.7 Digitized Vector at a large scale. In this case the vector data (green lines) was digitized from a large scale (1:50 000) map

Vector data have as described above many advantage but if not careful could also have some problems. Firstly as already mentioned, issues can arise with vectors captured at different scales. Vector data also needs a lot of work and maintenance to ensure that it is accurate and reliable. Inaccurate vector data can occur when the instruments used to capture the data are not properly set up, when the people capturing the data aren't being careful (digitization), when time or money don't allow for enough detail in the collection process, and so on. If you have poor quality vector data, you can often detect this when viewing the data in a GIS. For example slivers can occur when the edges of two polygon areas don't meet properly (see Figure 1.9). These slivers occur when the vertices of two polygons do not match up on their borders. At a small scale (e.g. 1 on the left) you may not be able to see these errors. At a large scale they are visible as thin strips between two polygons (2 on the right).

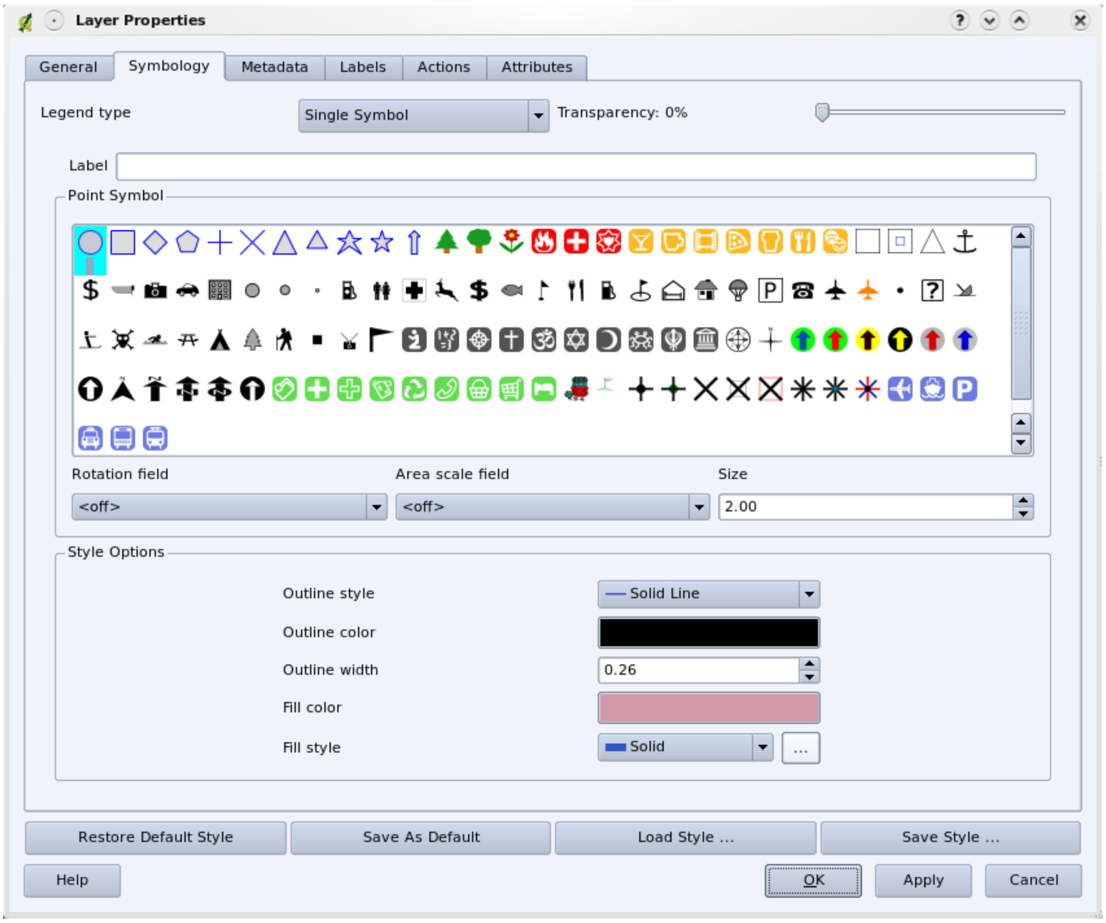


Figure 2.8 Vector Symbology. In GIS, you can use a panel (like the one above) to adjust how features in your layer should be drawn.

Vector data have as described above many advantage but if not careful could also have some problems. Firstly as already mentioned, issues can arise with vectors captured at different scales. Vector data also needs a lot of work and maintenance to ensure that it is accurate and reliable. Inaccurate vector data can occur when the instruments used to capture the data are not properly set up, when the people capturing the data aren't being careful (digitization), when time or money don't allow for enough detail in the collection process, and so on. If you have poor quality vector data, you can often detect this when viewing the data in a GIS. For example slivers can occur when the edges of two polygon areas don't meet properly (see Figure 1.9). These slivers occur when the vertices of two polygons do not match up on their borders. At a small scale (e.g. 1 on left) you may not be able to see these errors. At a large scale they are visible as thin strips between two polygons (2 on right).

Another common problem in vector data are overshoots and undershoots. Overshoots can occur when a line feature such as a road does not meet another road exactly at an intersection. Specifically overshoots happen if a line ends beyond the line it should connect to. Undershoots can occur when a line feature (e.g. a river) does not exactly meet another feature to which it should be connected. Specifically undershoots occur when digitized vector lines that should connect to each other don't quite touch. Figure 1.10 demonstrates what undershoots and overshoots look like. Because of these types of errors, it is very important to digitize data carefully and accurately.

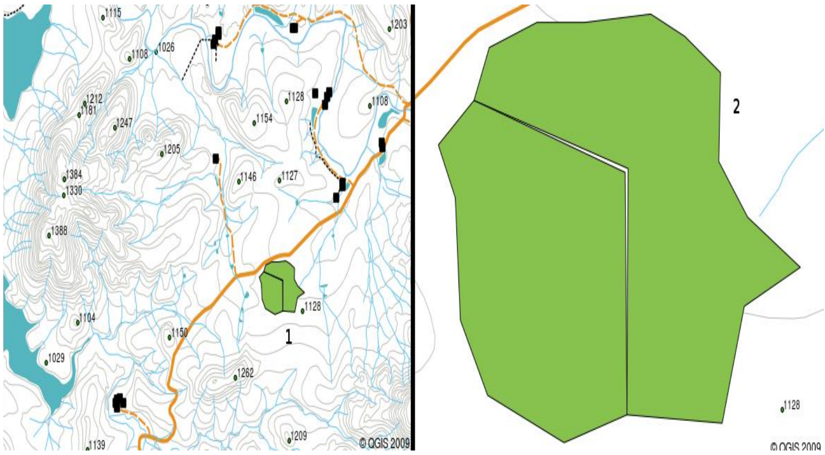


Figure 2.9 Vector slivers can be seen better as the scale increases (right image) (source: https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/vector_data.html)

Figure 2.10 Vector problems include undershoots (seen in line 1) and overshoots (seen in line 2) (source: https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/vector_data.html)

Now let's recap what was covered in this section:

- Vector data is used to represent real world features in a GIS.
- A vector feature can have a geometry type of point, line or a polygon.
- Each vector feature has attribute data that describes it.
- Feature geometry is described in terms of vertices.
- Point geometries are made up of a single vertex (X,Y and optionally Z).
- Polyline geometries are made up of two or more vertices forming a connected line.
- Polygon geometries are made up of at least four vertices forming an enclosed area. The first and last vertices are always in the same place.
- Choosing which geometry type to use depends on scale, convenience and what you want to do with the data in the GIS.
- Most GIS applications do not allow you to mix more than one geometry type in a single layer.

- Digitizing is the process of creating digital vector data by drawing it in a GIS application.
- Vector data can have quality issues such as undershoots, overshoots and slivers which you need to be aware of and corrected.
- Vector data can be used for spatial analysis in a GIS application, for example to find the nearest hospital to a school.

2.1.2 Raster data

Raster is another frequently representation of data in GIS. While vector features use geometry (points, polylines and polygons) to represent the real world, raster data takes a different approach. Rasters are made up of a matrix of pixels (also called cells), each containing a value that represents the conditions for the area covered by that cell (see Figure 1.11). In this chapter we focus on raster data and especially on when it is useful and when it makes more sense to use them instead of vector data. Typically a raster dataset is composed of rows (running across) and columns (running down) of pixels (also known as cells). Each pixel represents a geographical region, and the value in that pixel represents some characteristic of that region.

Raster data are used in a GIS application when we want to display information that is continuous across an area and cannot easily be divided into vector features. When describing vector data we showed you the image in Figure 1.1. Point, polyline and polygon features work well for representing some features on this landscape, such as trees, roads and buildings. Other features on a landscape can be more difficult to represent using vector features. For example the grasslands shown have many variations in color and density of cover. It would be easy enough to make a single polygon around each grassland area, but a lot of the information about the grassland would be lost in the process of simplifying the features to a single polygon. This is because when you give a vector feature attribute values, they apply to the whole feature. This indicates that vectors aren't very good at representing features that are not homogeneous (entirely the same) all over. Another approach you could take is to digitize every small variation of grass color and cover as a separate polygon. The problem with that approach is that it will take a huge amount of work and money in order to create a good vector dataset. In cases when representing large areas with continuously changing values, raster data can be a better choice than vector.

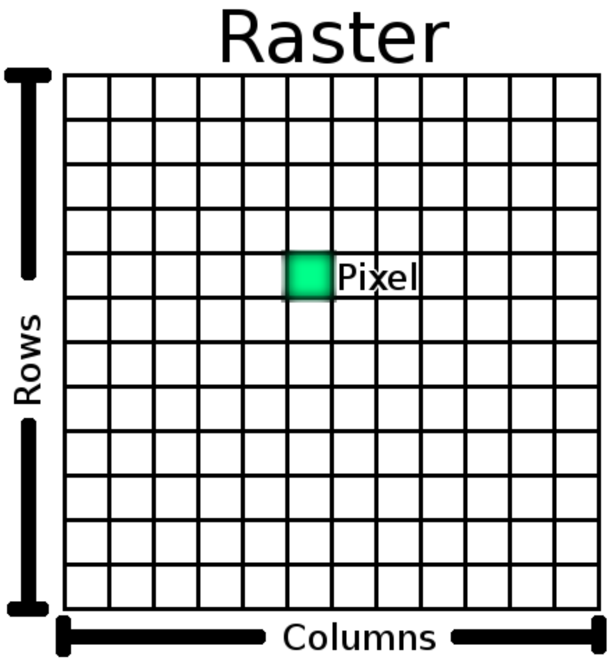


Figure 2.11 Raster general content
(source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/raster_data.html)

Many people use raster data as a backdrop to be used behind vector layers in order to provide more meaning to the vector information. The human eye is very good at interpreting images and so using an image behind vector layers, results in maps with a lot more meaning. Raster data is not only good for images that depict the real world surface (e.g. satellite images and aerial photographs); they are also good for representing more abstract ideas. For example, raster data can be used to show rainfall trends over an area, or to depict the flood risk on a landscape. In these kinds of applications, each cell in the raster represents a different value e.g. risk of flood on a scale of one to ten. An example that shows the difference between an image obtained from a satellite and one that shows calculated values can be seen in Figure 1.12. True color raster images are useful as they provide a lot of detail that is hard to capture as vector features but easy to see when looking at the raster image. Raster data can also be non-photographic data such as the raster layer shown on the right (see Figure 1.12) which shows the calculated average minimum temperature in the Western Cape for the month of March.

Georeferencing is the process of defining exactly where on the earth's surface an image or raster dataset was created. This is an essential process when working with data in GIS programs. This positional information is stored with the digital version of the aerial photo. When the GIS application opens the photo, it uses the positional information to ensure that the photo appears in the correct place on the map. Normally this positional information consists of a coordinate for the top left pixel in the image, the size of each pixel in the X direction, the size of each pixel in the Y direction, and the amount (if any) by which the image is rotated. With these few pieces of information, the GIS application can ensure that raster data are displayed in the correct place. The georeferencing information for a raster is often provided in a small text file accompanying the raster.

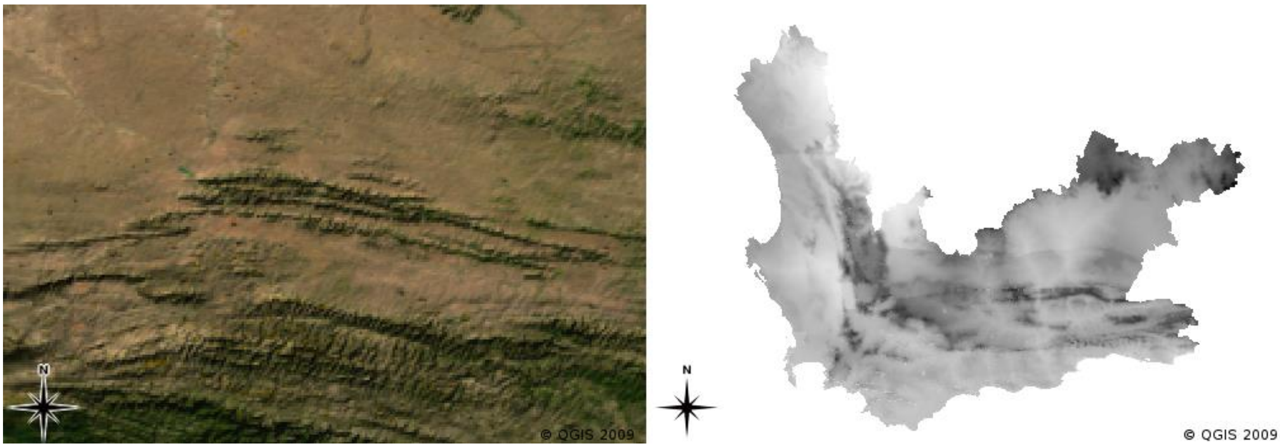


Figure 2.12 Raster types. Raster data can be from color images (left) but also non non-photographic data (source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/raster_data.html)

Raster data can be obtained in a number of ways. Two of the most common ways are aerial photography and satellite imagery. In aerial photography, an airplane flies over an area with a camera mounted underneath it. The photographs are then imported into a computer and georeferenced. Satellite imagery is created when satellites orbiting the earth point special digital cameras towards the earth and then take an image of the area on earth they are passing over. Once the image has been taken it is sent back to earth using radio signals to special receiving stations such as the one shown in Figure 1.13. These stations have special antennae track satellites as they pass overhead and download images using radio waves. The process of capturing raster data from an airplane or satellite is called remote sensing.

In other cases, raster data can be computed. For example meteorologists might generate a province level raster showing average temperature, rainfall and wind direction using data collected from weather stations (see right image in Figure 1.13). In these cases, they will often use raster analysis techniques such as interpolation.

Sometimes raster data are created from vector data because the data owners want to share the data in an easy to use format. For example, a company with road, rail, cadastral and other vector datasets may choose to generate a raster version of these datasets so that employees can view these datasets in a web browser. This is normally only useful if the attributes, that users need to be aware of, can be represented on the map with labels or symbology. If the user needs to look at the attribute table for the data, providing it in raster format could be a bad choice because raster layers do not usually have any attribute data associated with them.

Every raster layer in a GIS has pixels (cells) of a fixed size that determine its spatial resolution. This becomes apparent when you look at an image at a small scale (see Figure 1.14) and then zoom into a large scale (see Figure 1.15). This satellite image looks good when using a small scale, but when viewed at a large scale you can see the individual pixels that the image is composed of.

Figure 2.13 The CSIR Satellite Applications Center at Hartebeeshoek in North West Province, South Africa used to collect satellite data (source: Leo za1)

Several factors determine the spatial resolution of an image. For remote sensing data, spatial resolution is usually determined by the capabilities of the sensor used to take an image. For example SPOT5 satellites can take images where each pixel is 10 m x 10 m. Other satellites, for example MODIS take images only at 500 m x 500 m per pixel. In aerial photography, pixel sizes of 50 cm x 50 cm are not uncommon. Images with a pixel size covering a small area are called 'high resolution' images because it is possible to make out a high degree of detail in the image. Images with a pixel size covering a large area are called 'low resolution' images because the amount of detail the images show is low.

In raster data that is computed by spatial analysis (such as the rainfall map we mentioned earlier), the spatial density of information used to create the raster will usually determine the spatial resolution. For example if you want to create a high resolution average rainfall map, you would ideally need many weather stations in close proximity to each other.

One of the main things to be aware of with rasters captured at a high spatial resolution is storage requirements. Think of a raster that is 3 x 3 pixels, each of which contains a number representing average rainfall. To store all the information contained in the raster, you will need to store 9 numbers in the computer's memory. Now imagine you want to have a raster layer for the whole of Spain with pixels of 1 km x 1 km. Spain is around 643.801 km ^{2} which means your computer would need to store over a 600 hundred thousand numbers on its hard disk in order to hold all of the information. Making the pixel size smaller would greatly increase the amount of storage needed. In contrast increasing the pixel size would reduce the storage needed but would a decrease in the detail provided.

Sometimes using a low spatial resolution is useful when you want to work with a large area and are not interested in looking at any one area in a lot of detail. The cloud maps you see on the weather report, are an example of this — it's useful to see the clouds across the whole country. Zooming in to one particular cloud in high resolution will not tell you very much about the upcoming weather.

On the other hand, using low resolution raster data can be problematic if you are interested in a small region because you probably won't be able to make out any individual features from the image.

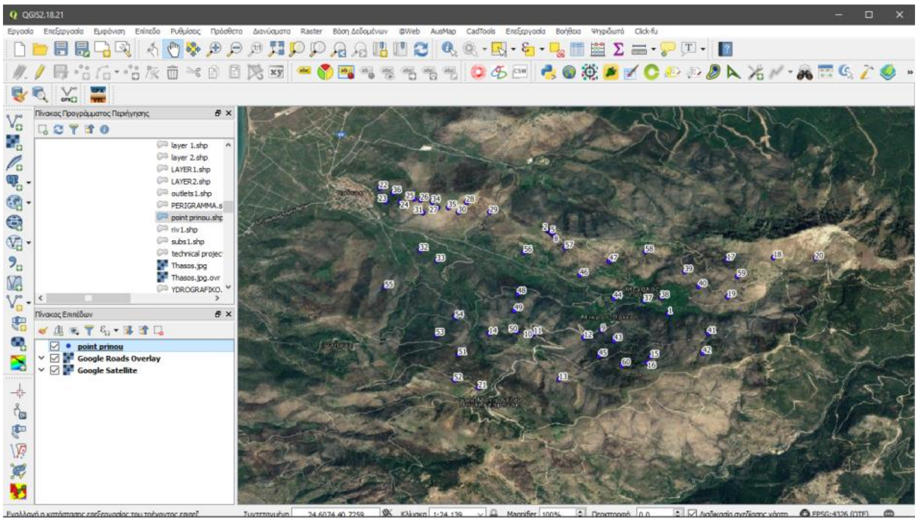


Figure 2.14 Raster data at a small scale

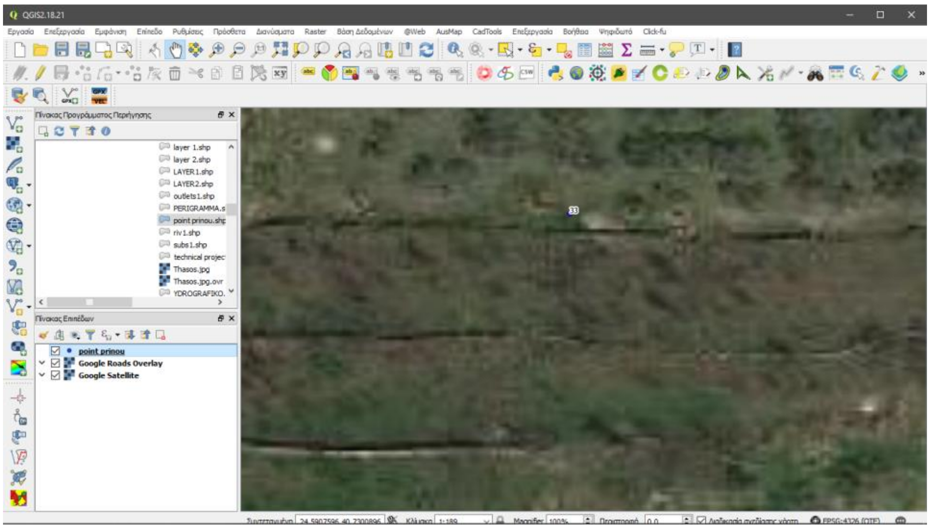


Figure 2.15 Raster data at a large scale

A major advantage of raster data is that there are a great many analytical tools that can be run on raster data which cannot be used with vector data. For example, rasters can be used to model water flow over the land surface (e.g. ArcSWAT). This information can be used to calculate where watersheds and stream networks exist, based on the terrain. Raster data are also often used in agriculture and forestry to manage crop production. For example with a satellite image of a farmer's lands, you can identify areas where the plants are growing poorly and then use that information to apply more fertilizer on the affected areas only. Foresters use raster data to estimate how much timber can be harvested from an area.

Raster data is also very important for disaster management. Analysis of Digital Elevation Models (a kind of raster where each pixel contains the height above sea level) can be used to identify areas that are likely to be flooded. This can then be used to target rescue and relief efforts to areas where it is needed the most and be more efficient and cost-effective.

Now let's recap what was covered in this section:

- Raster data are a grid of regularly sized pixels.
- Raster data are good for showing continually varying information.
- The size of pixels in a raster determines its spatial resolution.
- The size of pixels in a raster determines the detail of the information of the raster layer.
- Raster images can consume a large amount of storage space.
- The best size of the pixel depend on the scale of the area that we are interested.
- Raster data can be used to support watershed, forest and disaster management.

2.1.3 Projection systems

Map projections try to portray the surface of the earth or a portion of the earth on a flat piece of paper or computer screen. A coordinate reference system (CRS) then defines, with the help of coordinates, how the two-dimensional, projected map in your GIS is related to real places on the earth. The decision as to which map projection and coordinate reference system to use, depends on the regional extent of the area you want to work in, on the analysis you want to do and often on the availability of data.

A traditional method of representing the earth's shape is the use of globes. The problem with globes are that while they preserve the majority of the earth's shape and illustrate the spatial configuration of continent-sized features, they are very difficult to carry in one's pocket. They are also only convenient to use at extremely small scales (e.g. 1:100,000,000).

Most of the thematic map data commonly used in GIS applications are of considerably larger scale. Typical GIS datasets have scales of 1:250,000 or greater, depending on the level of detail. A globe of this size would be difficult and expensive to produce and even more difficult to carry around. As a result, cartographers have developed a set of techniques called map projections designed to show, with reasonable accuracy, the spherical earth in two-dimensions.

When viewed at close range the earth appears to be relatively flat. However when viewed from space, we can see that the earth is relatively spherical. Maps, as we will see in the upcoming map production topic, are representations of reality. They are designed to not only represent features, but also their shape and spatial arrangement. Each map projection has advantages and disadvantages. The best projection for a map depends on the scale of the map, and on the purposes for which it will be used. For example, a projection may have unacceptable distortions if used to map the entire South American continent, but may be an excellent choice for a large-scale (detailed) map of your country. The properties of a map projection may also influence some of the design features of the map. Some projections are good for small areas, some are good for mapping areas with a large East-West extent, and some are better for mapping areas with a large North-South extent.

The process of creating map projections can be visualized by positioning a light source inside a transparent globe on which opaque earth features are placed. Then project the feature outlines onto a two-dimensional flat piece of paper. Different ways of projecting can be produced by surrounding the globe in a cylindrical fashion, as a cone, or even as a flat surface. Each of these methods produces what is called **a** map projection family. Therefore, there is a family of planar or azimuthal projections, a family of cylindrical projections, and another called conical projections (see Figure 1.16).

Today, of course, the process of projecting the spherical earth onto a flat piece of paper is done using the mathematical principles of geometry and trigonometry that recreate the physical projection of light through the globe.

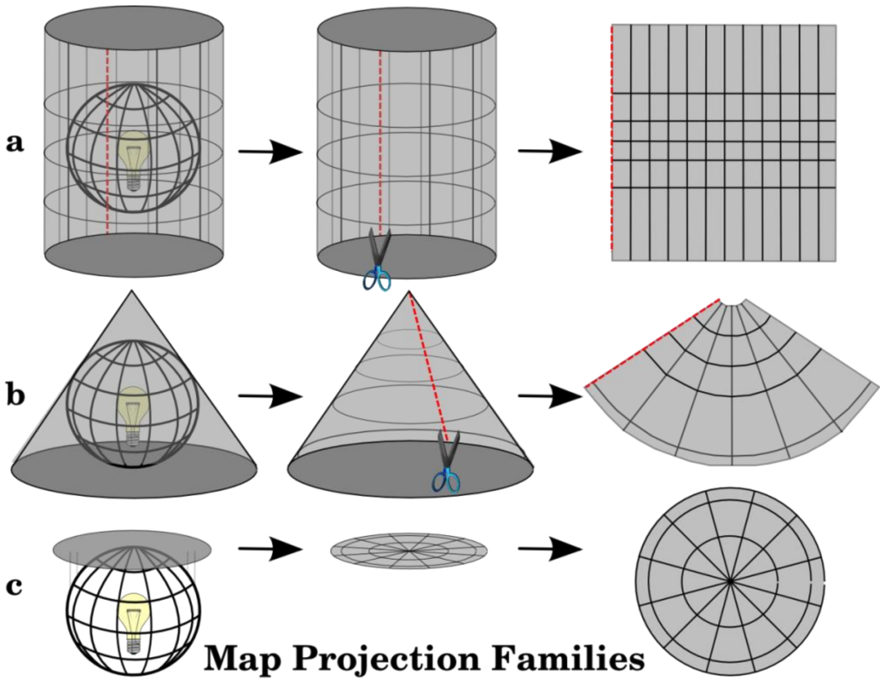


Figure 2.16 The three families of map projections are: a) cylindrical, b) conical and c) planar or azimuthal (source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/coordinate_reference_systems.html)

Map projections are never absolutely accurate representations of the spherical earth. As a result of the map projection process, every map shows distortions of angular conformity, distance and area. A map projection may combine several of these characteristics, or may be a compromise that distorts all the properties of area, distance and angular conformity, within some acceptable limit. Examples of a compromise projection is the Robinson projection (see Figure 1.17), which is often used for world maps.

It is usually impossible to preserve all characteristics at the same time in a map projection. This means that when you want to carry out accurate analytical operations, you need to use a map projection that provides the best characteristics for your analyses. For example, if you need to measure distances on your map, you should try to use a map projection for your data that provides high accuracy for distances.

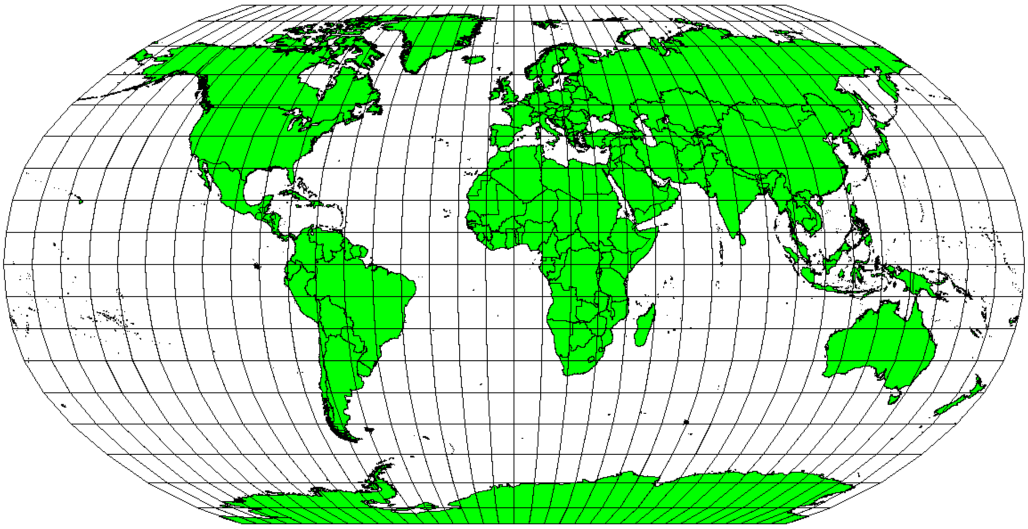


Figure 2.17 The Robinson projection is a compromise where distortions of area, angular conformity and distance are acceptable
(source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/coordinate_reference_systems.html)

When working with a globe, the main directions of the compass rose (North, East, South and West) will always occur at 90 degrees to one another. In other words, East will always occur at a 90 degree angle to North. Maintaining correct angular properties can be preserved on a map projection as well. A map projection that retains this property of angular conformity is called a conformal or orthomorphic projection.

These projections are used when the preservation of angular relationships is important. They are commonly used for navigational or meteorological tasks. It is important to remember that maintaining true angles on a map is difficult for large areas and should be attempted only for small portions of the earth. The conformal type of projection results in distortions of areas, meaning that if area measurements are made on the map, they will be incorrect. The larger the area the less accurate the area measurements will be. Examples are the Mercator projection (see Figure 1.18) and the Lambert Conformal Conic projection. The Mercator projection, is used where angular relationships are important, but the relationship of areas are distorted. The U.S. Geological Survey uses a conformal projection for many of its topographic maps.

If your goal in projecting a map is to accurately measure distances, you should select a projection that is designed to preserve distances well. Such projections, called equidistant projections, require that the scale of the map is kept constant. A map is equidistant when it correctly represents distances from the center of the projection to any other place on the map. Equidistant projections maintain accurate distances from the center of the projection or along given lines. These projections are used for radio and seismic mapping, and for navigation. The Plate Carree Equidistant Cylindrical (see Figure 1.19) and the Equirectangular projection are two good examples of equidistant projections. The Plate Carree Equidistant Cylindrical projection, is used when accurate distance measurement is important.

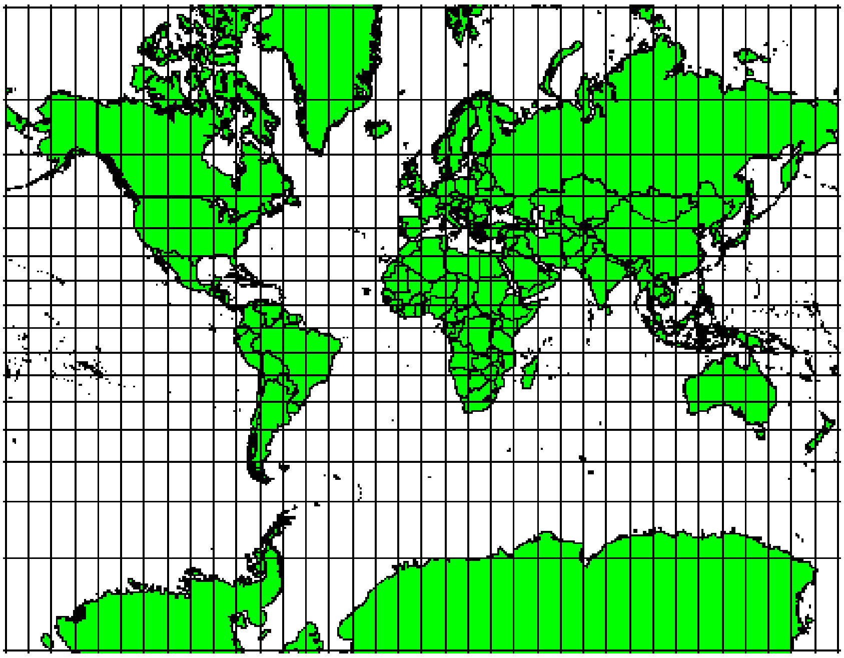


Figure 2.18 The Mercator Projection
(source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/coordinate_reference_systems.html)

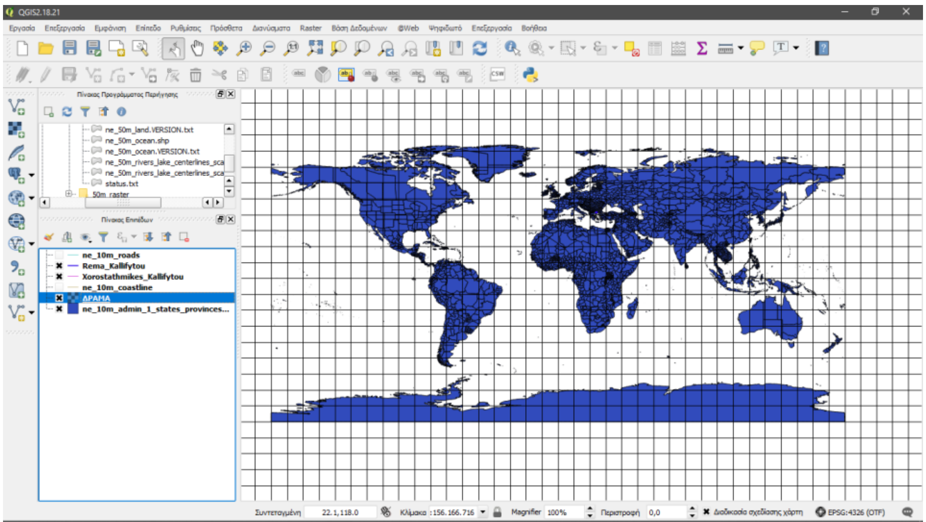


Figure 2.19 The Plate Carree Projection

When a map portrays areas over the entire map, so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an **equal area map**. In practice, general reference and educational maps most often require the use of **equal area projections**. As the name implies, these maps are best used when calculations of area are the dominant calculations you will perform. If, for example, you are trying to analyses a particular area in your town to find out whether it is large enough for a new shopping mall, equal area projections are the best choice. On the one hand, the larger the area you are analyzing, the more precise your area measures will be, if you use an equal area projection rather than another type. On the other hand, an equal area projection results in** distortions of angular conformity** when dealing with large areas. Small areas will be far less prone to having their angles distorted when you use an equal area projection. Alber's equal area, Lambert's equal area and Mollweide Equal Area Cylindrical projections (shown in Figure 1.120) are types of equal area projections that are often encountered in GIS work. The Mollweide Equal Area Cylindrical projection ensures that all mapped areas have the same proportional relationship to the areas on the Earth.

Keep in mind that map projection is a very complex topic. There are hundreds of different projections available worldwide each trying to portray a certain portion of the earth's surface as faithfully as possible on a flat piece of paper. In reality, the choice of which projection to use, will often be made for you. Most countries have commonly used projections and when data is exchanged people will follow the national trend.

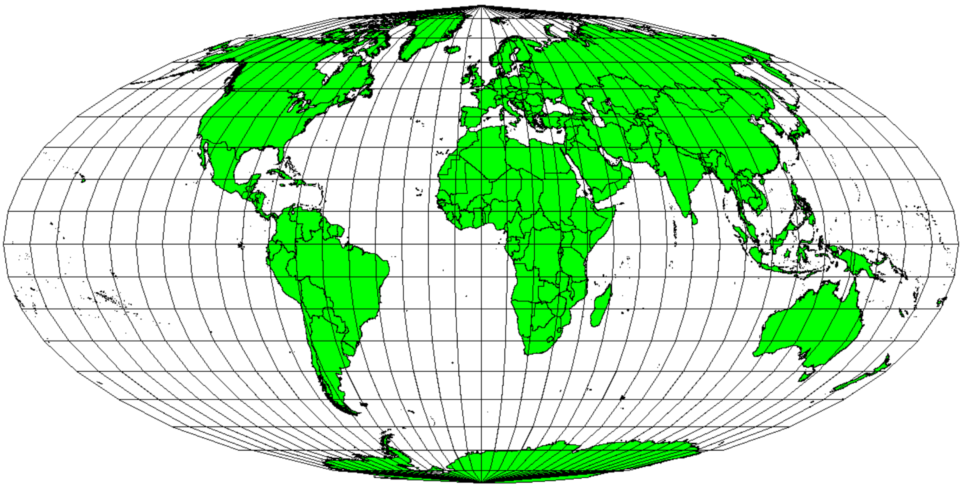


Figure 2.120 The Mollweide Equal Area Projection
(source: https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/coordinate_reference_systems.html)

Now let's recap what was covered in this section:

- Map projections try to portray the entire or portion of the earth.
- A coordinate reference system (CRS) the projected map in relation to its real location on the earth.
- Projecting the spherical earth onto a map is done using geometry and trigonometry.
- These projections need to preserve the angular relationships. These maps have a conformal or orthomorphic projection.
- Hundreds of different projections are available worldwide.
- The projection used depends on the scale and the purpose of the map.
- Different projections are used to accurately measure distances or areas.
- Most countries have designated national used projections.

2.2 Open-source GIS

2.2.1 Overview

QGIS (previously known as Quantum GIS) is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data. It functions as a geographic information system (GIS) software, allowing users to analyze and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports both raster and vector layers; vector data is stored as either, point, line, or polygon features. Multiple formats of raster images are supported and the software can georeference images. QGIS supports shapefiles, coverages, personal geodatabases, dxf, MapInfo, PostGIS, and other formats. Web services, including Web Map Service and Web Feature Service, are also supported to allow use of data from external sources. Finally it integrates with other open-source GIS packages, including PostGIS, GRASS GIS, and MapServer.

2.2.2 Implementing QGIS

When QGIS starts, you are presented with the GUI as shown below in Figure 1.21 in yellow circle numbered 1 through 5 that refer to the five major areas of its interface. Note that your window decorations (title bar, etc.) may appear different depending on your operating system and window manager.

The QGIS GUI five areas are (see Figure 1.21):

1. Menu Bar
2. Tool Bar
3. Map Legend
4. Map View
5. Status Bar

These five components of the QGIS interface are described in more detail in the following paragraphs. Additional paragraphs present the keyboard shortcuts and context help.

The menu bar provides access to various QGIS features using a standard hierarchical menu. The top-level menus and a summary of some of the menu options are listed below, together with the icons of the corresponding tools as they appear on the toolbar, as well as keyboard shortcuts. Keyboard shortcuts can also be configured manually (shortcuts presented in this section are the defaults), using the [Configure Shortcuts] tool under ***Settings***.

Although most menu options have a corresponding tool and vice-versa, the menus are not organized quiet like the toolbars. The toolbar containing the tool is listed after each menu option as a checkbox entry. Some menu options only appear if the corresponding plugin is loaded. More information about tools and toolbars are in the next paragraph that decsribe the Tool Bar

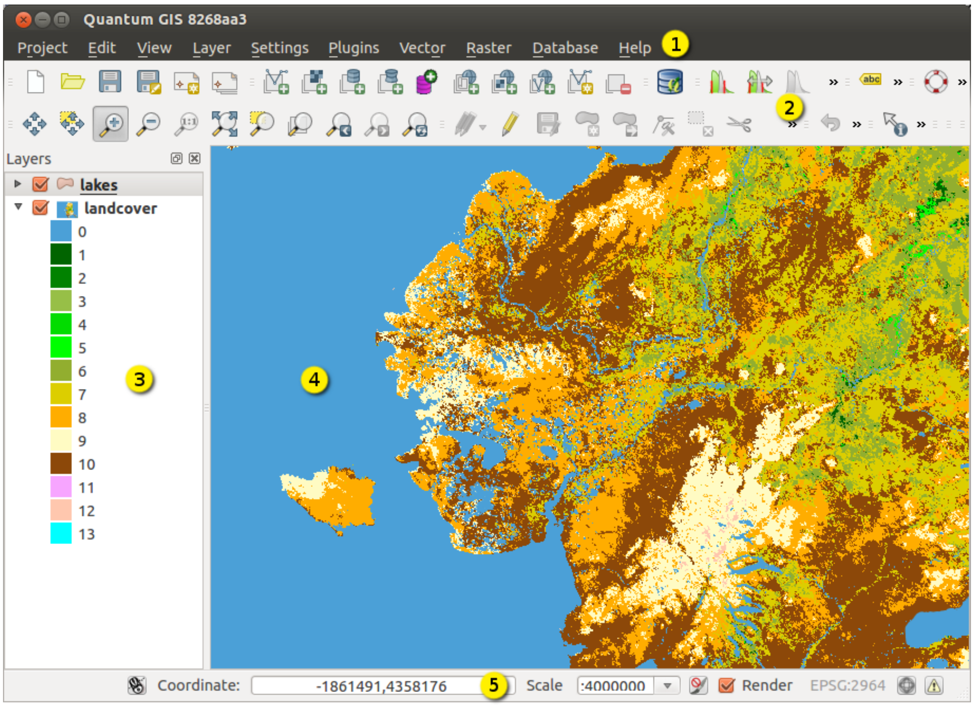


Figure 2.21 The QGIS GUI 1 and its five main components (numbered in yellow circles)

The tool bar provides access to most of the same functions as the menus, plus additional tools for interacting with the map. Each toolbar item has a popup help available. Hold your mouse over the item and a short description of the tool's purpose will be displayed.

Every menu bar can be moved around according to your needs. Additionally every menu bar can be switched off by using your right mouse button context menu, by holding the mouse over the toolbars (read also ***Panels and Toolbars***).

If you have accidentally hidden all your toolbars, you can restore them back by choosing menu option ***Settings*** ► ***Toolbars*** ►. If a toolbar disappears under Windows, which seems to be a problem in QGIS from time to time, you have to remove \HKEY_CURRENT_USER\Software\QGIS\qgis\UI\state in the registry. When you restart QGIS, the key is written again with the default state, and all toolbars are visible again.

The map legend area lists all the layers in the project. The checkbox in each legend entry can be used to show or hide the layer. A layer can be selected and dragged up or down in the legend to change the z-ordering. Z-ordering means that layers listed nearer the top of the legend are drawn over layers listed lower down in the legend. This behaviours can be overridden by 'Layer order' panel.

Layers in the legend window can be organised into groups. There are two ways to do so:

1. Right click in the legend window and choose ***Add Group***. Type in a name for the group and press Enter. Now click on an existing layer and drag it onto the group.
2. Select some layers, right click in the legend window and choose ***Group Selected***. The selected layers will automatically be placed in a new group.

To bring a layer out of a group you can drag it out, or right click on it and choose ***Make to toplevel item***. Groups can be nested inside other groups. The checkbox for a group will show or hide all the layers in the group with one click.

The content of the right mouse button context menu depends on whether the selected legend item is a raster or a vector layer. For the GRASS vector layers Toggle editing it is not available.

Map Viewing is is the “business end” of QGIS, with maps displayed in this area. The map displayed in this window will depend on the vector and raster layers you have chosen to load. The map view can be panned (shifting the focus of the map display to another region) and zoomed in and out. Various other operations can be performed on the map as described in the toolbar description above. The map view and the legend are tightly bound to each other - the maps in view reflect changes you make in the legend area.

Some important when viewing map include:

Zooming the Map with the Mouse Wheel. You can use the mouse wheel to zoom in and out on the map. Place the mouse cursor inside the map area and roll the wheel forward (away from you) to zoom in and backwards (towards you) to zoom out. The mouse cursor position is the center where the zoom occurs. You can customize the behavior of the mouse wheel zoom using the ***Map tools*** menu under the ***Settings ► Options*** menu.

Panning the Map with the Arrow Keys and Space Bar. You can use the arrow keys to pan in the map. Place the mouse cursor inside the map area and click on the right arrow key to pan East, left arrow key to pan West, up arrow key to pan North and down arrow key to pan South. You can also pan the map using the space bar or the click on mouse wheel: just move the mouse while holding down the space bar or click on mouse wheel.

The status bar shows you, your current position in map coordinates (e.g. meters or decimal degrees) as the mouse pointer is moved across the map view. To the left of the coordinate display in the status bar is a small button that will toggle between showing coordinate position or the view extents of the map view as you pan and zoom in and out. Next to the coordinate display you find the scale display. It shows the scale of the map view. If you zoom in or out QGIS shows you the current scale. There is a scale selector which allows you to choose between predefined scales from 1:500 until 1:1000000.

A progress bar in the status bar shows progress of rendering as each layer is drawn to the map view. In some cases, such as the gathering of statistics in raster layers, the progress bar will be used to show the status of lengthy operations.

If a new plugin or a plugin update is available, you will see a message at the far left of the status bar. On the right side of the status bar is a small checkbox which can be used to temporarily prevent layers being rendered to the map view. The icon immediately stops the current map rendering process. To the right of the render functions you find the EPSG code of the current project CRS and a projector icon. Clicking on this opens the projection properties for the current project.

Now let’s recap what was covered in this section:

- QGIS is a free and open-source software for geographic information system (GIS).
- Five are the main components of the QGIS interface (Menu Bar, Tool Bar, Map Legend, Map View, Status Bar).

- Each component has its own functions.
- Map Viewing is the endpoint since it provides the final product the of display of the rae of interest as a map.

2.3 Utilizing GPS data

GPS, the Global Positioning System, is a satellite-based system that allows anyone with a GPS receiver to find their exact position anywhere in the world. It is used as an aid in navigation, for example in airplanes, in boats and by hikers. The GPS receiver (See figure 1.22) uses the signals from the satellites to calculate its latitude, longitude and (sometimes) elevation. Most receivers also have the capability to store locations (known as waypoints), sequences of locations that make up a planned route and a tracklog or track of the receivers movement over time. Waypoints, routes and tracks are the three basic feature types in GPS data. QGIS displays waypoints in point layers while routes and tracks are displayed in linestring layers.

Figure 2.22 A GPS receiver (left) and researchers using a GPS receiver (right)

2.3.1 Loading GPS data to QGIS

There are dozens of different file formats for storing GPS data. The format that QGIS uses is called GPX (GPS eXchange format), which is a standard interchange format that can contain any number of waypoints, routes and tracks in the same file.

To load a GPX file you first need to load the plugin. ***Plugins*** ► ***Plugin Manager...*** opens the Plugin Manager Dialog. Activate the ***GPS Tools*** checkbox. When this plugin is loaded two buttons with a small handheld GPS device will show up in the toolbar:

- Create new GPX Layer
- GPS Tools

For working with GPS data we provide an example GPX file available in the QGIS sample dataset: qgis_sample_data/gps/national_monuments.gpx. See Section ***Sample Data*** for more information about the sample data.

1. Select ***Vector* ► *GPS* ► *GPS Tools*** or click the GPS Tools icon in the toolbar and open the ***Load GPX file*** tab (see Figure 1.21).
2. Browse to the folder qgis_sample_data/gps/, select the GPX file national_monuments.gpx and click **[Open]**.

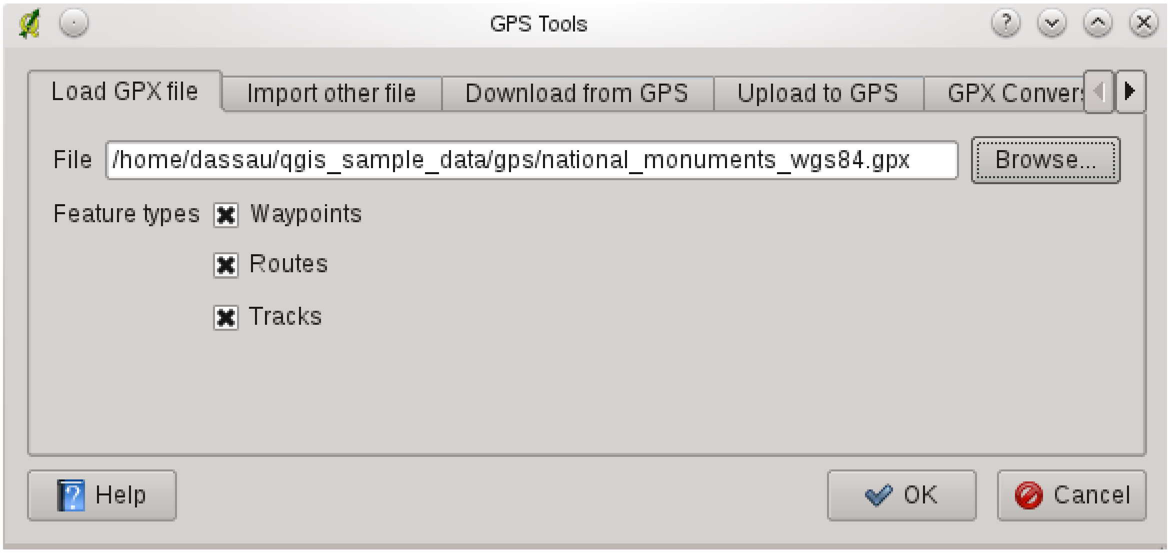


Figure 2.23 The GPS Tools dialog window

Use the **[Browse...]** button to select the GPX file, then use the checkboxes to select the feature types you want to load from that GPX file. Each feature type will be loaded in a separate layer when you click **[OK]**. The file national_monuments.gpx only includes waypoints.

NOTE: GPS units allow to store data in different coordinate systems. When downloading a GPX file (from your GPS unit or a web site) and then loading it in QGIS, be sure that the data stored in the GPX file uses WGS84 (latitude/longitude). QGIS expects this and it is the official GPX specification. See http://www.topografix.com/GPX/1/1/

2.3.2 GPSBabel

Since QGIS uses GPX files you need a way to convert other GPS file formats to GPX. This can be done for many formats using the free program GPSBabel, which is available at http://www.gpsbabel.org. This program can also transfer GPS data between your computer and a GPS device. QGIS uses GPSBabel to do these things, so it is recommended that you install it. However, if you just want to load GPS data from GPX files you will not need it. Version 1.2.3 of GPSBabel is known to work with QGIS, but you should be able to use later versions without any problems.

2.3.3 Importing GPS data to QGIS

To import GPS data from a file that is not a GPX file, you use the tool ***Import other file*** in the GPS Tools dialog. Here you select the file that you want to import (and the file type), which feature type you want to import from it, where you want to store the converted GPX file and what the name of the new layer should be. Note that not all GPS data formats will support all three feature types, so for many formats you will only be able to choose between one or two types.

2.3.4 Downloading GPS data from a device

QGIS can use GPSBabel to download data from a GPS device directly as new vector layers. For this we use the ***Download from GPS*** tab of the GPS Tools dialog (see Figure 1.24). Here, we select the type of GPS device, the port that it is connected to (or usb if your GPS supports this), the feature type that you want to download, the GPX file wheare the data should be stored, and the name of the new layer.

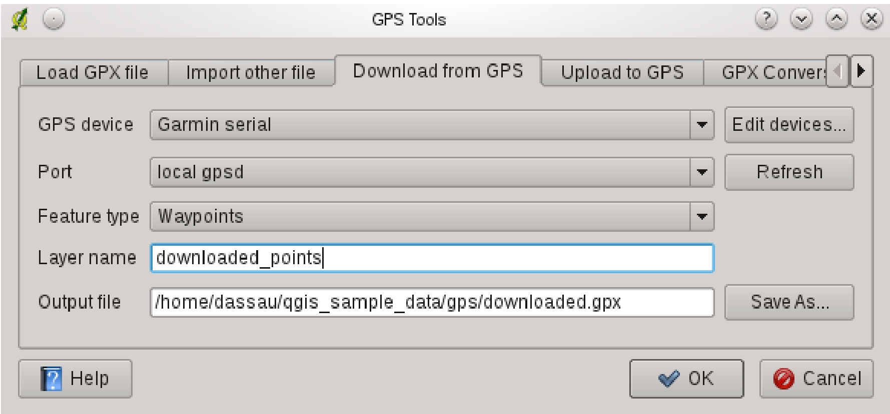


Figure 2.24 The QGIS tool to download GPS data

The device type you select in the GPS device menu determines how GPSBabel tries to communicate with your GPS device. If none of the available types work with your GPS device you can create a new type.

The port may be a file name or some other name that your operating system uses as a reference to the physical port in your computer that the GPS device is connected to. It may also be simply usb, for usb enabled GPS units. When you click **[OK]** the data will be downloaded from the device and appear as a layer in QGIS.

2.3.5 Uploading GPS data to a device

You can also upload data directly from a vector layer in QGIS to a GPS device using the ***Upload to GPS*** tab of the GPS Tools dialog. To do this you simply select the layer that you want to upload (which must be a GPX layer), your GPS device type, and the port (or usb) that it is connected to. Just as with the download tool you can specify new device types if your device isn't in the list.

This tool is very useful in combination with the vector editing capabilities of QGIS. It allows you to load a map, create waypoints and routes, and then upload them and use them on your GPS device.

Now let's recap what was covered in this section:

- GPS, is a satellite-based system that allows to find the exact position anywhere in the world.
- GPS data are stored in different file formats.
- The format that QGIS uses for GPS data is called GPX (GPS eXchange format).
- GPSBabel, a free program, converts other GPS file formats to GPX.
- The GPS Tools dialog can also import GPS data from a file that is not a GPX file.
- Vector layer data in QGIS can be uploaded directly into a GPS device.

2.4 Soil and water bioengineering gis applications

2.4.1 Geo-referencing Maps

Knowing the topography of the area where bioengineering activities will be implemented is essential for the success of the works that be done. This can be done at small scales with field measurements or this can be done utilizing maps and GIS. Two are the main processes that include a) the geo-referencing of the map and afterwards b) the digitizing of the contour lines.

Geo-referencing is the process of assigning real-world coordinates to each pixel of the raster. Many times these coordinates are obtained by doing field surveys - collecting coordinates with a GPS device for few easily identifiable features in the image or map. In some cases, where you are looking to digitize scanned maps, you can obtain the coordinates from the markings on the map image itself. Using these sample coordinates or GCPs (Ground Control Points), the image is warped and made to fit within the chosen coordinate system. In this tutorial I will discuss the concepts, strategies and tools within QGIS to achieve a high accuracy geo-referencing.

The steps to geo-reference a map follow:

1. Geo-referencing in QGIS is done via the 'Georeferencer GDAL' plugin. This is a core plugin - meaning it is already part of your QGIS installation. You just need to enable it. Go to Plugins ‣ Manage and Install Plugins and enable the Georeferencer GDAL plugin in the Installed tab (see Figure 1.25).

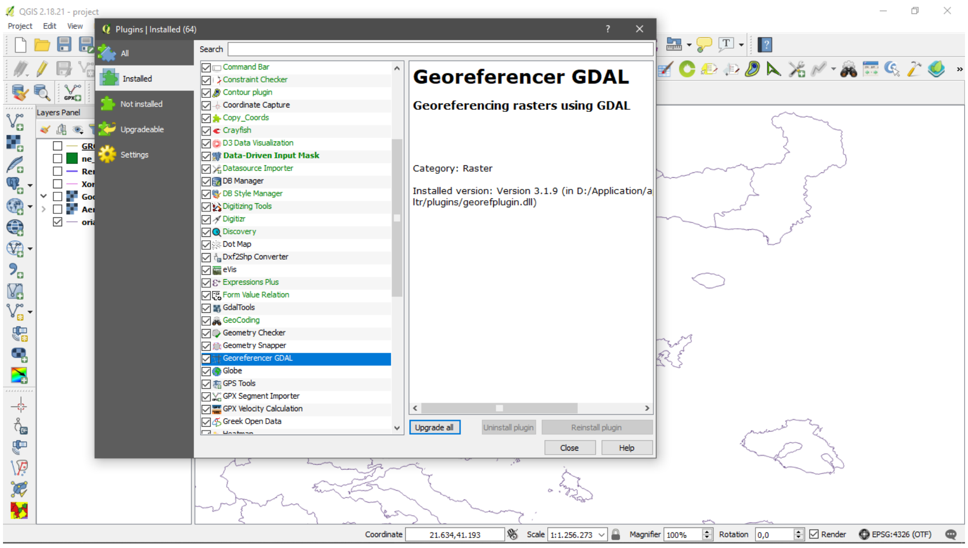


Figure 2.25 The Georeferencer GDAL plugins

2. The plugin is installed in the Raster menu. Click on Raster ▸ Georeferencer ▸ Georeferencer to open the plugin (see Figure 1.26).

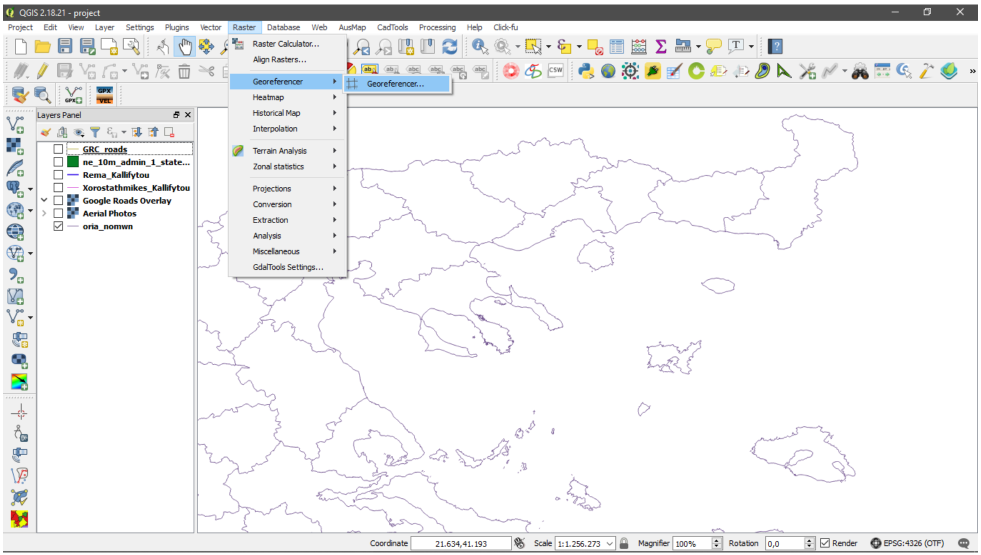


Figure 2.26 The Georeferencer in the Raster Menu

3. The plugin window is divided into 2 sections (see Figure 1.27). The top section where the raster will be displayed and the bottom section where a table showing your GCPs will appear.

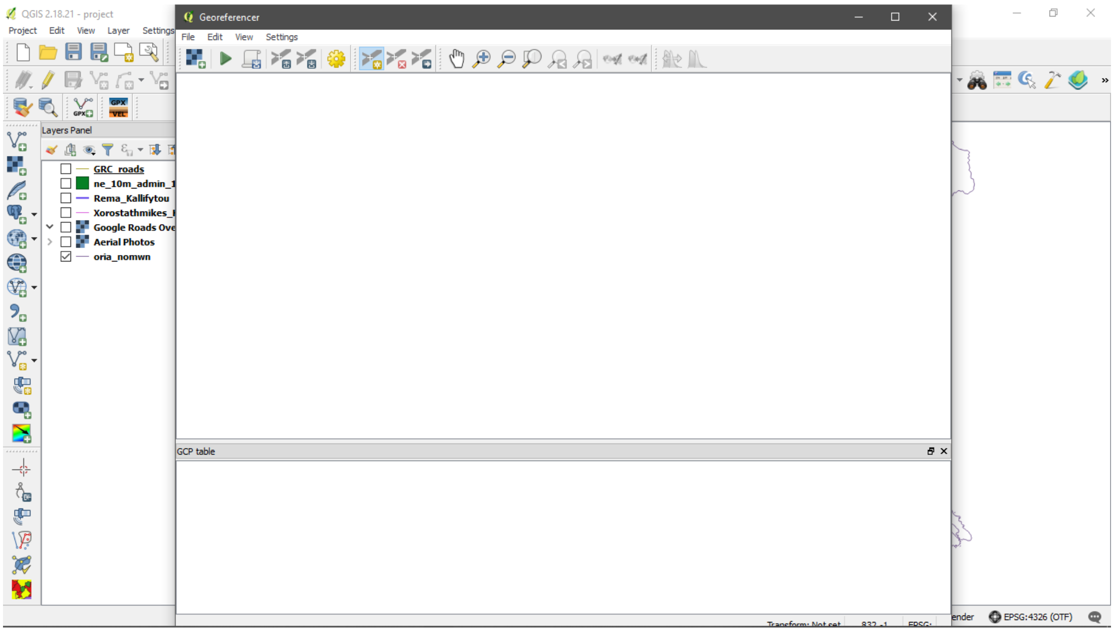


Figure 2.27 The Georeferencer window

4. Now we will open our JPG image. Go to File ‣ Open Raster (see Figure 1.28). Browse to the downloaded image of the scanned map and click Open.

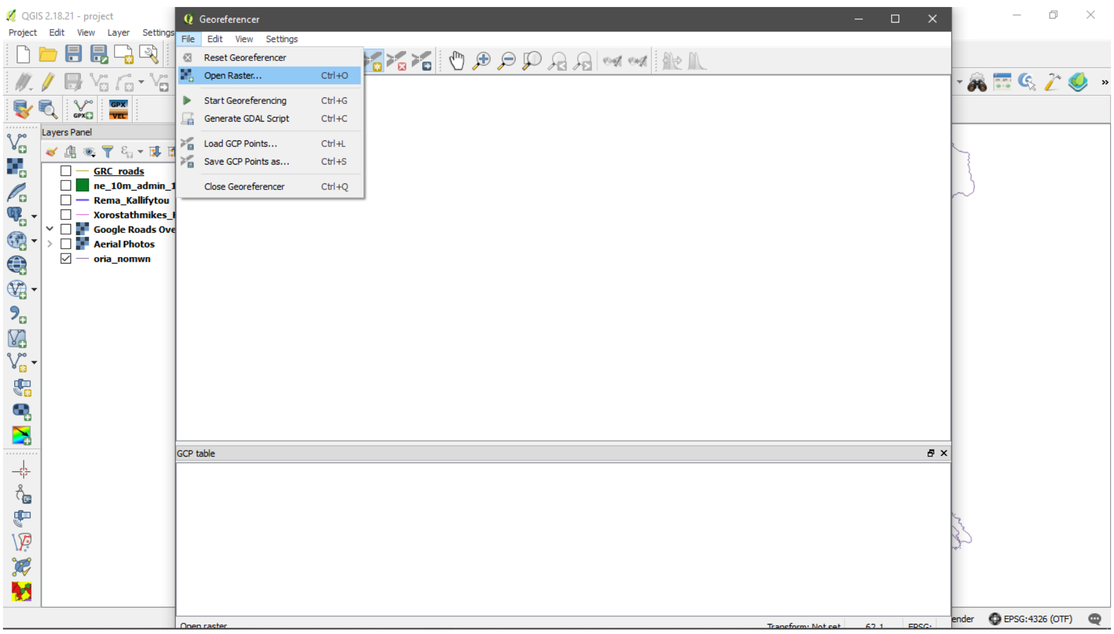


Figure 2.28 How to open the scanned image

5. The next screen, will ask you to choose the raster's coordinate reference system (CRS) (see Figure 1.29). This is to specify the projection and datum of your control points. If you have collected the ground control points using a GPS device, you would have the WGS84 CRS. If you are geo-referencing a scanned map like this, you can obtain the CRS information from the map itself. Looking at our map

image, the coordinates are in Lat/Long. There is no datum information given, so we have to assume an appropriate one. In Greece the GGRS87 is typically used.

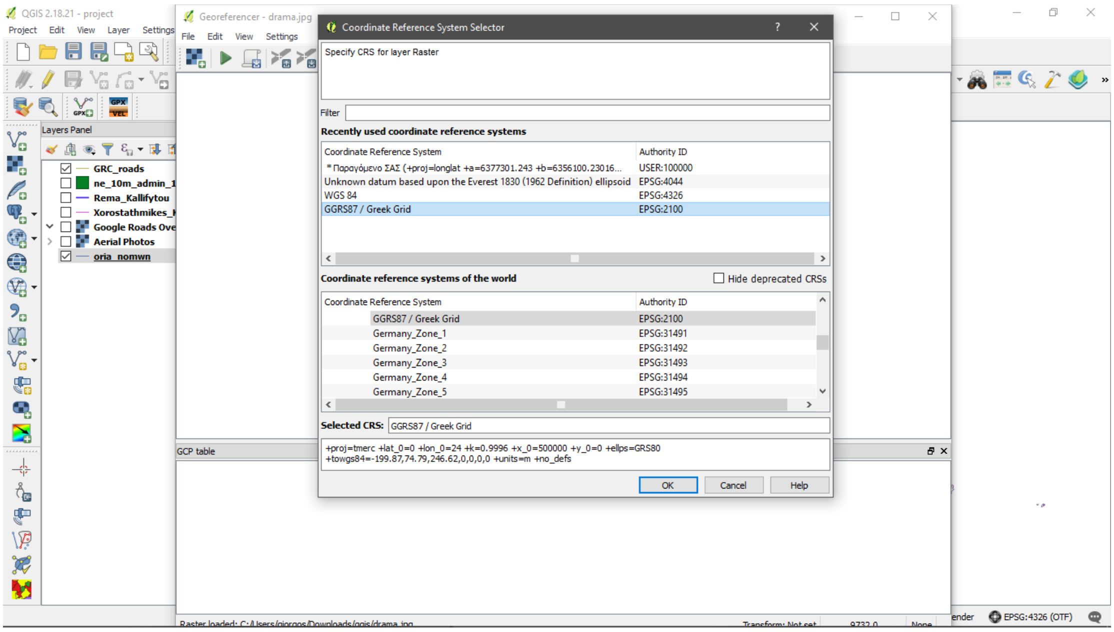


Figure 2.29 Selecting the Coordinate Reference System

6. You will see the image will be loaded on the top section (see Figure 1.30).

7. You can use the zoom/pan controls in the toolbar to learn more about the map (see Figure 1.30).

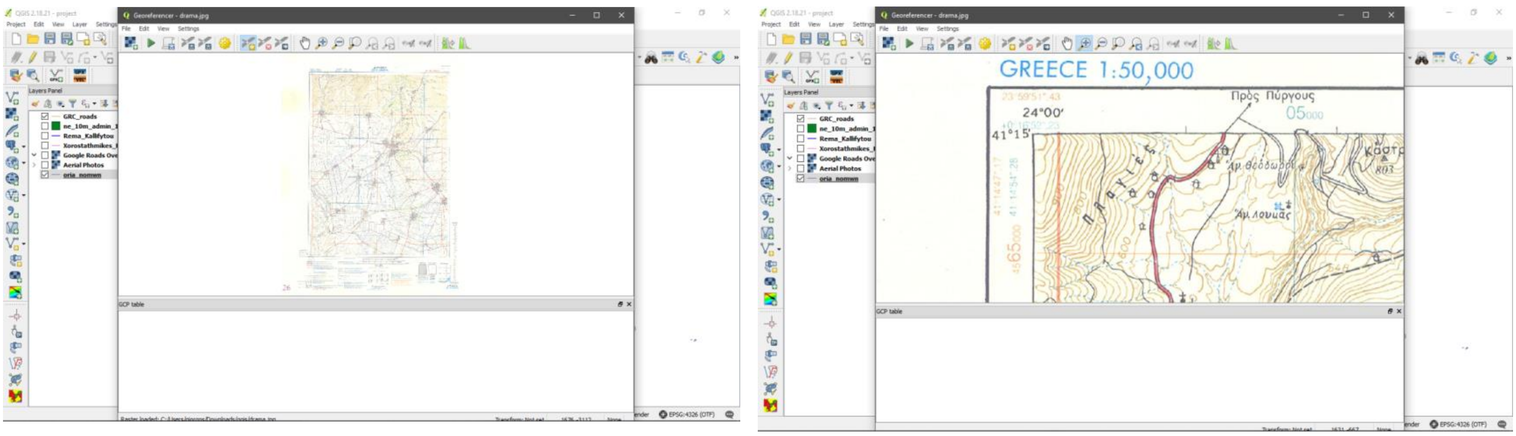


Figure 2.30 The image can be seen in the top of screen (left) and it can be zoom (right) and panned.

8. Now we need to assign coordinates to some points on this map (see Figure 1.31). If you look closely, you will see coordinate grid with markings. Using this grid, you can determine the X and Y coordinates of the points where the grids intersect. Click on Add Point in the toolbar.

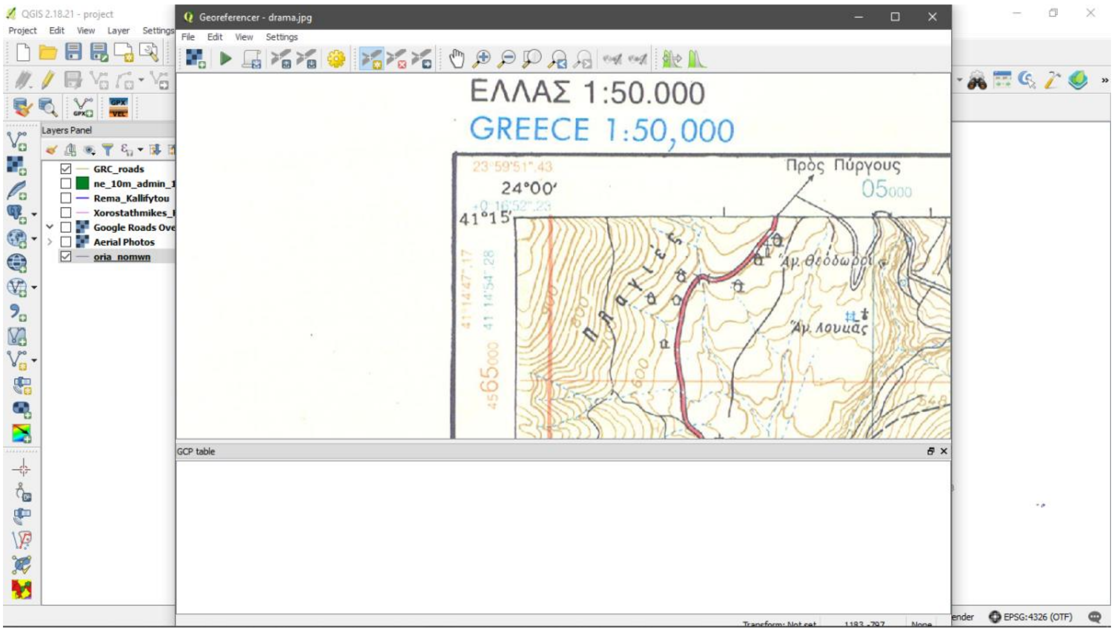


Figure 2.31 How to assign the coordinates

9. In the pop-up window, enter the coordinates (see Figure 1.32). Remember that X=longitude and Y=latitude. Click OK.

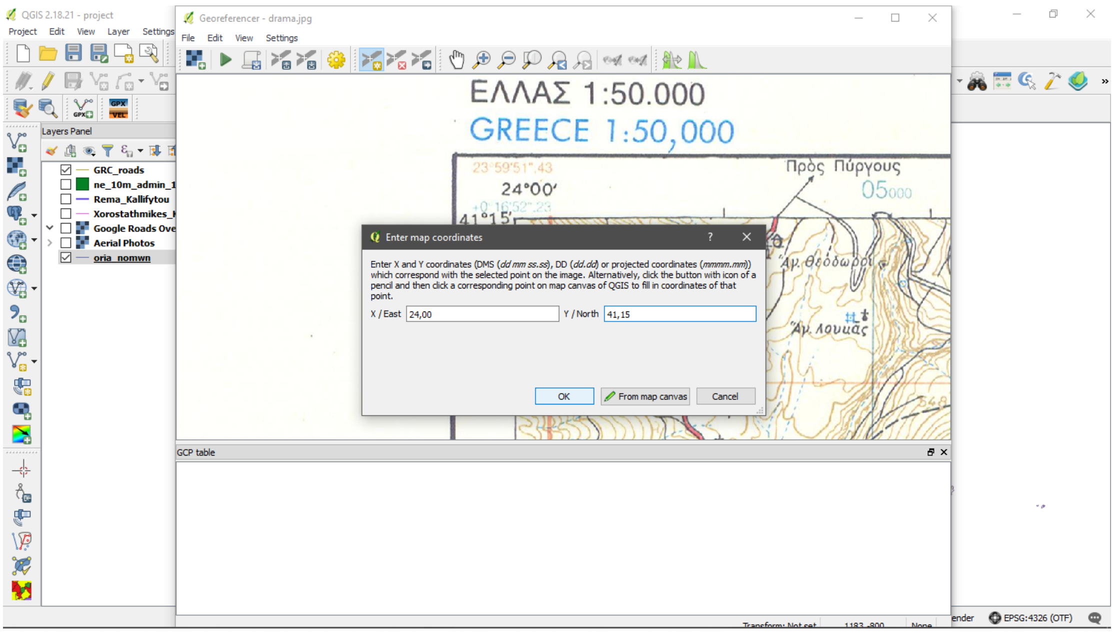


Figure 2.32 How to enter the coordinates in the pop-up menu

10. You will notice the GCP table now has a row with details of your first GCP (see Figure 1.33).

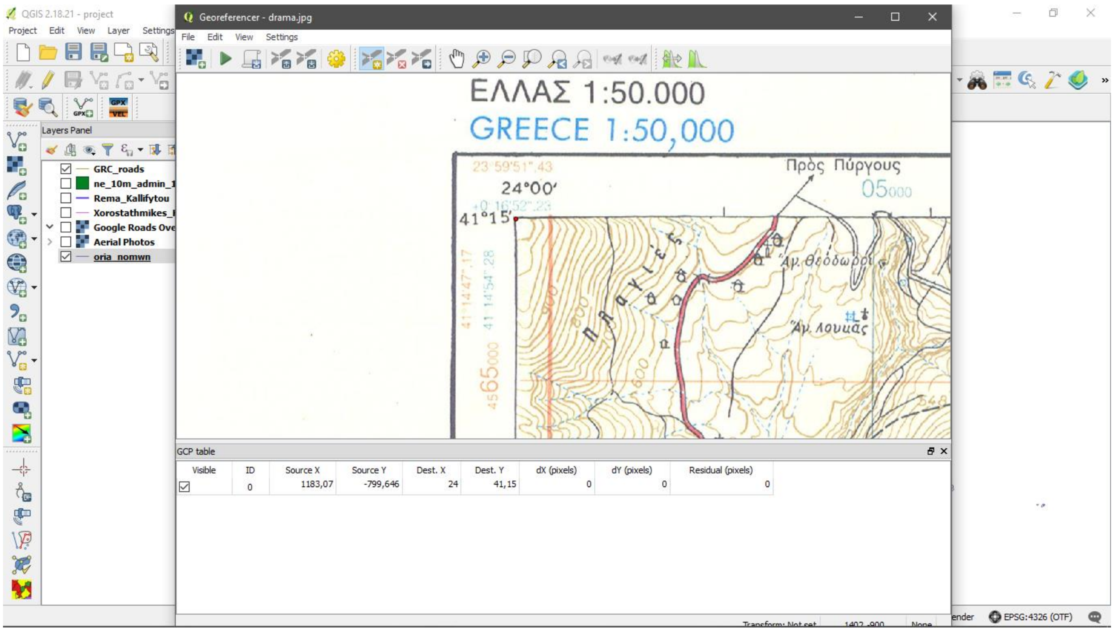


Figure 2.33 The row with the first GCP details

11. Similarly, add at least 4 GCPs covering the entire image (see Figure 1.34). The more points you have, the more accurate your image is registered to the target coordinates.

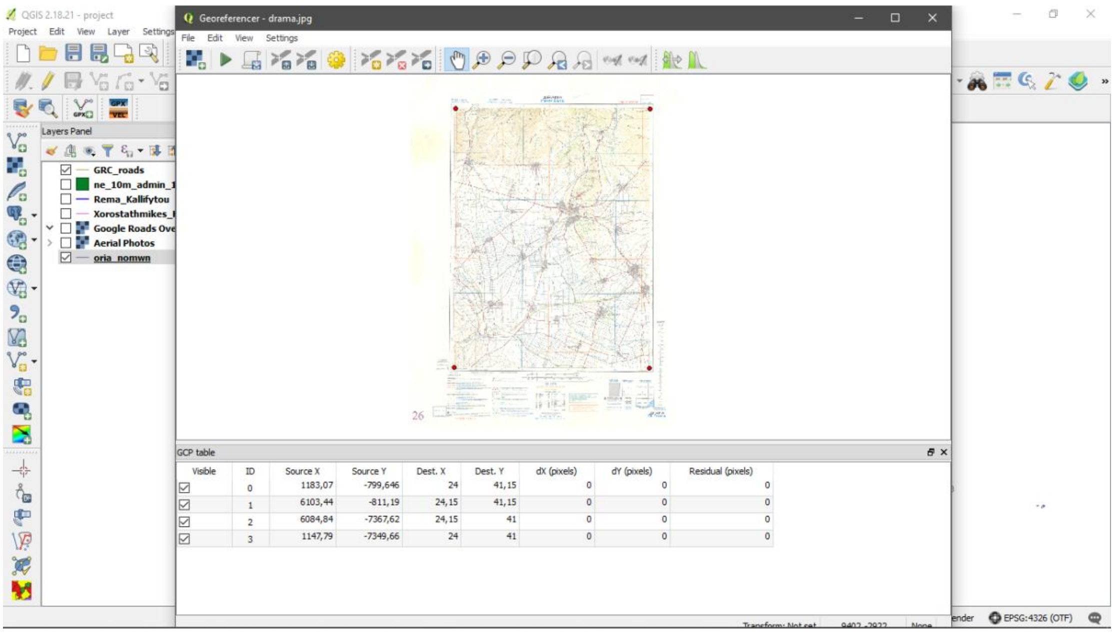


Figure 2.34 The rows with four GCP details

12. Once you have enough points, go to Settings -> Transformation settings (see Figure 1.35).

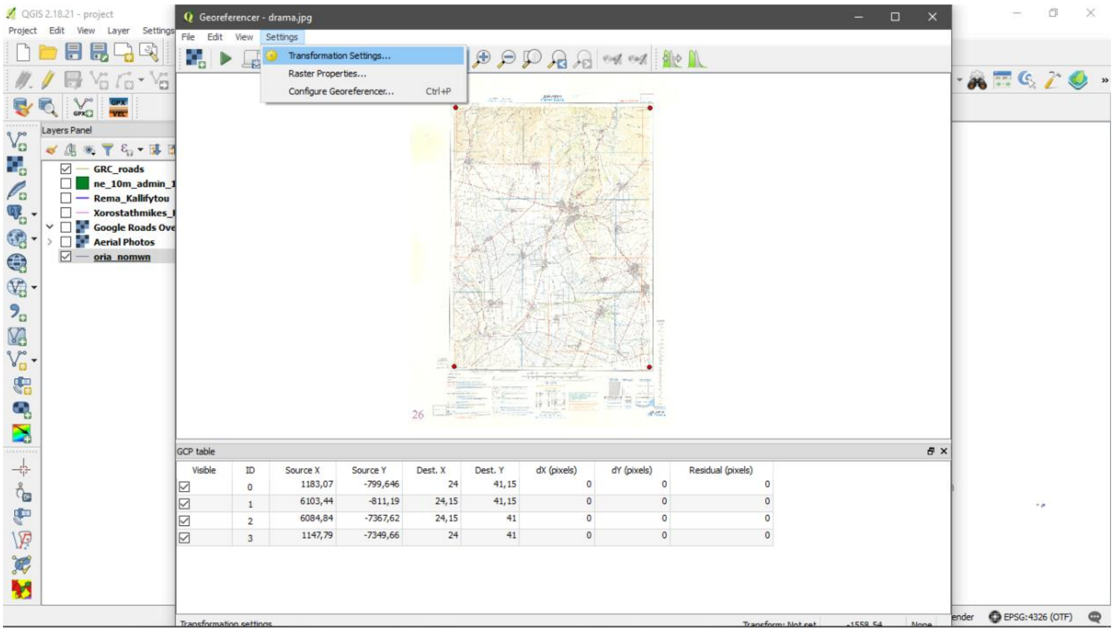


Figure 2.35 The transformation settings

13. In the Transformation settings dialog, choose the Transformation type as Thin Plate Spline (see Figure 1.36). Name your output raster as DRAMA-CITY_GREECE.tif. Choose EPSG:4326 as the target SRS so the resulting image is in a widely compatible datum. Make sure the Load in QGIS when done option is checked. Click OK.

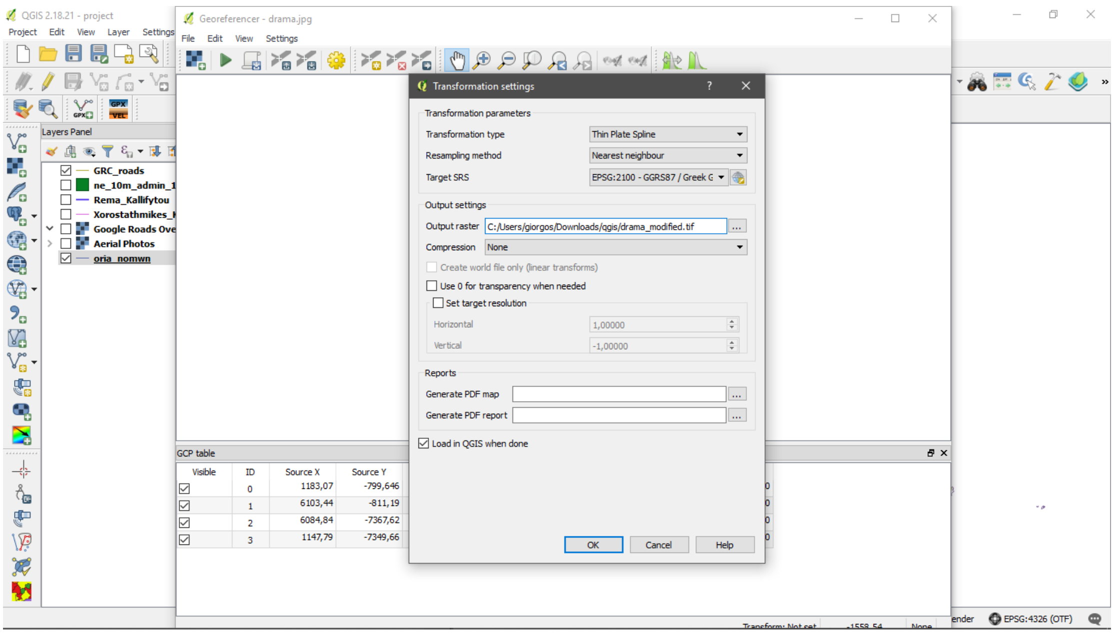


Figure 2.36 How to choose the transformation setting

14. Back in the Georeferencer window, go to File ‣ Start georeferencing. This will start the process of warping the image using the GCPs and creating the target raster (see Figure 1.37).

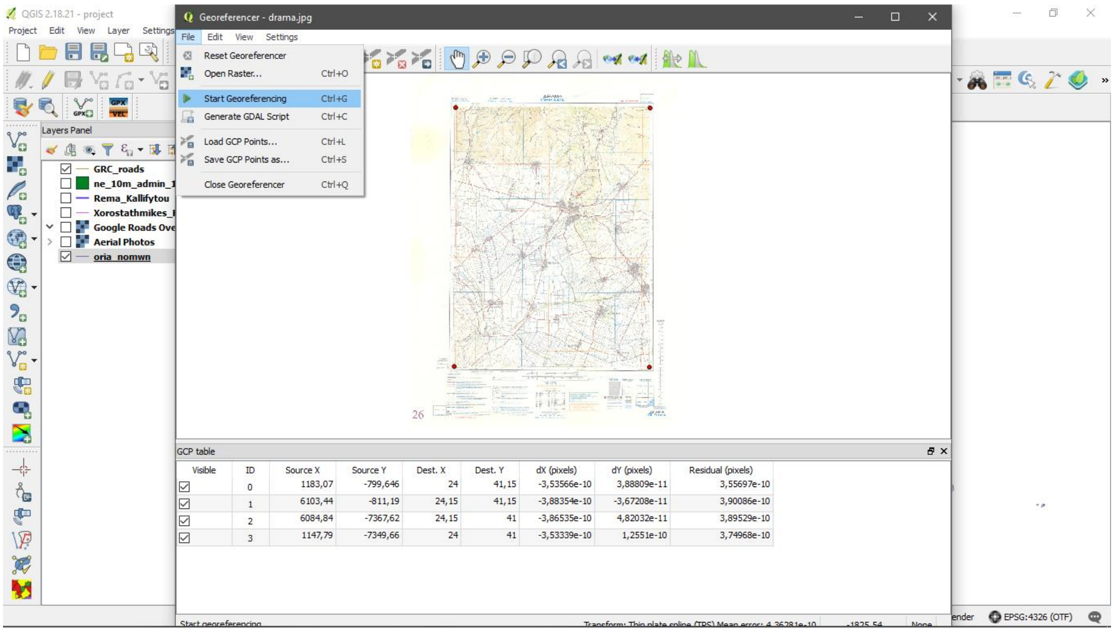


Figure 2.37 The Start georeferencing warps the image and creates the target raster

15. Once the process finishes, you will see the georeferenced layer loaded in QGIS (see Figure 1.38).

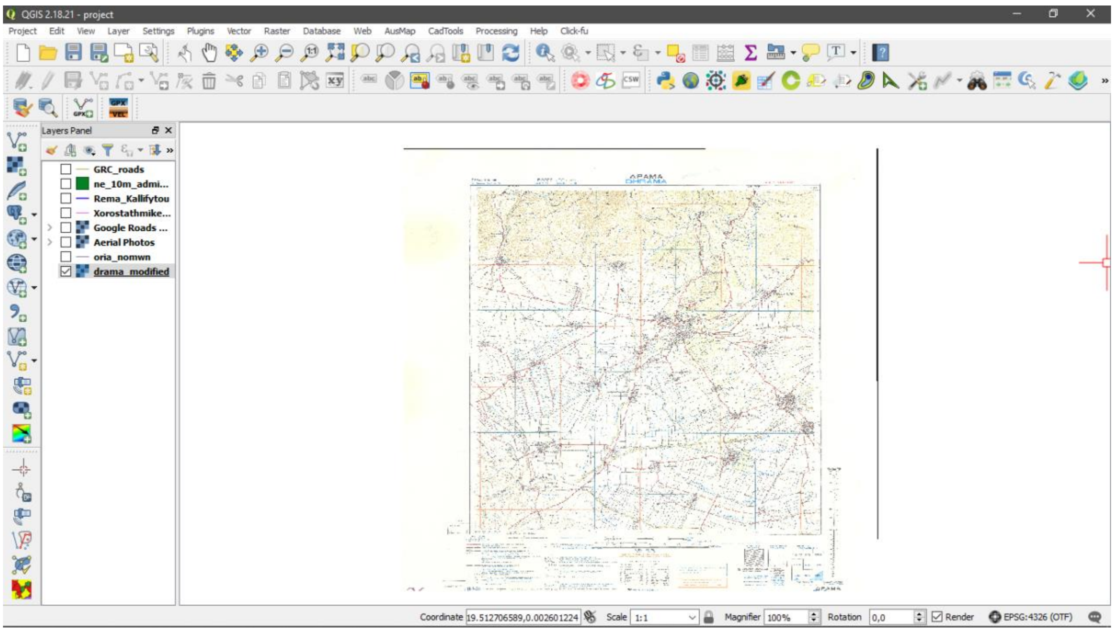


Figure 2.38 The geo-referenced layer in QGIS

16. The georeferencing is now complete (see Figure 1.39). But as always, it's a good practice to verify your work. How do we check if our georeferencing is accurate? In this case, load the country boundaries shapefile from a trusted source like the Natural Earth dataset and compare them. You will notice they

match up pretty nicely. There is some error and it can be further improved by taking more control points, changing transformation parameters and trying a different datum.

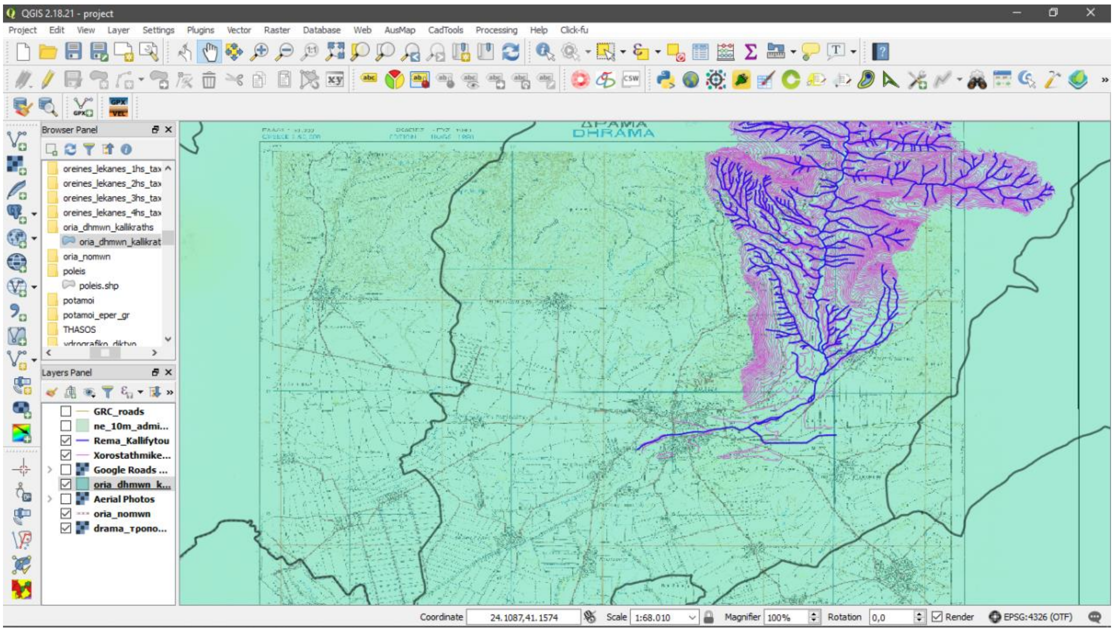


Figure 2.39 The complete geo-referencing of the map

2.4.2 Digitizing Basics – Control Lines, Hydrologic Network, Watershed, Study Areas

Digitizing is one of the most common tasks that a GIS Specialist has to do. Often a large amount of GIS time is spent in digitizing raster data to create vector layers that you use in your analysis. QGIS has powerful on-screen digitizing and editing capabilities. In this case we will use a raster topographic map and create several vector layers representing features around a park.

1. Go to Layer ‣ Add Raster Layer. Locate the downloaded DRAMA-CITY_GREECE.tif and click Open (see Figure 1.40).

2. This is a large raster file and you may notice that when you zoom or pan around the map, the map takes a little time to render the image. QGIS offers a simple solution to make rasters load much faster by using **Image Pyramids** (see Figure 1.41). QGIS creates pre-rendered tiles at different resolutions and these are presented to you instead of the full raster. This makes map navigation snappy and responsive. Right-click the DRAMA-CITY_GREECE layer and choose Properties.

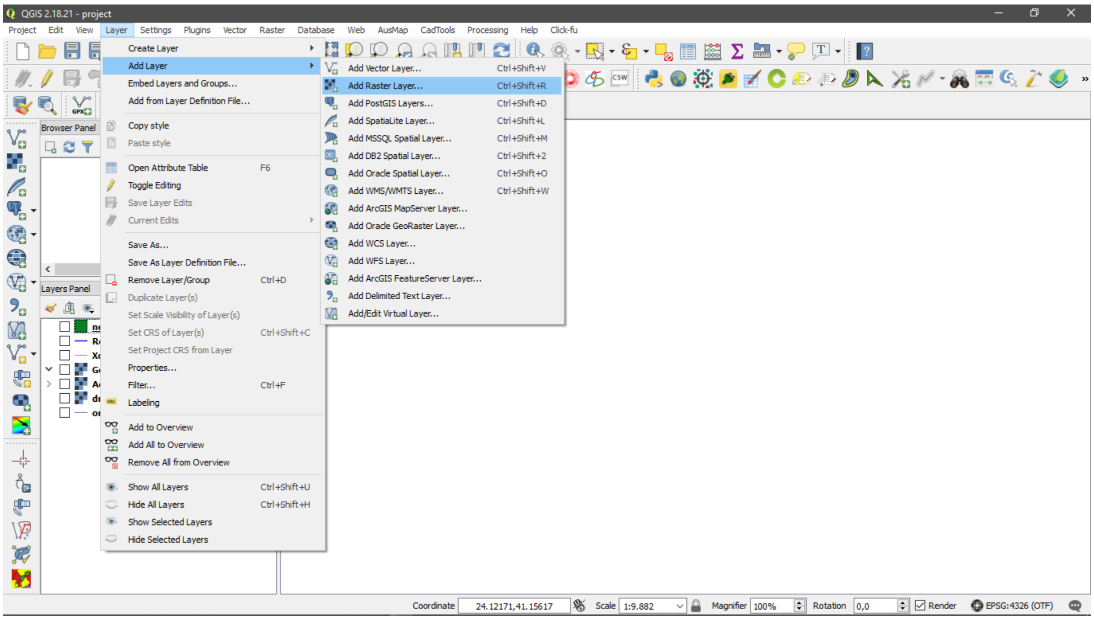


Figure 2.40 How to download an image

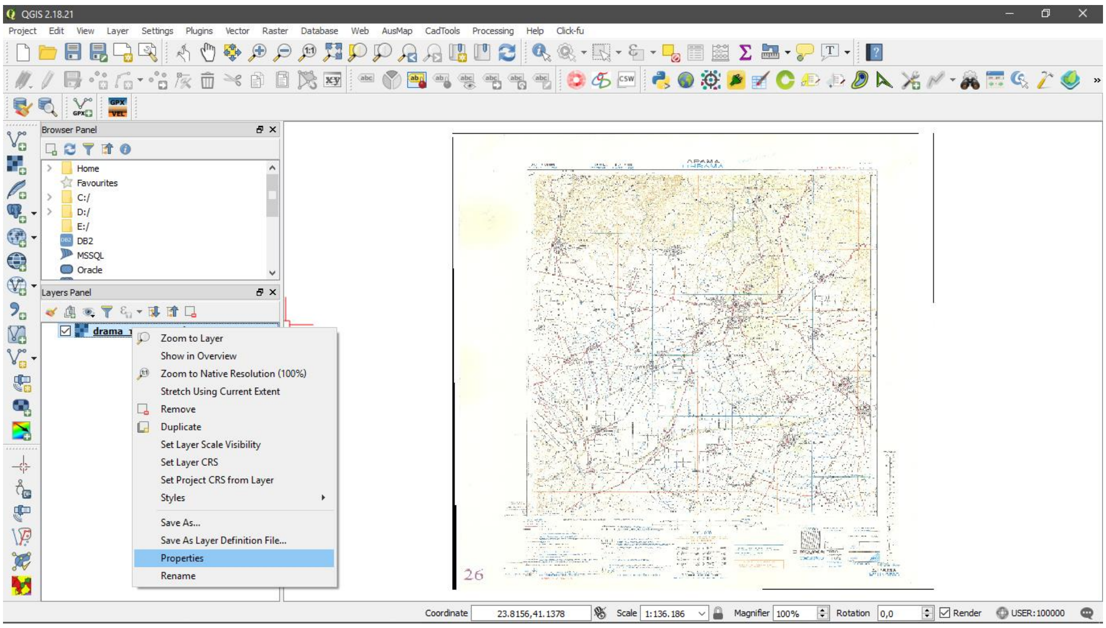


Figure 2.41 Image Pyramids in QGIS can make rasters load much faster

3. Choose the Pyramids tab (see Figure 1.42). Hold the Ctrl key and select all the resolutions offered in the Resolutions panel. Leave other options to defaults and click Build pyramids. Once the process finishes, click OK.

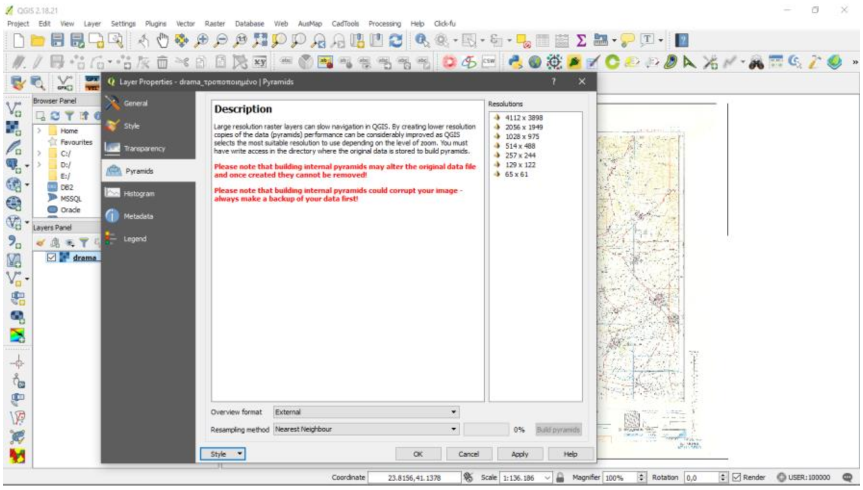


Figure 2.42 You can select different resolutions with the Pyramids tab

4. Back in the main QGIS window, use the Zoom tool to locate *Santa Barbara* area in Drama city (see Figure 1.43). This is the park that we will be digitizing.

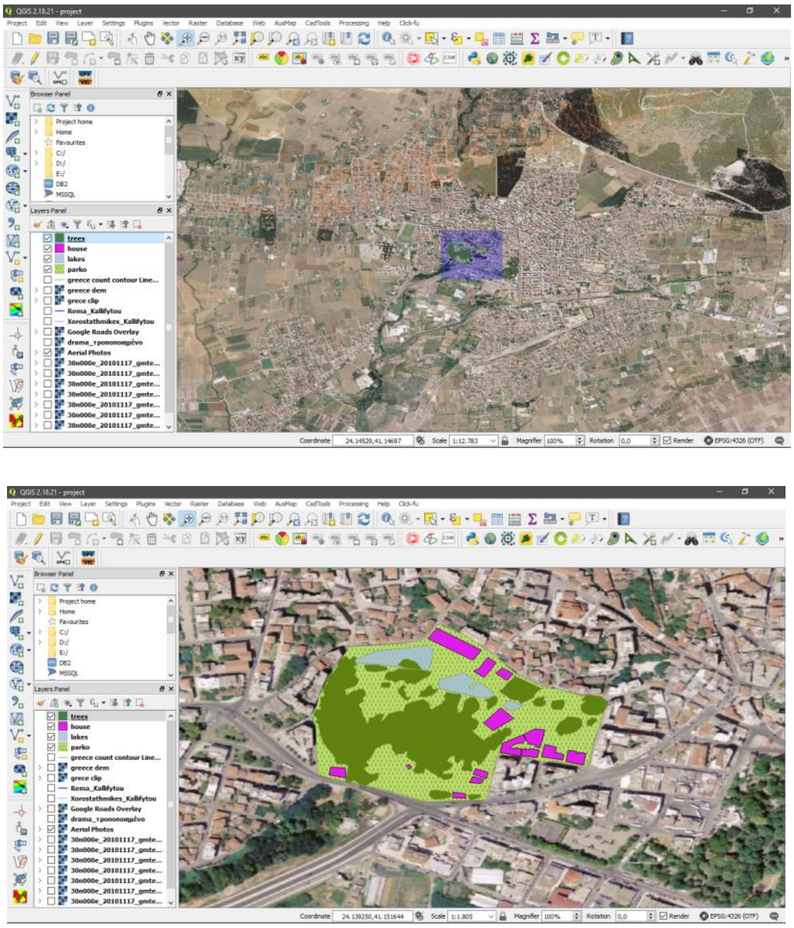


Figure 2.43 Using the Zoom tool to locate Santa Barbara area in Drama City

5. Before we start, we need to set default **Digitizing Options** (see Figure 1.44). Go to Settings ▸ Options....

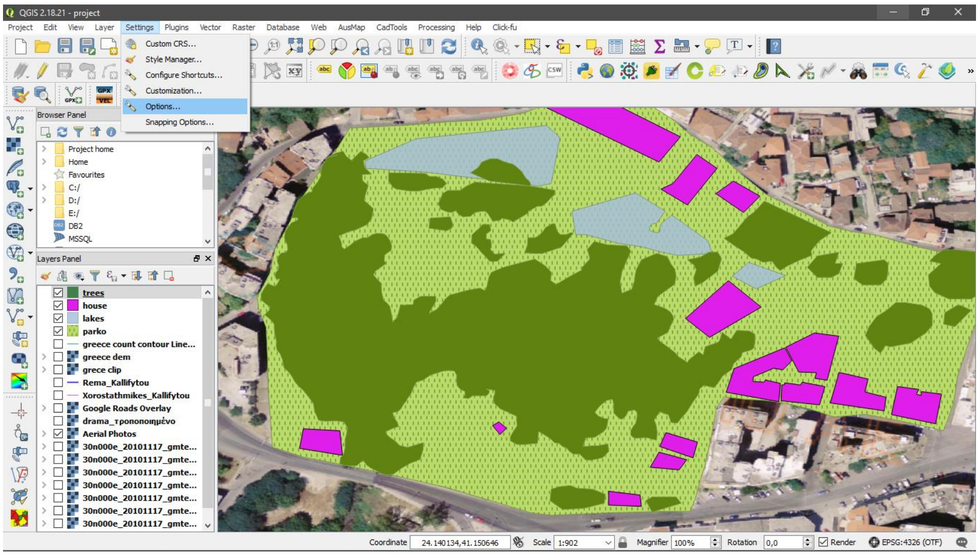


Figure 2.44 Setting the default Digitizing Options

6. Select the Digitizing tab in the Options dialog (see Figure 1.45). Set the Default snap mode to To vertex and segment. This will allow you to snap to the nearest vertex or line segment. It is also preferred to set the Default snapping tolerance and Search radius for vertex edits in pixels instead of map units. This will ensure that the snapping distance remains constant regardless of zoom level. Depending on your computer screen resolution, you may choose an appropriate value. Click OK.

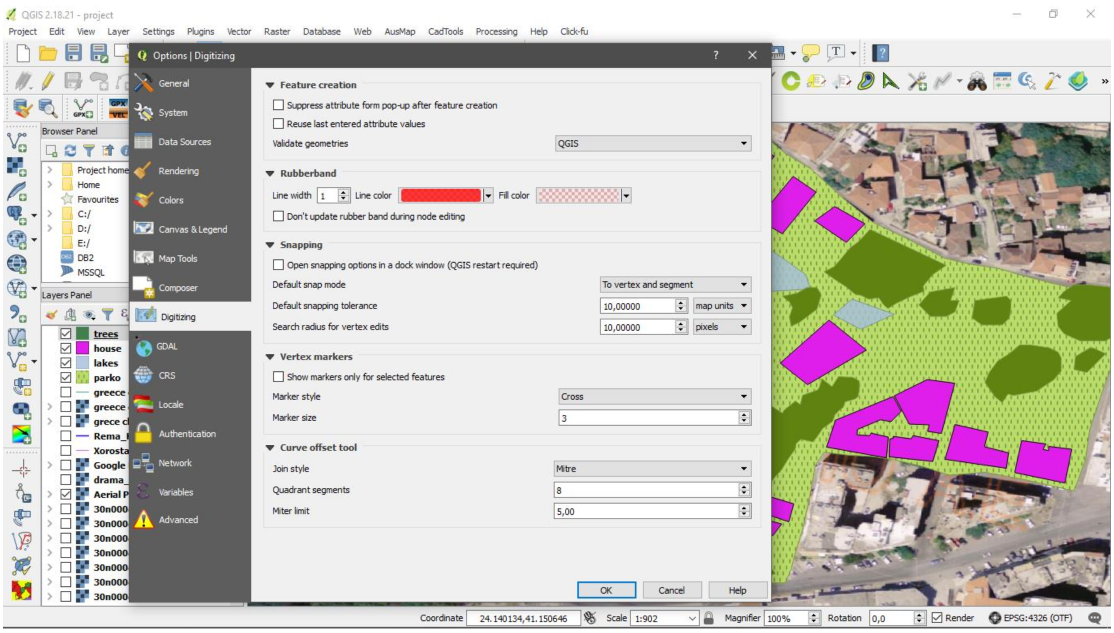


Figure 2.45 Setting the Default snap mode To vertex and segment

7. Now we are ready to start digitizing (see Figure 1.46). We will first create a roads layer and digitize the roads around the park area. Select Layer ‣ New ‣ New Spatialite Layer.... You may also choose to create a New Shapefile Layer... instead if you prefer. Spatialite is an open database format similar to ESRI's geodatabase format. Spatialite database is contained within a single file on your hard drive and can contain diferent types of spatial (point, line, polygon) as well as non-spatial layers. This makes is much easier to move it around instead of a bunch of shapefiles. In this tutorial, we are creating a couple of polygon layers and a line layer, so a Spatialite database will be better suited. You can always load a spatialite layer and save it as a shapefile or any other format you want.

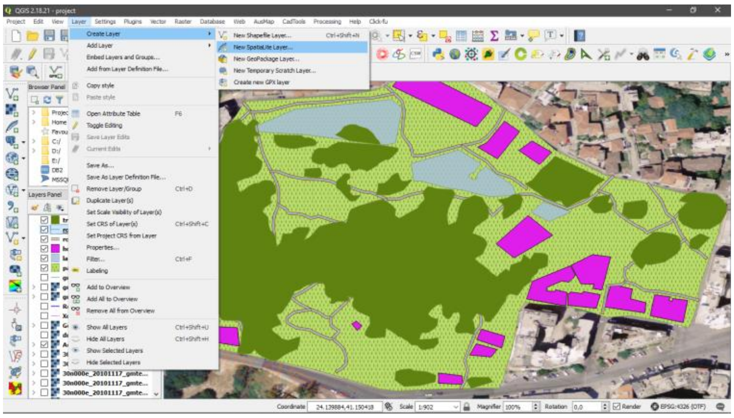


Figure 2.46 create a roads layer and digitize the roads around the park area

8. In the New Spatialite Layer dialog, click the ... button and save a new spatialite database named nztopo.sqlite (see Figure 1.47). Choose the Layer name as Roads and select Line as the Type. The base topographic map is in the EPSG:2193 - NZGD 2000 CRS, so we can select the same for our roads layer. Check the Create an autoincrementing primary key box. This will create a field called **pkuid** in the table and assign a unique numeric id automatically to each feature. When creating a GIS layer, you must decide on the attributes that each feature will have. Since this is a roads layer, we will have 2 basic attributes - Name and Class. Enter Name as the Name of the attribute in the New attribute section and click Add to attribute list.attribute

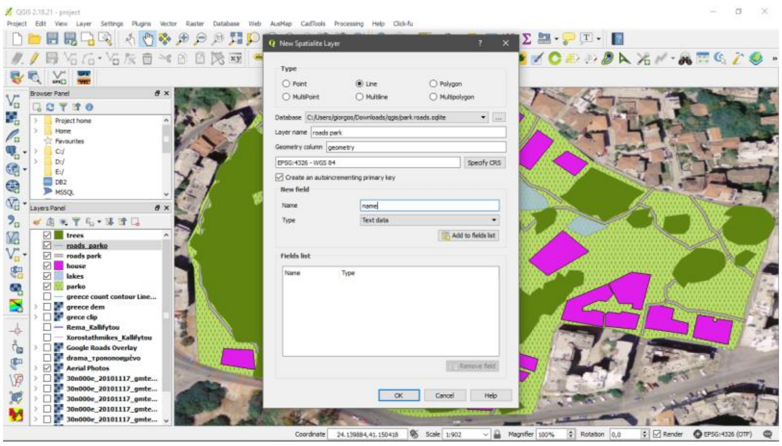


Figure 2.47 How to create a new line layer

9. Similarly create a new attribute Class of the type Text data (see Figure 1.48). Click OK.

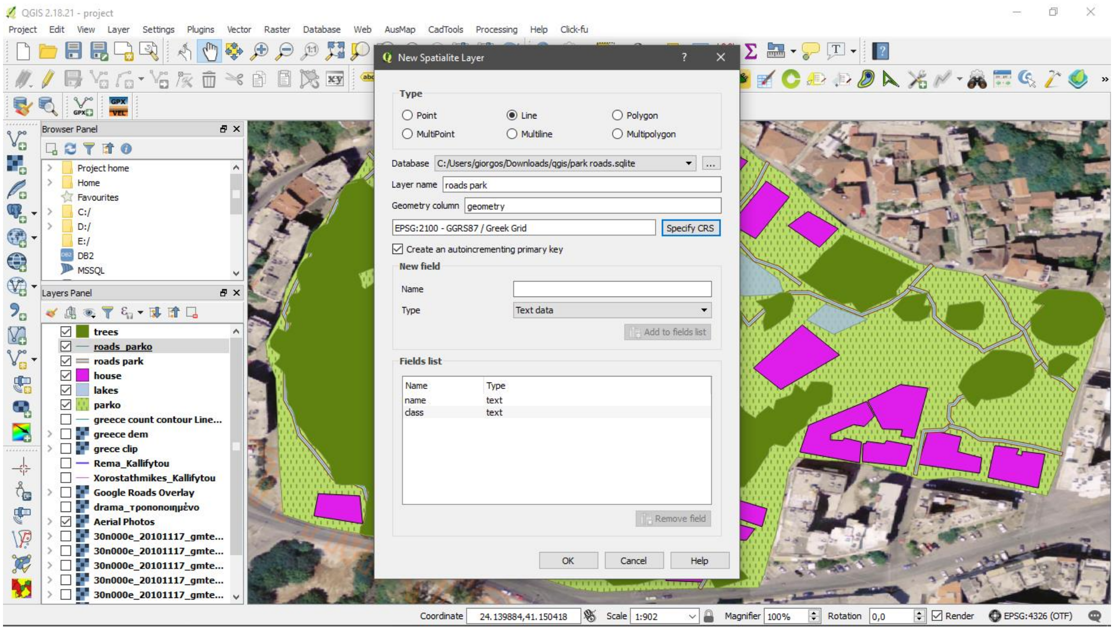


Figure 2.48 How to create a new Class attribute

10. Once the layer is loaded, click the Toggle Editing button to put the layer in editing mode (see Figure 1.49).

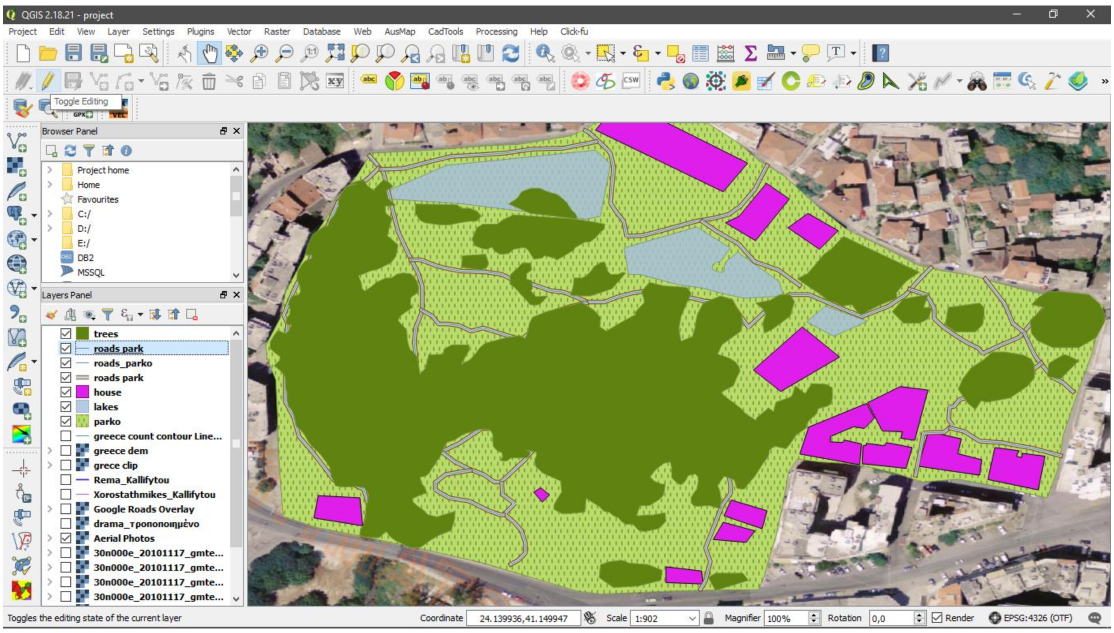


Figure 2.49 Editing is done with the Toggle Editing button

11. Click the Add feature button. Click on the map canvas to add a new vertex (see Figure 1.50). Add new vertices along the road feature. Once you have digitized a road segment, right-click to end the feature. NOTE: You can use the scroll wheel of the mouse to zoom in or out while digitizing. You can also hold the scroll button and move the mouse to pan around.

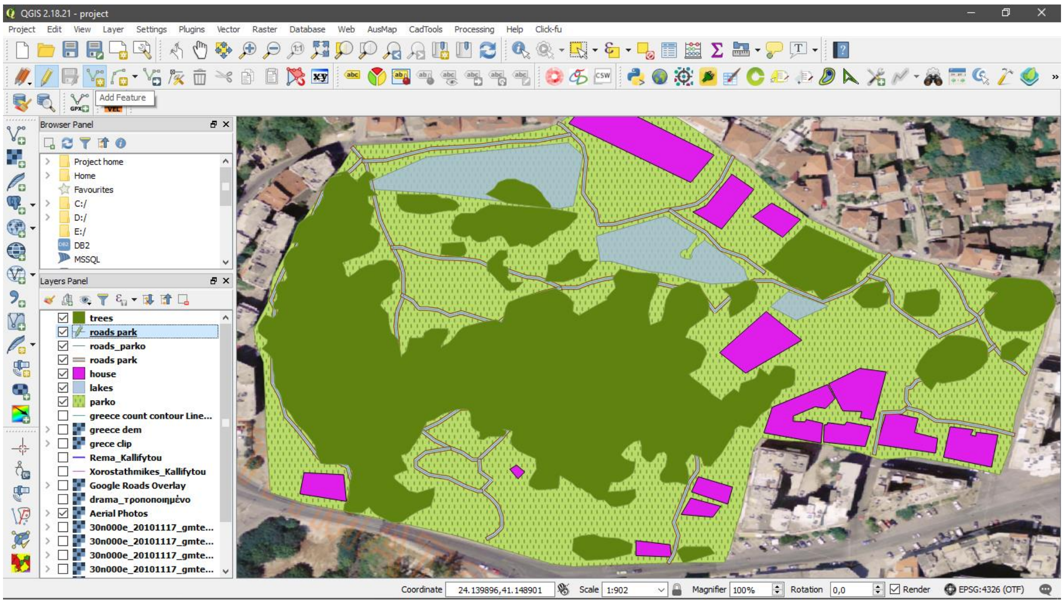


Figure 2.48 How to add a new vertex in line layer

12. After you right-click to end the feature, you will get a pop-up dialog called Attributes (see Figure 1.51). Here you can enter attributes of the newly created feature. Since the pkuid is an auto-incrementing field, you will not be able to enter a value manually. Leave it blank and enter the road name as it appears on the topo map. Optionally, assign a Road Class value as well. Click OK.

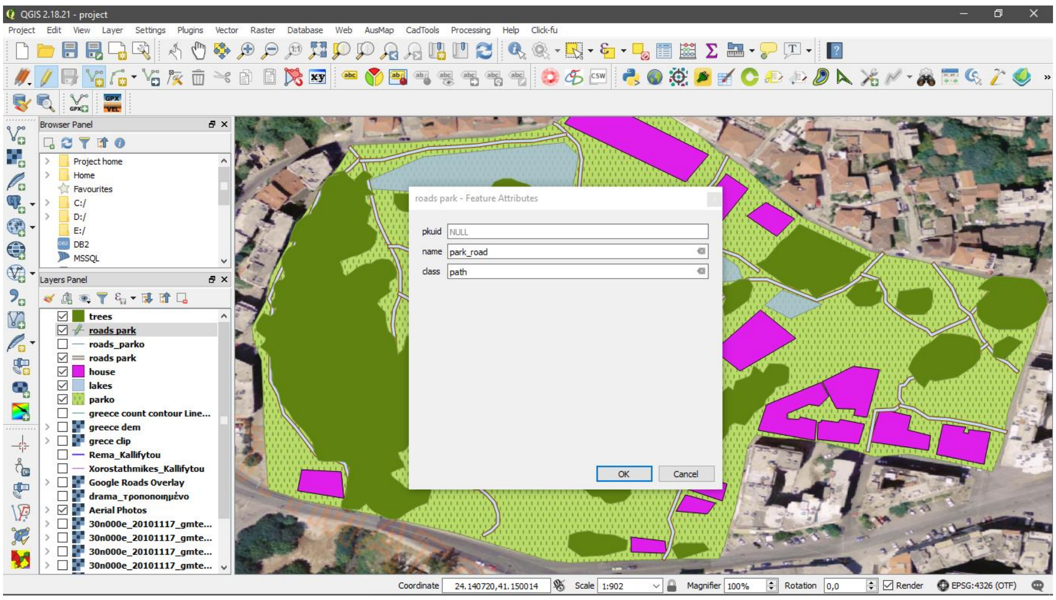


Figure 2.51 How to enter attributes of the newly created feature

13. The default style of the new line layer is a thin line. Let's change it so we can better see the digitized features on the canvas. Right click the Roads layer and select Properties (see Figure 1.52).

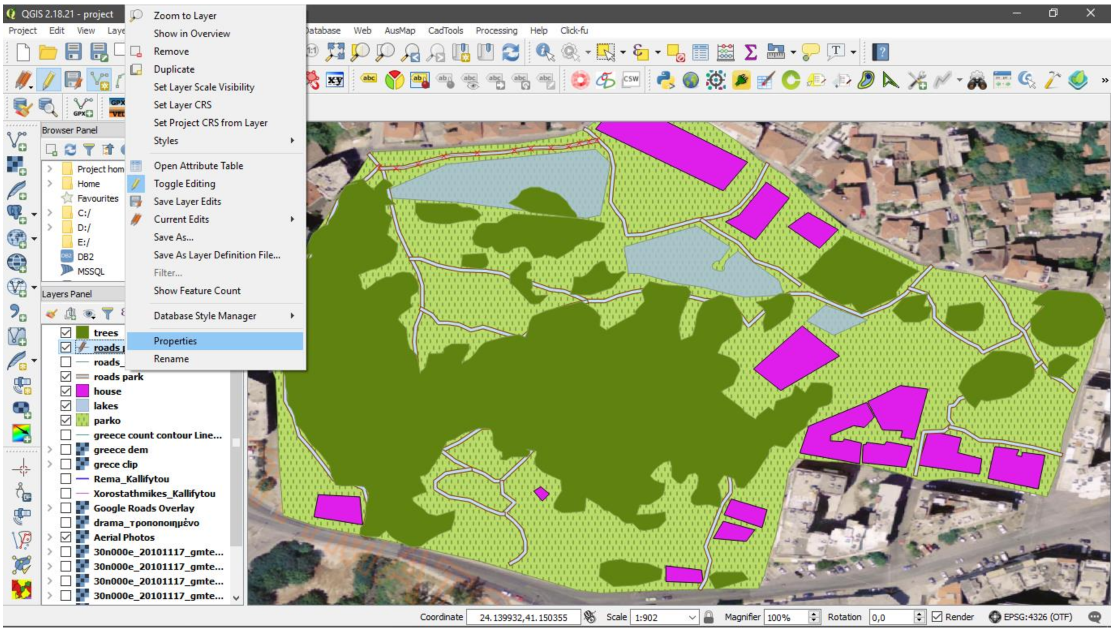


Figure 2.52 How to change a line feature

14. Select the Style tab in the Layer Properties dialog (see Figure 1.53). Choose a thicker line style such as Primary from the predefined styles. Click OK.

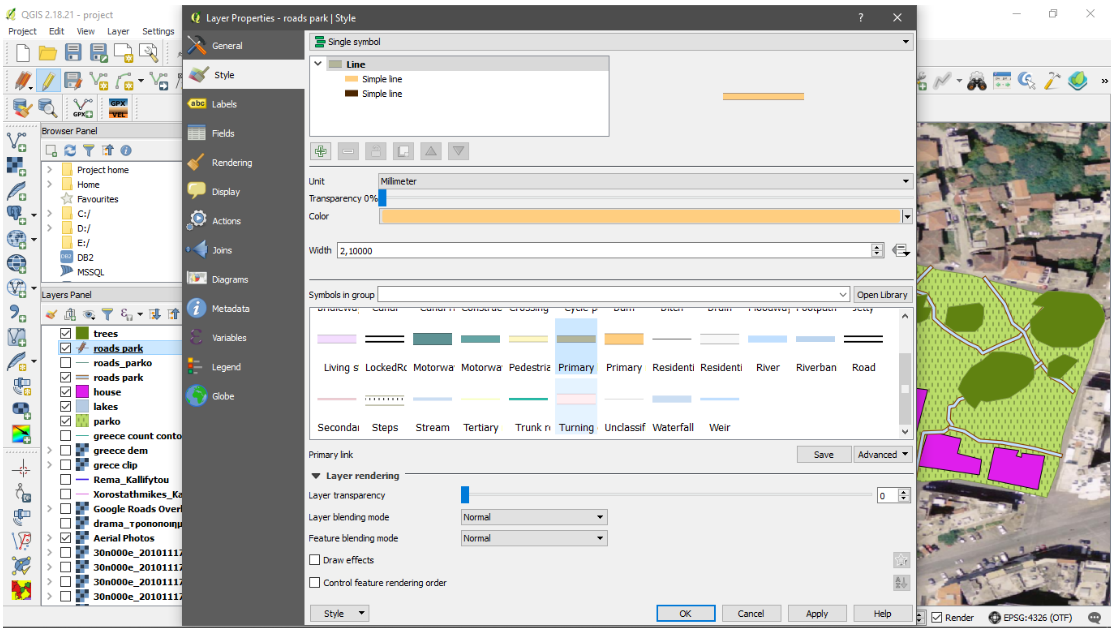


Figure 2.53 The Style Tab allow you change your line feature

15. Now you will see the digitized road feature clearly. Click Save Layer Edits to commit the new feature to disk (see Figure 1.54).

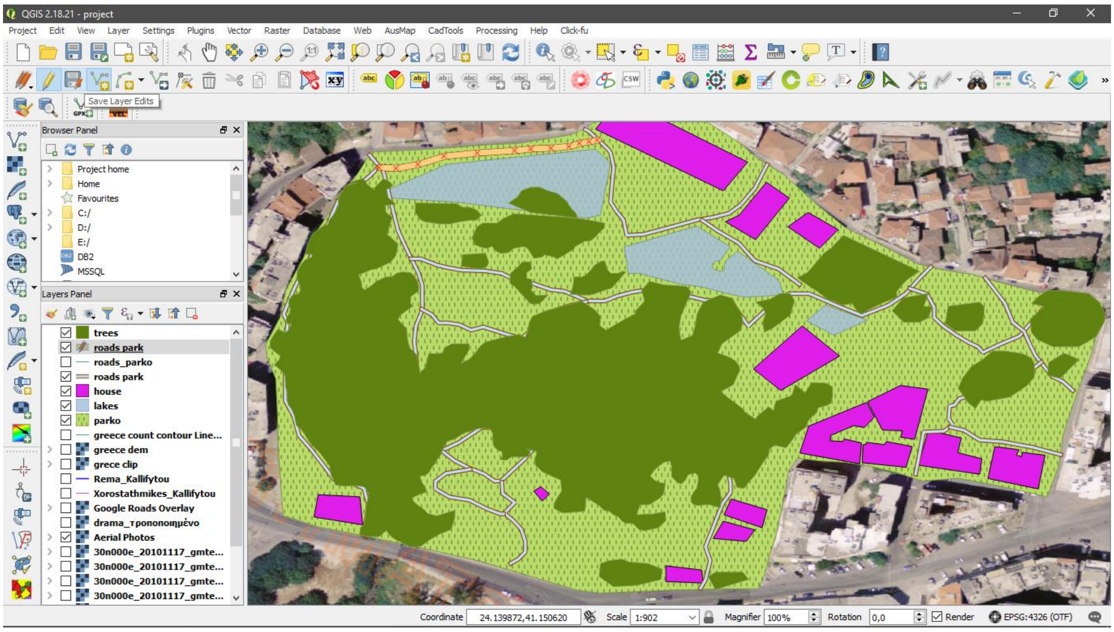


Figure 2.54 How to save the layer edits

16. Before we digitize remaining roads, it is important to update some other settings that are important to create an error free layer (see Figure 1.55). Go to Settings ‣ Snapping Options....

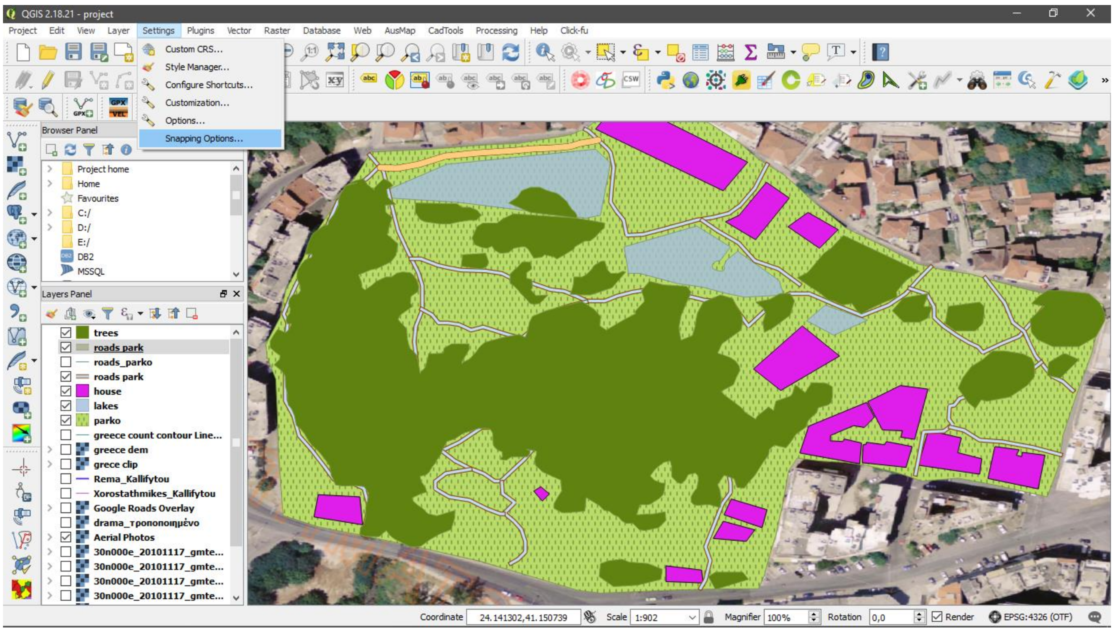


Figure 2.55 The Snapping Option

17. In the Snapping Options dialog, check the Enable topological editing (see Figure 1.56). This option will ensure that the common boundaries are maintained correctly in polygon layers. Also check the Enable snapping on intersection which allows you to snap on an intersection of a background layer.

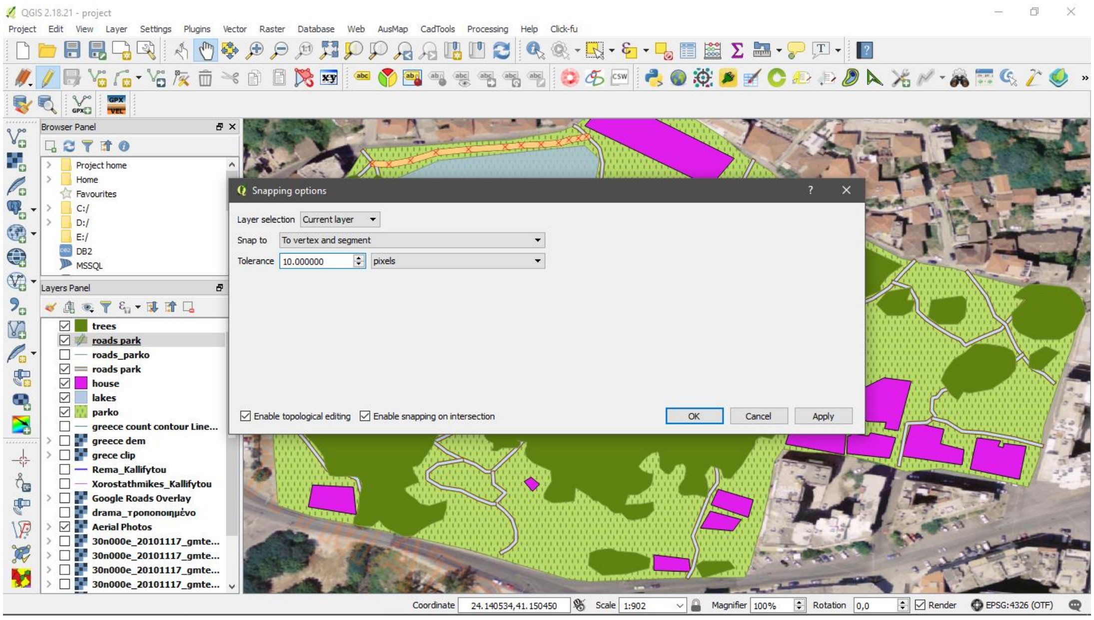


Figure 2.56 The Snapping Options dialog box

18. Now you can click Add feature button and digitize other roads around the park (see Figure 1.57). Make sure to click Save Edits after you add a new feature to save your work. A useful tool to help you with digitizing is the **Node Tool**. Click the Node Tool button.

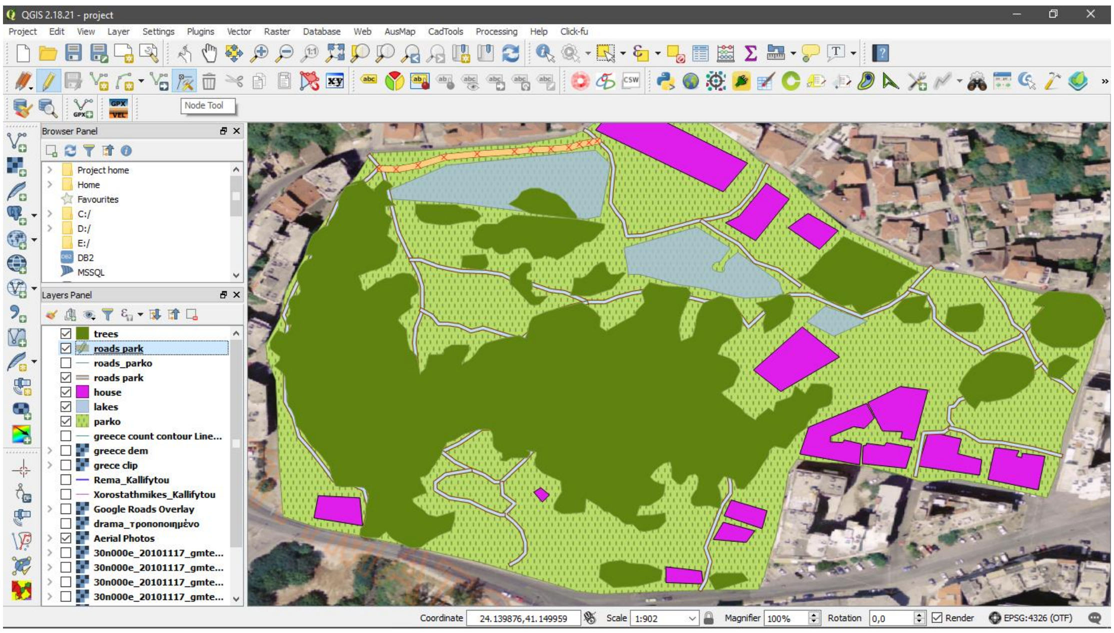


Figure 2.57 The Add feature button allows digitizing other roads

19. Once the node tool is activated, click on any feature to show the vertices. Click on any vertex to select it (see Figure 1.58). The vertex will change the color once it is selected. Now you can click and drag your mouse to move the vertex. This is useful when you want to make adjustments after the feature is created. You can also delete a selected vertex by clicking the Delete key.

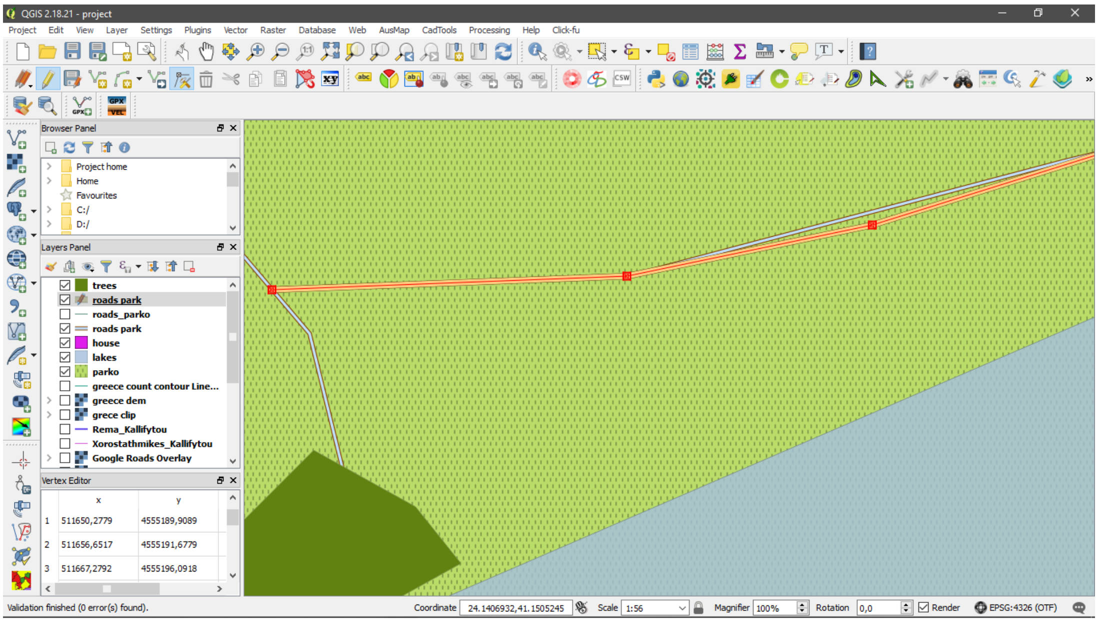


Figure 2.58 How to make adjustments after the feature is created

20. Once you have finished digitizing all the roads, click the Toggle Editing button (see Figure 1.59).

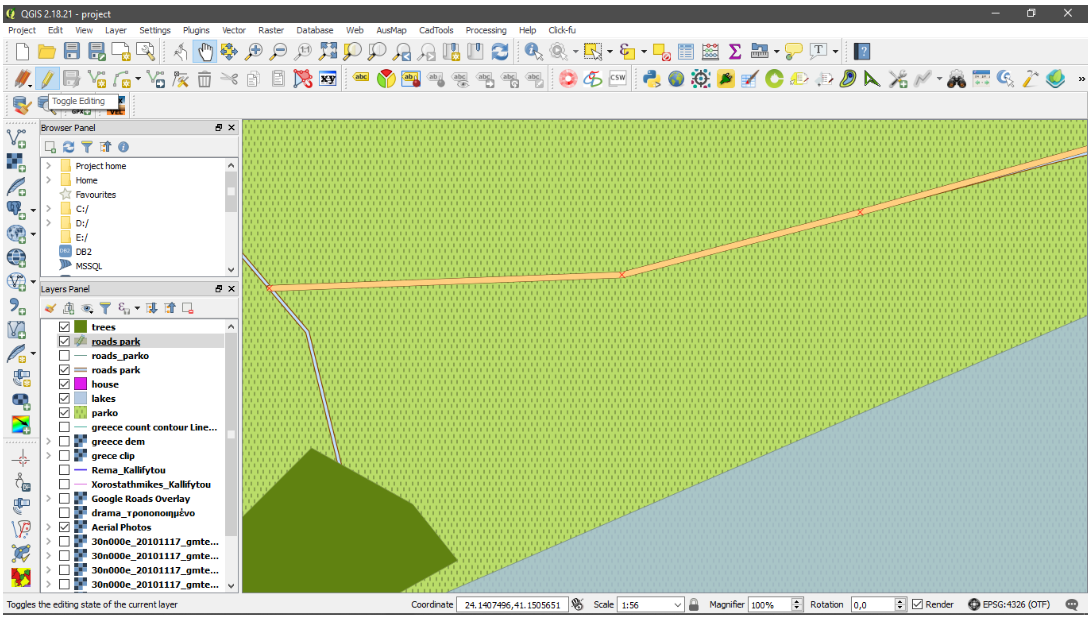


Figure 2.59 When digitizing is finalized click the Toggle Editing button

21. Now we will create a polygon layer representing the park boundaries (see Figure 1.60). Go to Layer ‣ New ‣ New Spatialite Layer…. Select thenztopo.sqlite database from the dropdown list. Name the new layer as Parks. Select Polygon as the Type. Create a new attribute called Name. Click OK.

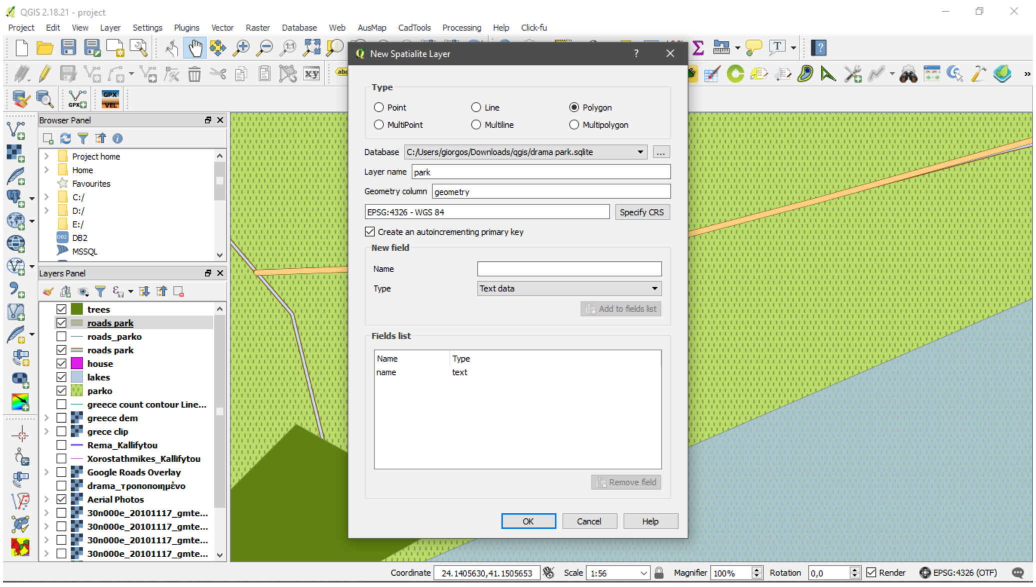


Figure 2.60 How to create a polygon layer

22. Click the Add feature button and click on the map canvas to add a polygon vertex (see Figure 1.61). Digitize the polygon representing the park. Make sure you snap to the roads vertices so there are no gaps between the park polygons and road lines. Right-click to finish the polygon.

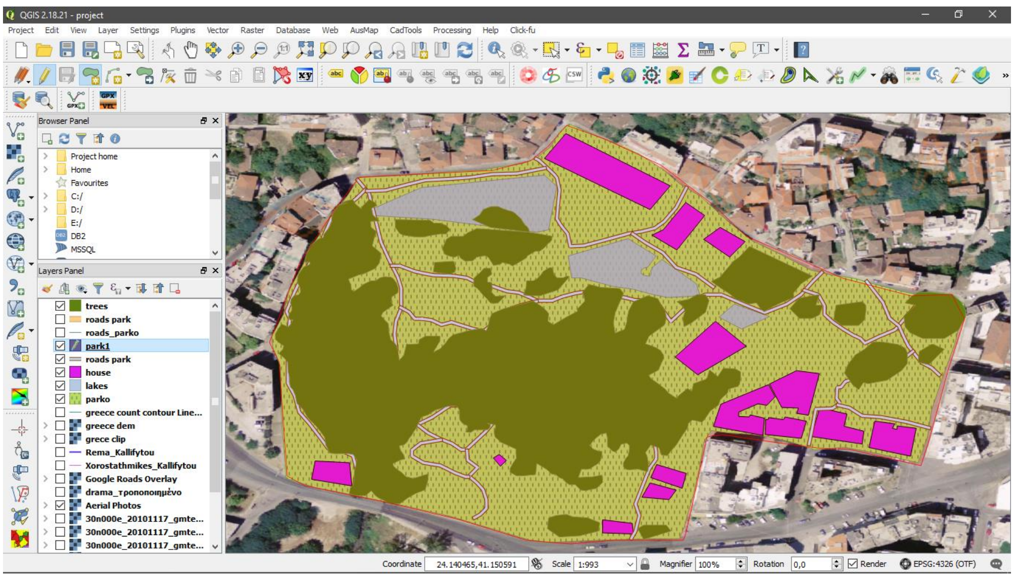


Figure 2.61 The Add feature button can add a polygon vertex

23. Enter the park name in the Attributes pop-up (see Figure 1.62).

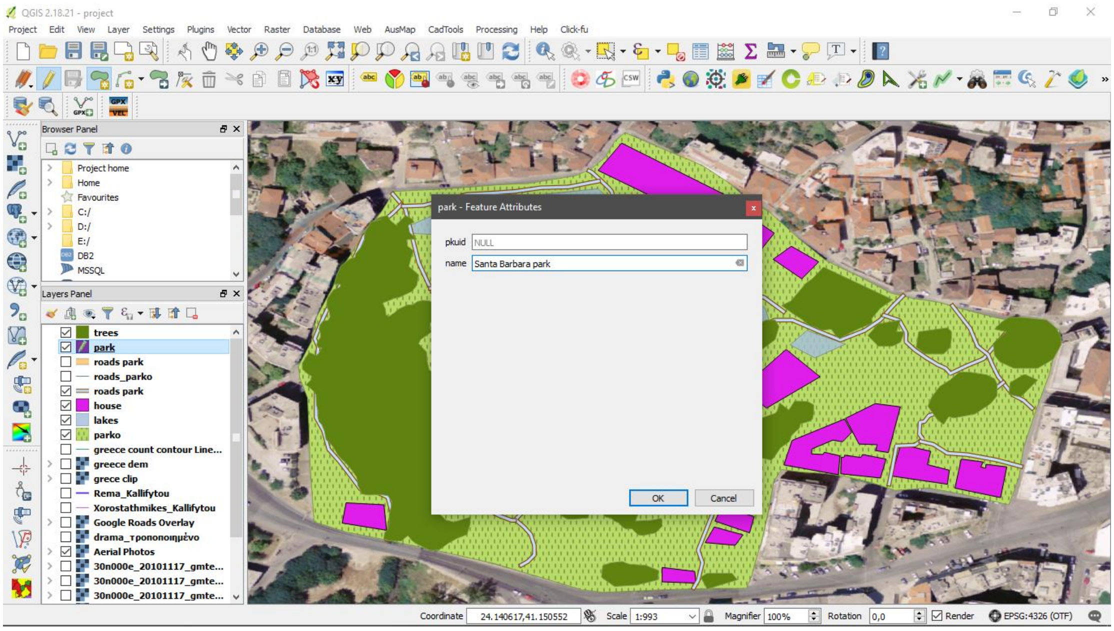


Figure 2.62 The Attributes pop-up

24. Polygon layers offer another very useful setting called **Avoid intersections of new polygons** (see Figure 1.63). Go to Settings ‣ Snapping Options.... Check the box in the Avoid Int column in the row for the Parks layer. Click OK.

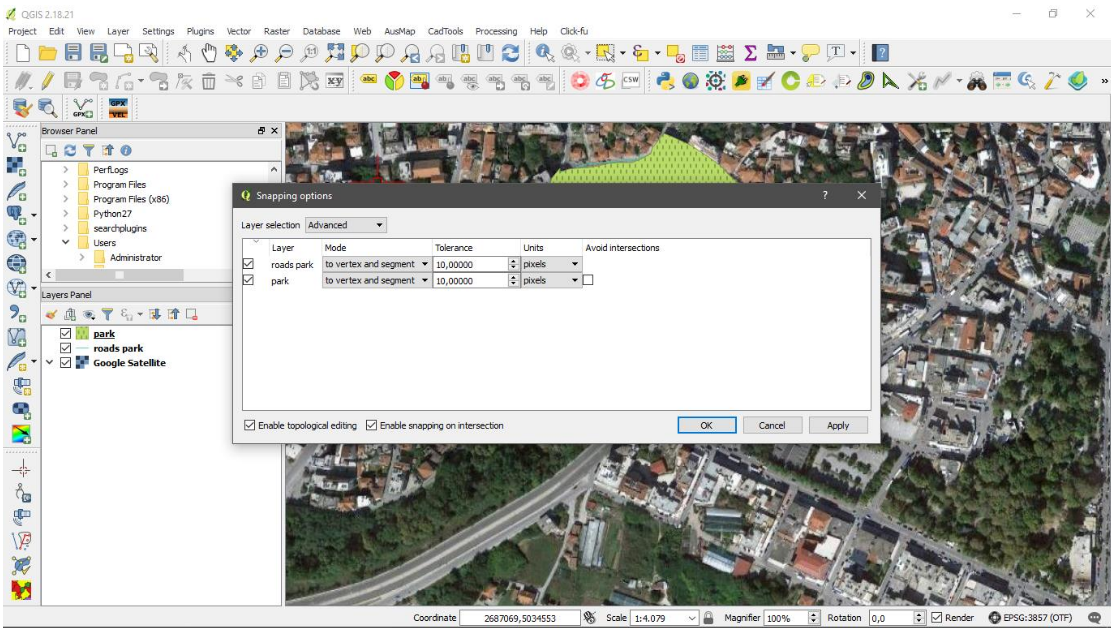


Figure 2.63 Avoid intersections of new polygons is another very useful setting for polygon layers

25. Now click on Add feature to add a polygon. With the **Avoid intersections of new polygons**, you will be able to quickly digitize a new polygon without worrying about snapping exactly to the neighboring polygons (see Figure 1.64).

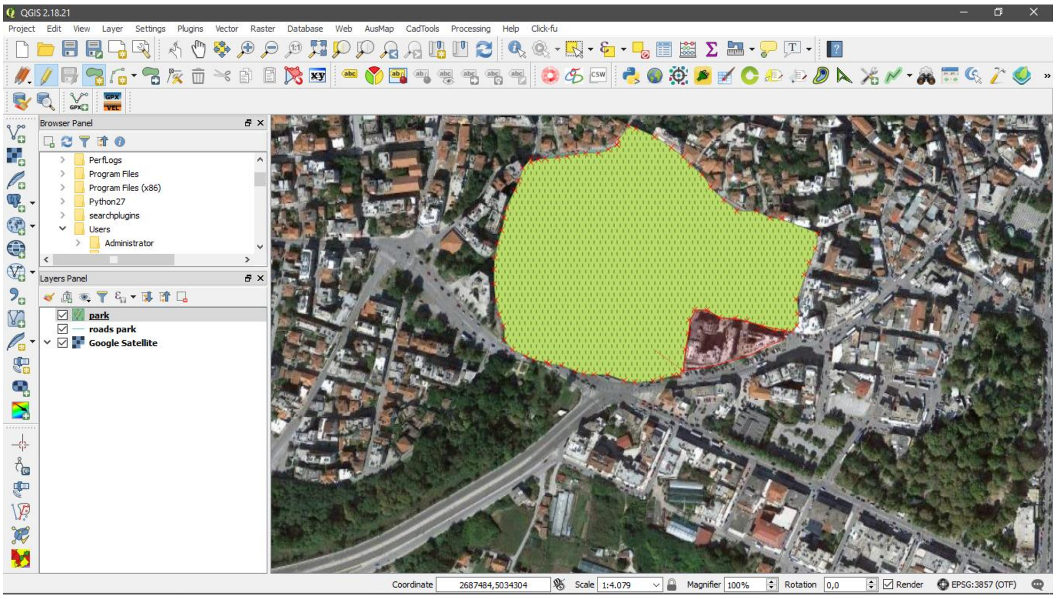


Figure 2.64 How to add a new polygon without worrying about snapping exactly to the neighboring polygons

26. Right-click to finish the polygon and enter the attributes (see Figure 1.65). Magically the new polygon is shrunk and snapped exactly to the boundary of the neighboring polygons! This is very useful when digitizing complex boundaries where you need not be very precise and still have topologically correct polygon. Click Toggle Editing to finish editing the Parks layer.

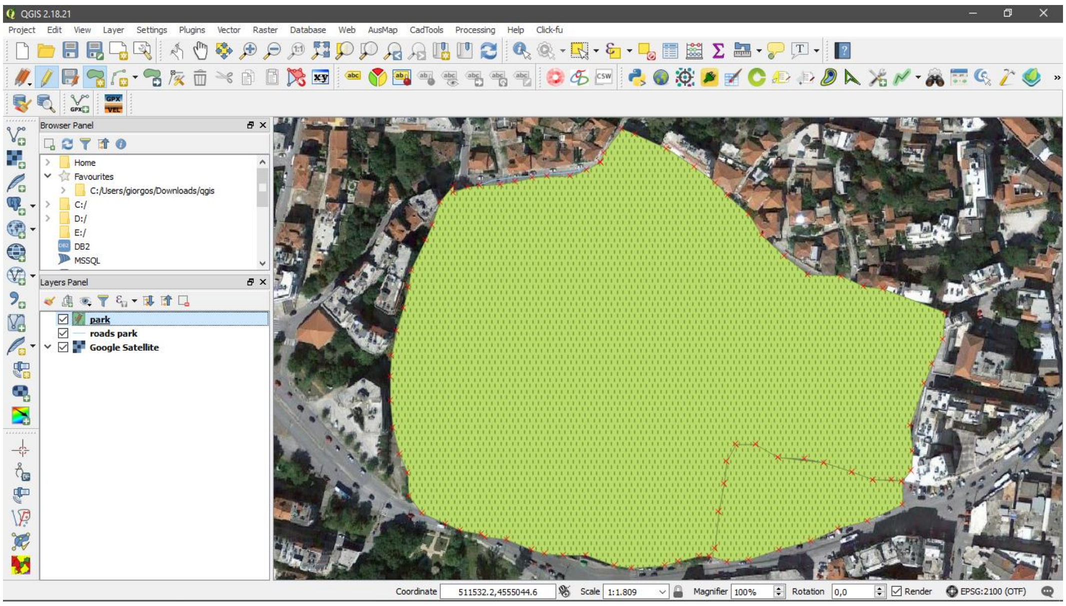


Figure 2.65 How to finish the polygon and enter the attributes

27. Now it is time to digitize a buildings layer (see Figure 1.66). Create a new polygon layer named Buildings by going to Layer ▸ New ▸ New Spatialite Layer

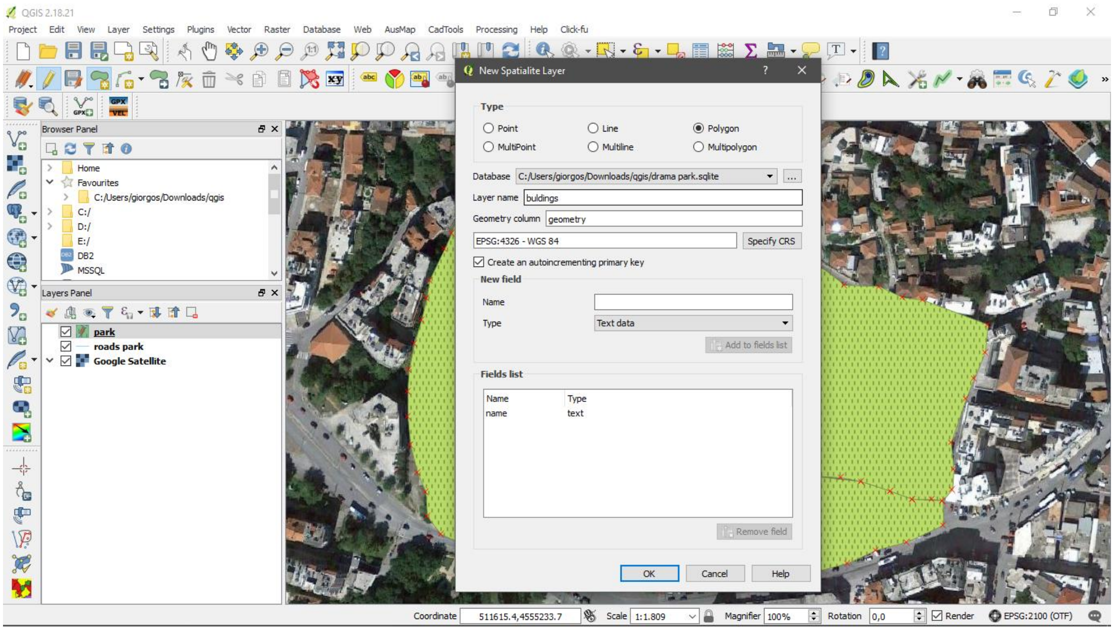


Figure 2.66 Creating a new polygon layer

28. Once the Buildings layer is added, turn off the Parks and Roads layer so the base topographic map is visible. Select the Buildings layer and click Toggle Editing (see Figure 1.67).

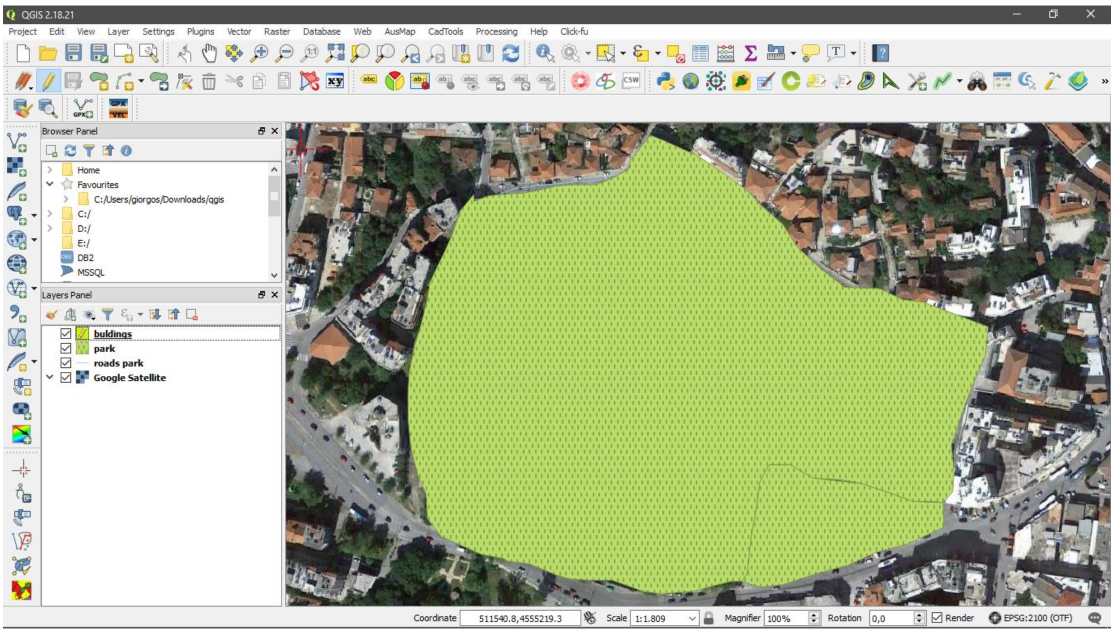


Figure 2.67 How to edit a new layer

29. Digitizing buildings can be a cumbersome task. Also it is difficult to add vertices manually so that the edges are perpendicular and form a rectangle. We will use a plugin called **Rectangles Ovals Digitizing** to help with this task (see Figure 1.68). See *Using Plugins* to see how to search and install plugins. Once the **Rectangles Ovals Digitizing** plugin is installed, you will see a new toolbar appear above the canvas.

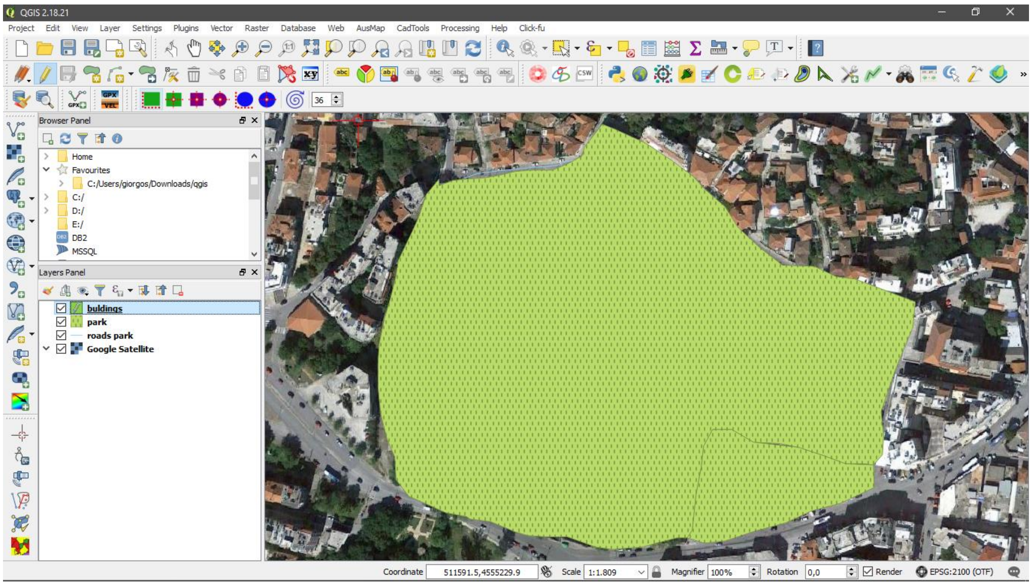


Figure 2.68 Rectangles Ovals Digitizing plugin can help digitizing buildings easier

30. Zoom to an area with the buildings and click Rectangle by Extent button. Click and drag the mouse to draw a perfect rectangle (see Figure 1.69). Similarly, add remaining buildings.

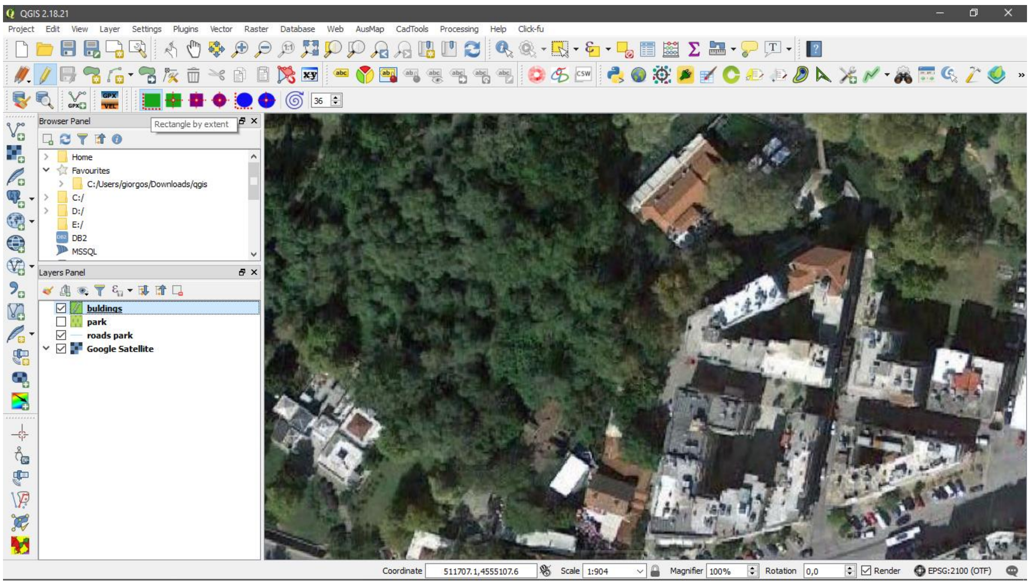


Figure 2.69 How to digitize a perfect rectangular

31. You will notice that some buildings are not vertical. We will need to draw a rectangle at an angle to match the building footprint. Click the Rectangle from center (see Figure 1.70).

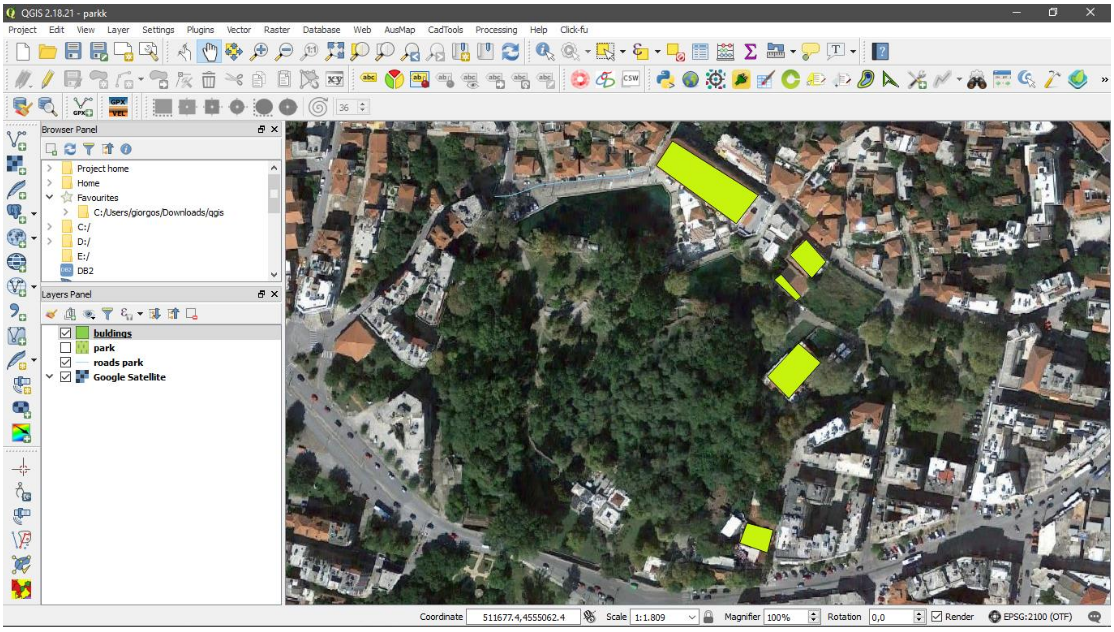


Figure 2.70 What to do in case some buildings are not vertical, part 1

32. Click at the center of the building and drag the mouse to draw a vertical rectangle (see Figure 1.71).

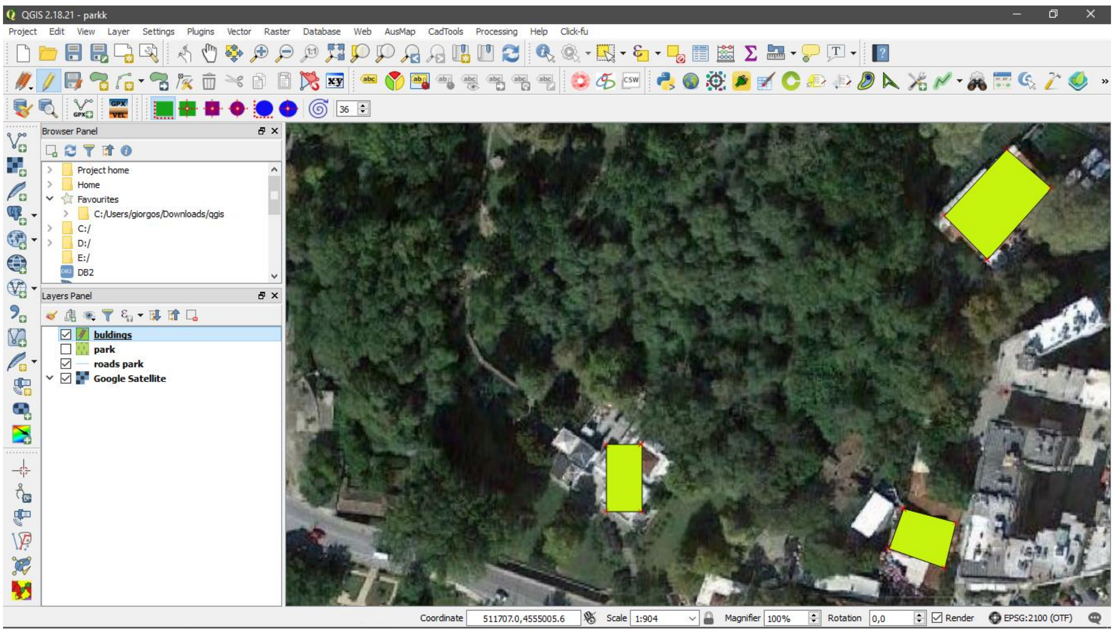


Figure 2.71 What to do in case some buildings are not vertical, part 2

33. We need to rotate this rectangle to match the image on the topographic map. The rotate tool is available in the **Advanced Digitizing** toolbar (see Figure 1.72). Right-click on an empty area on the toolbar section and enable the Advanced Digitizing toolbar.

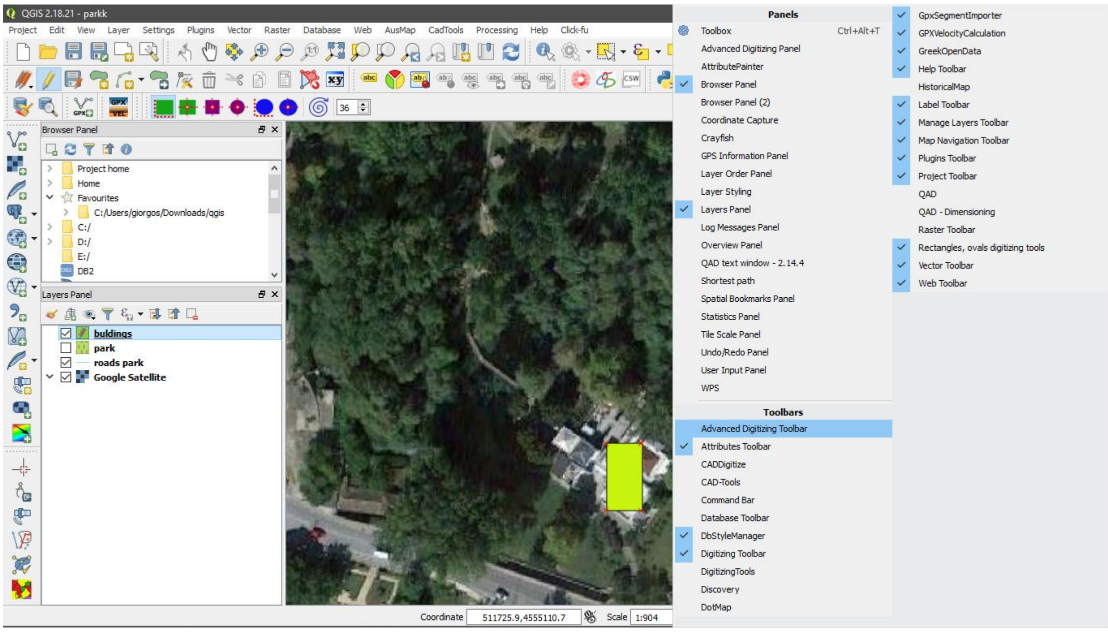


Figure 2.72 The Advanced Digitizing toolbar is for rotation

34. Click the Rotate Feature(s) button (see Figure 1.73).

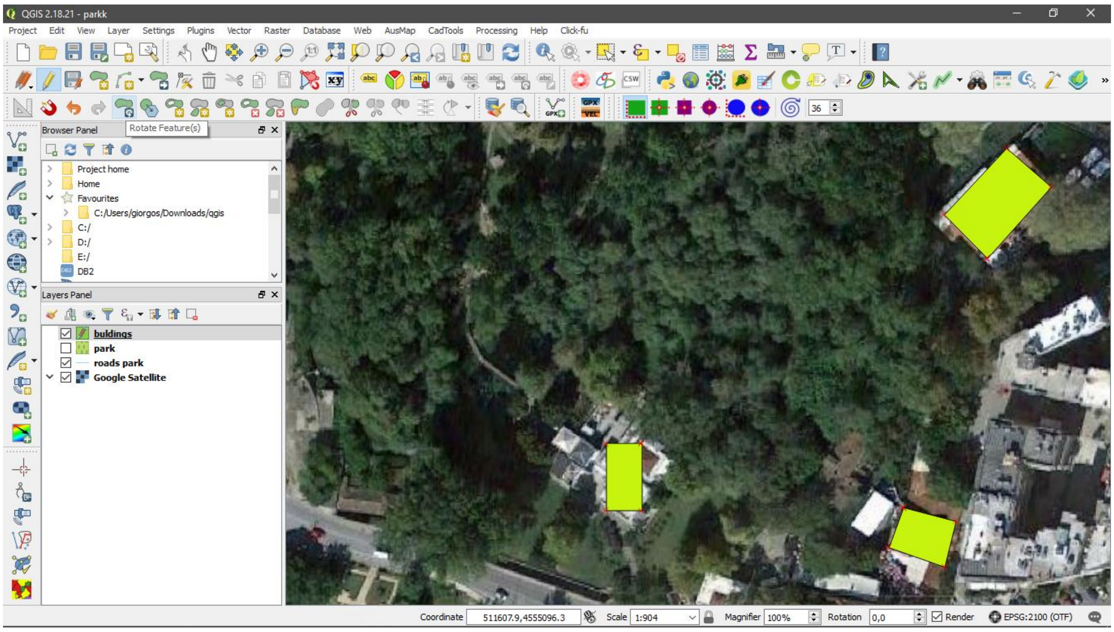


Figure 2.73 The Rotate Feature(s) button

35. Use the Select Single feature tool to select the polygon that you want to rotate (see Figure 1.74). Once the Rotate Feature(s) tool is activated, you will see crosshairs at the center of the polygon. Click exactly on that crosshairs and drag the mouse while holding the left-click button. A preview of the rotated feature will appear. Let go of the mouse button when the polygon aligns with the building footprint.

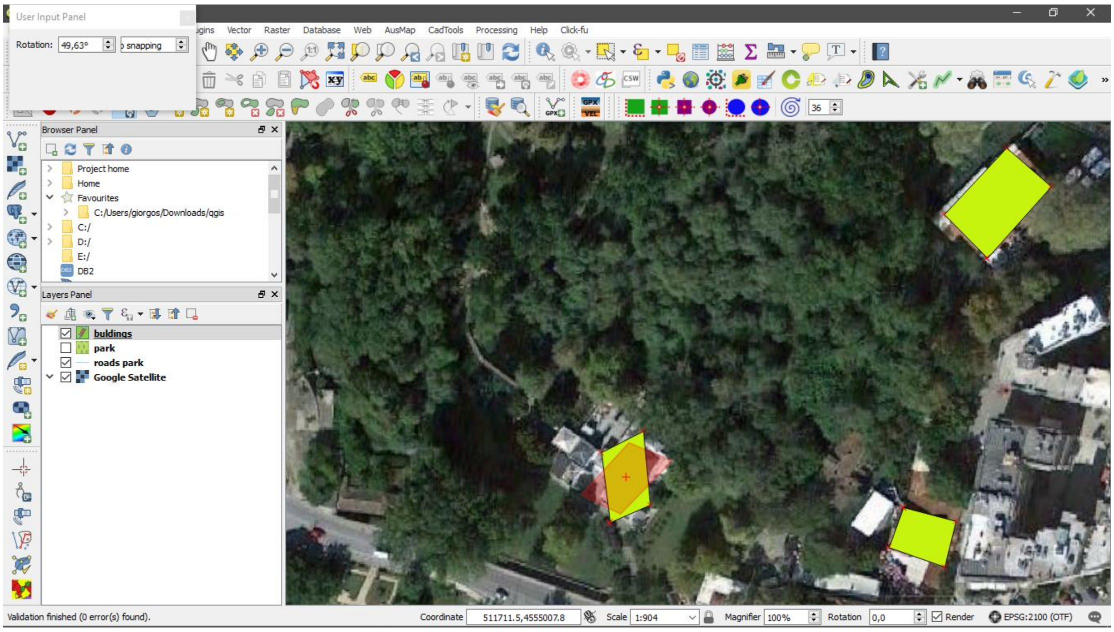


Figure 2.74 The Select Single feature tool to can rotate the polygon you select

36. Save the layer edits and click Toggle Editing once you finish digitizing all buildings (see Figure 1.75). You can drag the layers to change their order of appearance.

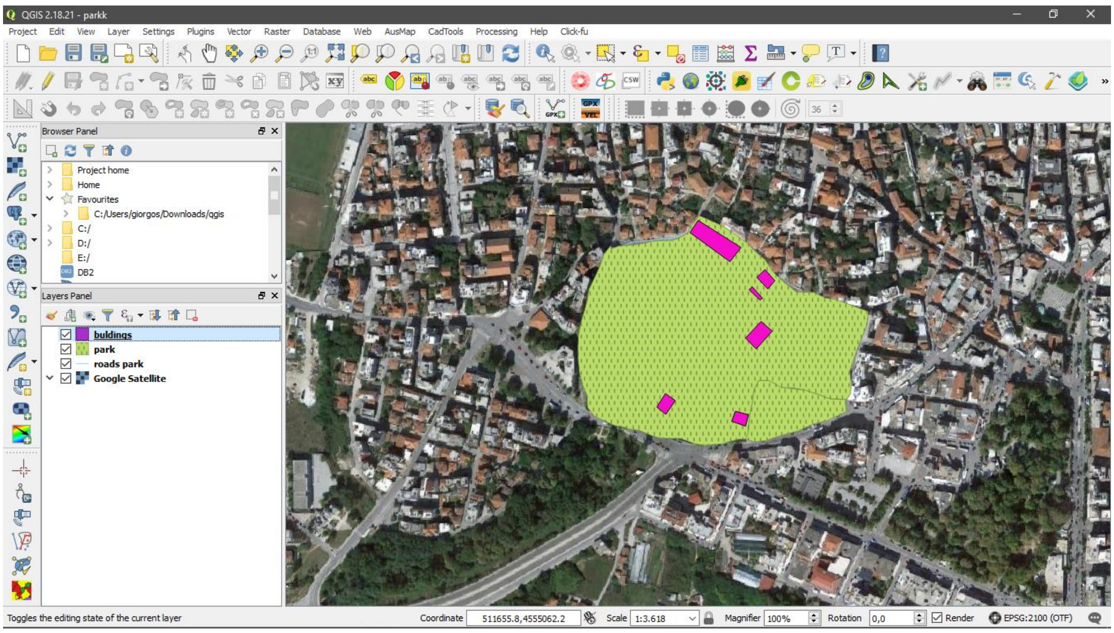


Figure 2.75 Saving the layer edits

37. The digitizing task is now complete (see Figure 1.76). You can play with the styling and labeling options in layer properties to create a nice looking map from the data you created.

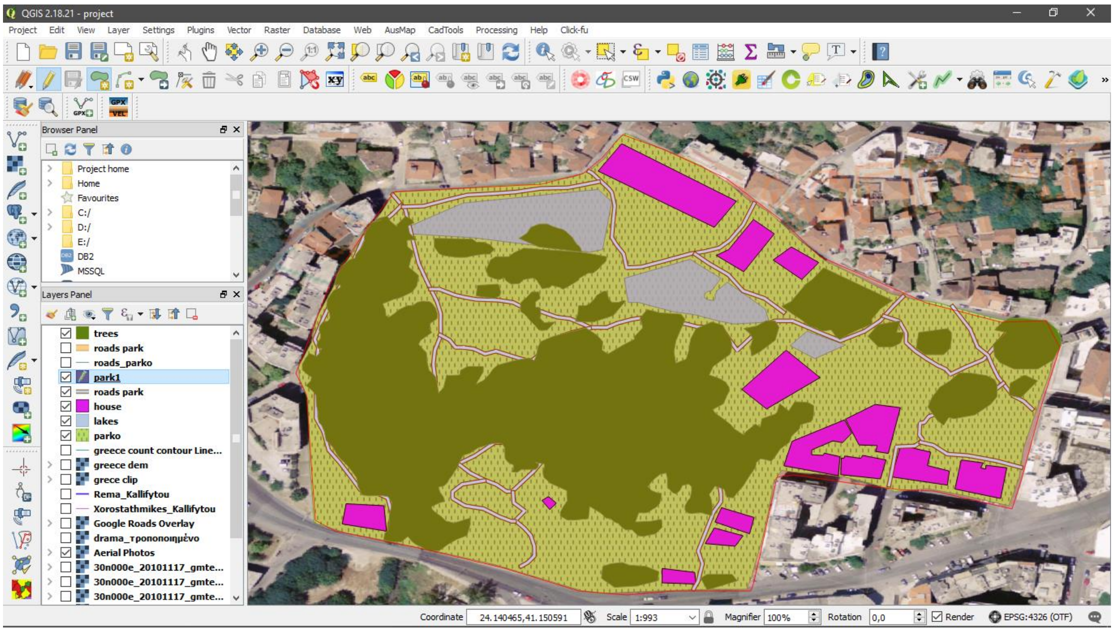


Figure 2.76 Finalization of the digitization

38. With a similar process the contour lines, the hydrologic network, the watershed boundaries can be digitized (see Figure 1.77).

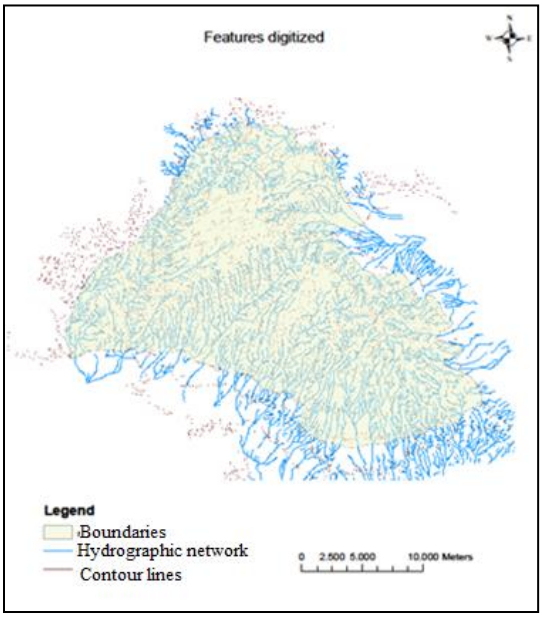


Figure 2.77 A digitized watershed with its boundaries, contour lines and the hydrologic network

2.4.3 Working with Terrain Data

Terrain or elevation data is useful for many GIS Analysis and it is often used in maps. QGIS has good terrain processing capabilities built-in. In this tutorial, we will work through the steps to generate various products from elevation data such as contours, hillshade etc. Specifically we will create contours and hillshade map for Drama in northern Greece.

We will be working with GMTED2010 dataset from USGS. This data can be downloaded from the USGS Earthexplorer site. GMTED (Global Multi-resolution Terrain Elevation Data) is a global terrain dataset that is the newer version of GTOPO30 dataset.

First we see how to search and download the relevant data from USGS Earthexplorer.

1. Go to the USGS Earthexplorer (see Figure 1.78). In the Search Criteria tab, search for the place name Drama, Greece. Click on the result to select the location.

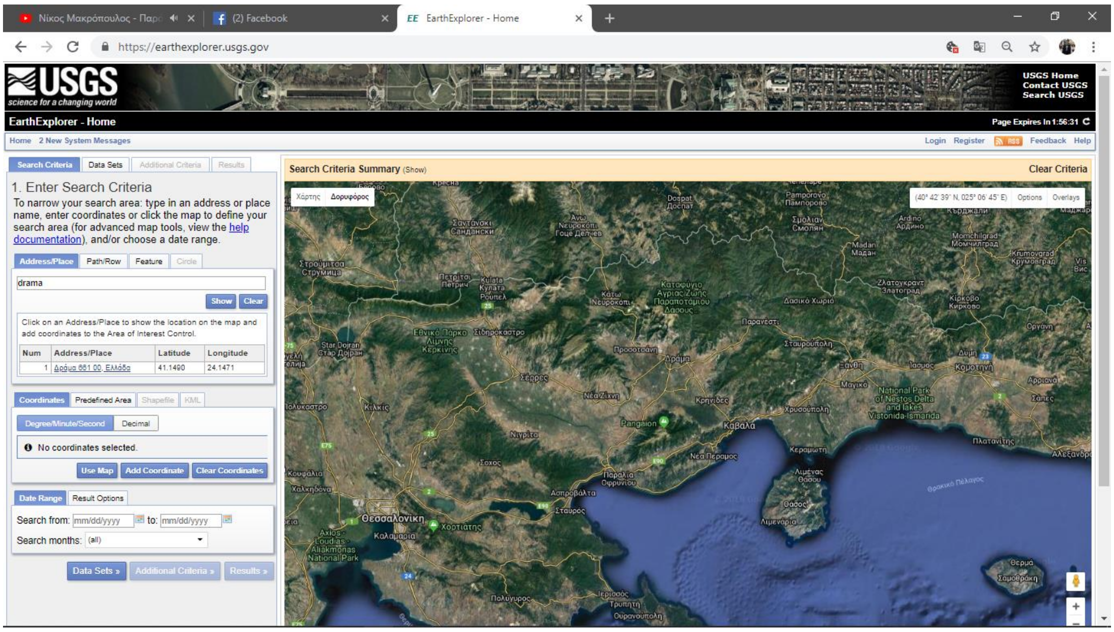


Figure 2.78 Using USGS Earthexplorer.

2. In the Data Sets tab, expand the Digital Elevation group, and check GMTED2010 (see Figure 1.79).

3. You can now skip to the Results tab and see the part of the dataset intersecting your search criteria (see Figure 1.80). Click the Download Options button. You will have to log in to the site at this point. You can create a free account if you do not have one.

4. Select the 30 ARC SEC option and click Select Download Option (see Figure 1.81). You will now have a file named GMTED2010N10E060_300.zip. Elevation data is distributed in various raster formats such as ASC, BIL, GeoTiff etc. QGIS supports a wide variety of raster formats via the GDAL library. The GMTED data comes as GeoTiff files which are contained in this zip archive.

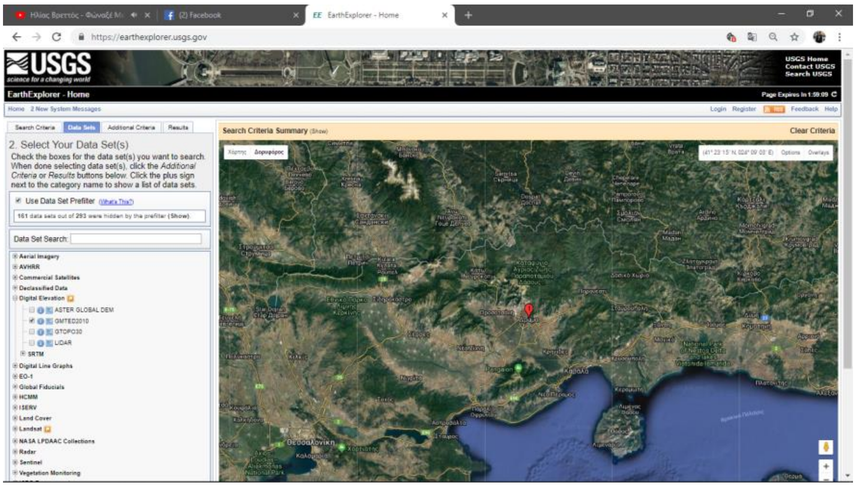


Figure 2.79 The Data Sets tab provide the Digital Elevation group

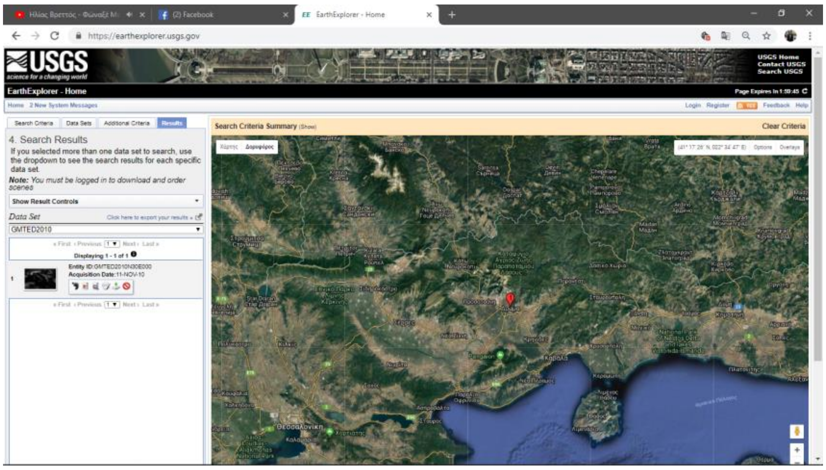


Figure 2.80 How to find the dataset intersecting your search criteria

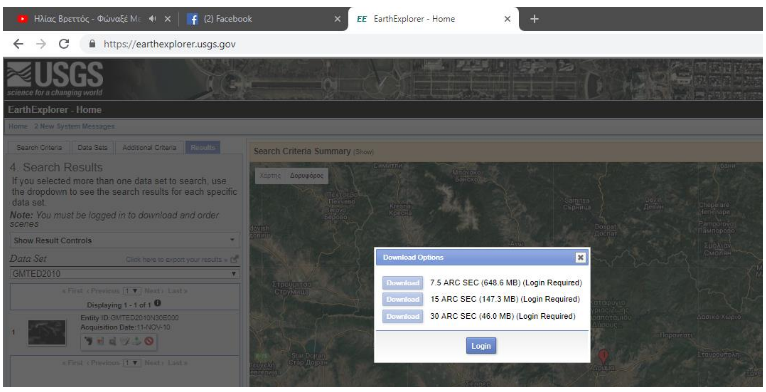


Figure 2.81 The Download options

5. Procedure includes: Open Layer ‣ Add Raster Layer and browse to the downloaded zip file (see Figure 1.82).

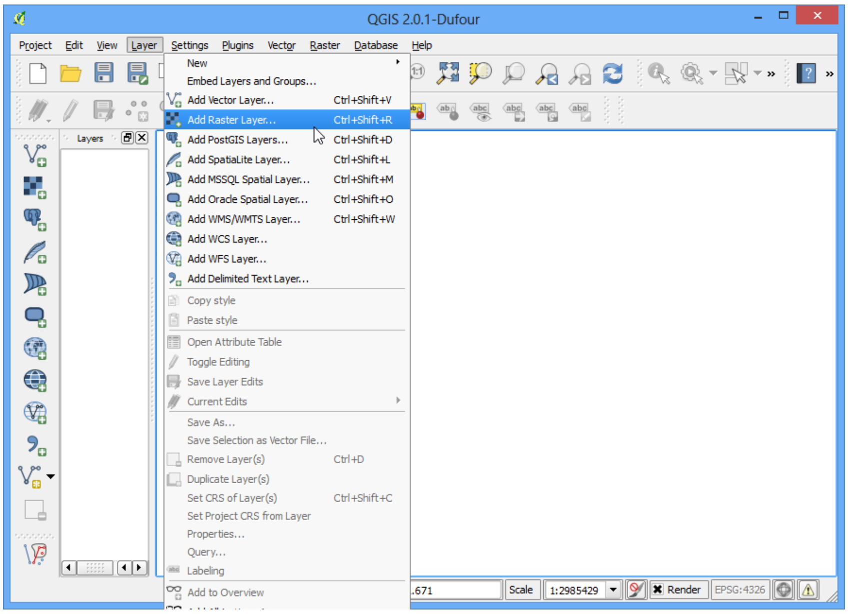


Figure 2.82 How to open and add a layer

6. There are many different files generated from different algorithms (see Figure 1.83). For this tutorial, we will use the file named 10n060e_20101117_gmted_mea300.tif.

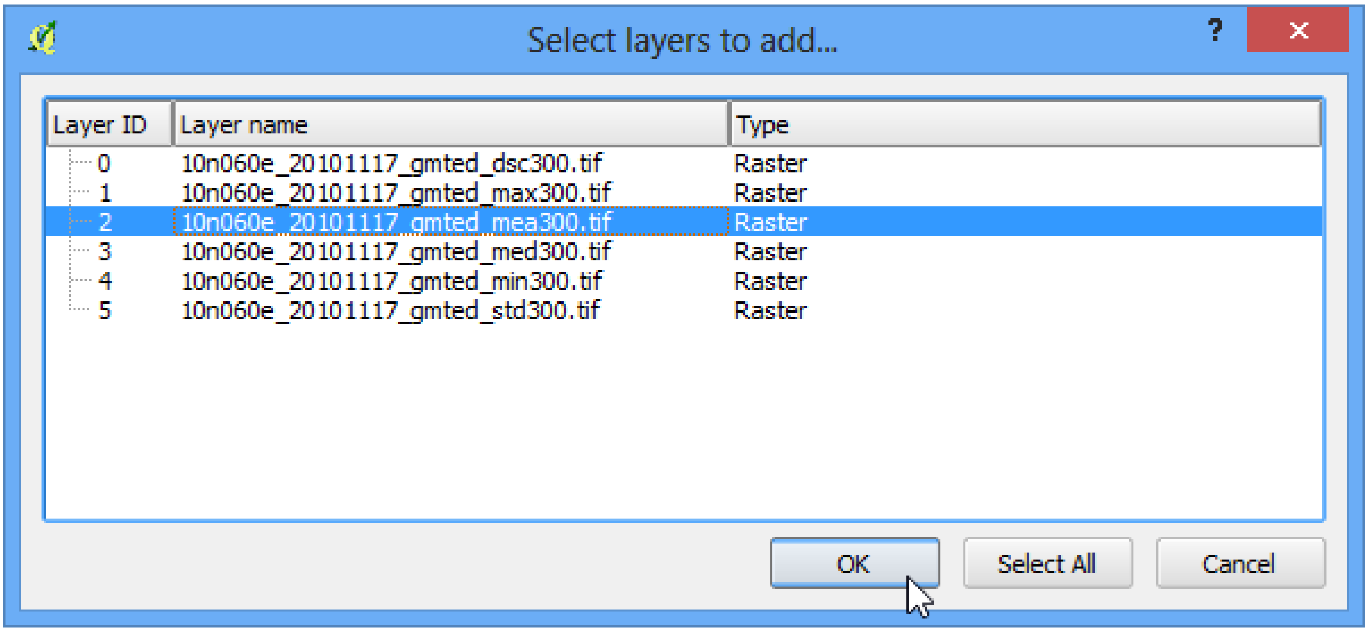


Figure 2.83 There can be many different files generated from different algorithms

7. You will see the terrain data rendered in the QGIS Canvas (see Figure 1.84). Each pixel in the terrain raster represents the average elevation in meters at that location. The dark pixels represent areas with low altitude and lighter pixels represent areas with high altitude.

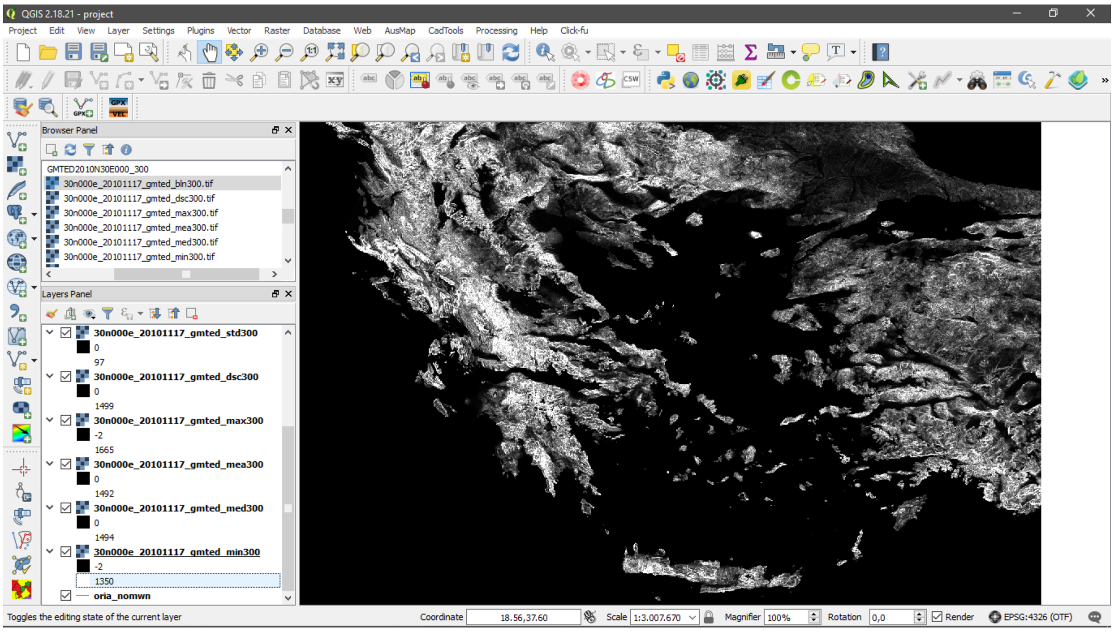


Figure 2.84 the terrain data rendered in the QGIS Canvas

8. Let's find our area of interest. From Wikipedia, we find that the coordinates for our area of interest – Drama City - is located at the coordinates 41°9′ N 24°8′ E. Note that QGIS uses the coordinates in (X,Y) format, so you must use the coordinates as (Longitude, Latitude). Paste 24.8, 41.9 these at the bottom of QGIS window where it says Coordinate and press Enter. The viewport will be centered at this coordinate (see Figure 1.85). To zoom in, Enter 1:1000000 in the Scale field and press Enter. You will see the viewport zoom to the area around Drama.

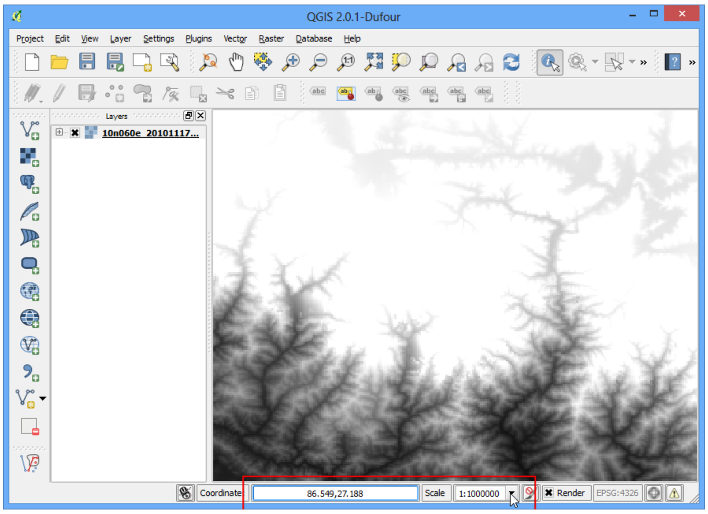


Figure 2.85 The viewport can be centered at the specified coordinates

9. We will now crop the raster to this area of interest (see Figure 1.86). Select the Clipper tool from Raster ‣ Extraction ‣ Clipper. NOTE: We will now crop the raster to this area of interest. Select the Clipper tool from Raster ? Extraction ? Clipper.

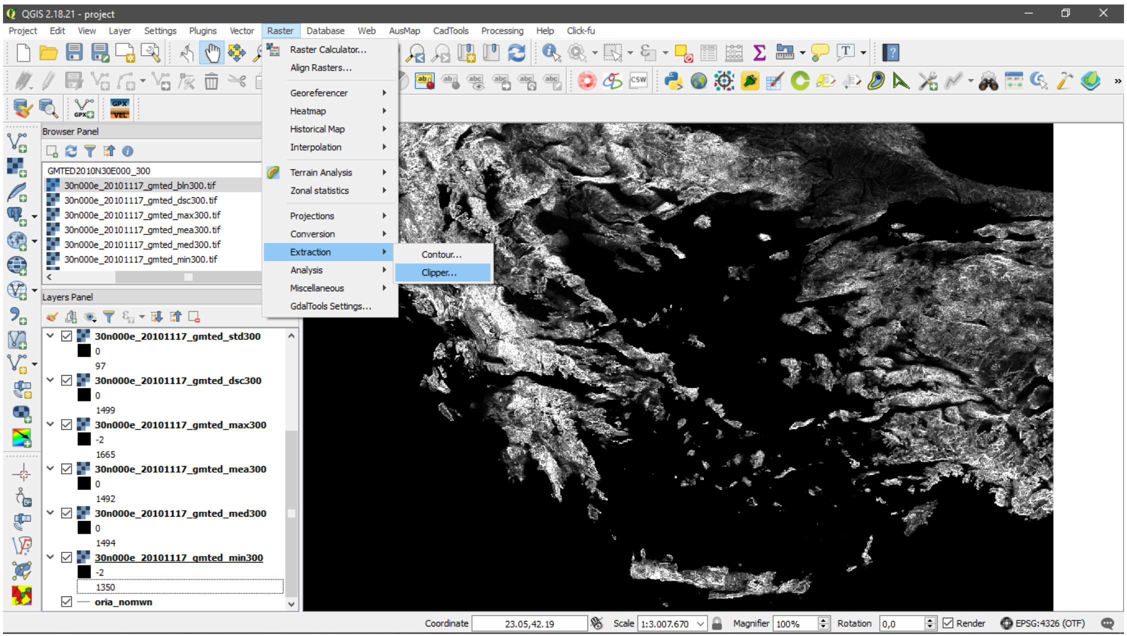


Figure 2.86 The Clipper tool can crop the raster to the area of interest

10. In the Clipper window (see Figure 1.87), name your output file as everest_gmted30.tif. Select the Clipping mode as Extent.

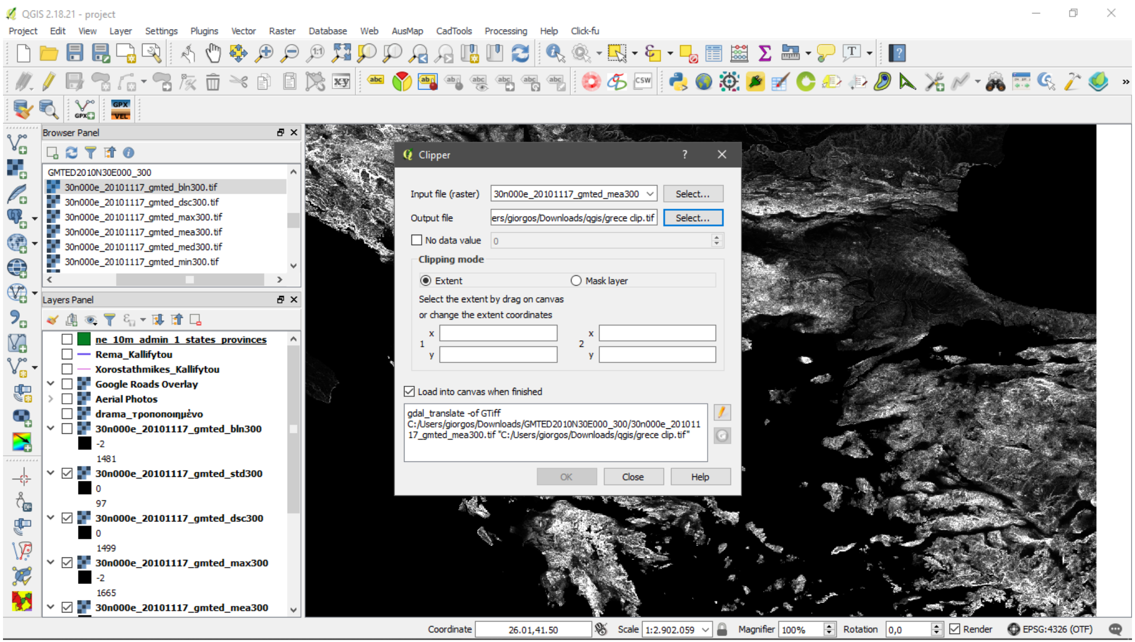


Figure 2.87 The Clipper window

11. Keep the Clipper window open and switch to the main QGIS window (see Figure 1.88). Hold your left mouse button and draw a rectangle covering the full canvas.

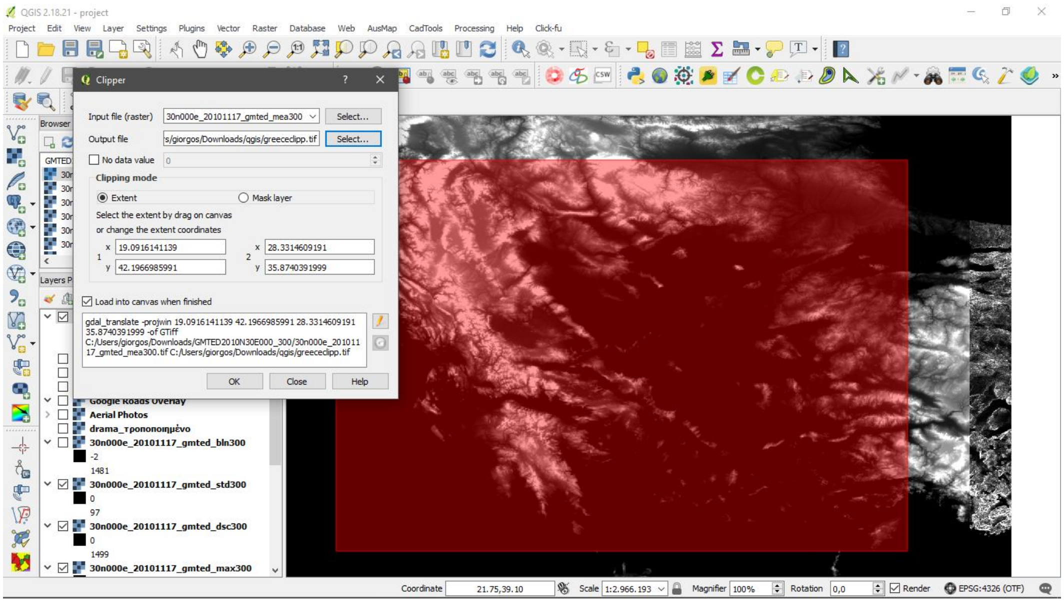


Figure 2.88 How to clip the area of interest

12. Now back in the Clipper window, you will see the coordinates auto-populated from your selection (see Figure 1.89). Make sure the Load into canvas when finished option is checked, and click OK.

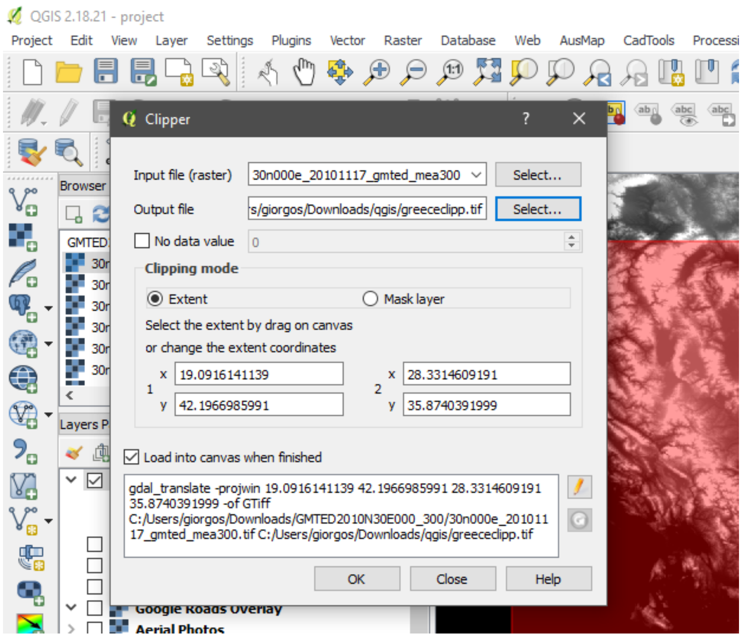


Figure 2.89 The Clipper window after the cropping process

13. Once the process finishes, you will see a new layer loaded in QGIS (see Figure 1.90). This layer covers only the area around Mt. Everest. Now we are ready to generate contours. Select the contour tool from Raster ▸ Extraction ▸ Contour.

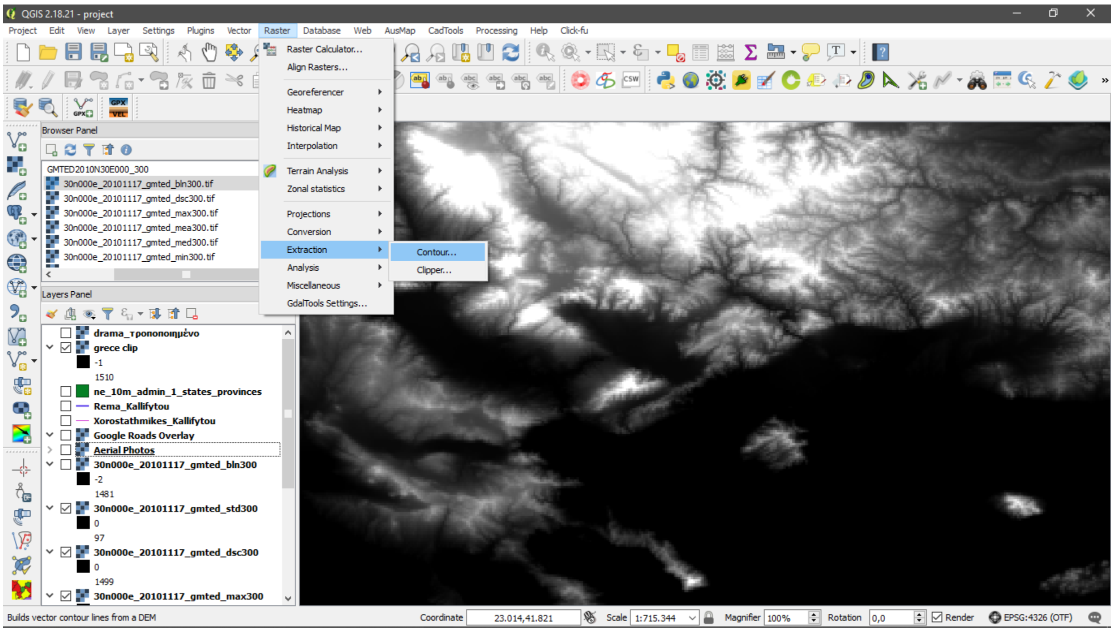


Figure 2.90 The new layer loaded in QGIS after the cropping process

14. In the Contour dialog, select everest_gmted30 as the Input file. Name the Output file for contour lines as drama_countours.shp. We will generate contour lines for 100m intervals, so put 100 as the Interval between contour lines (see Figure 1.91). Also check the Attribute name option so elevation value will be recorded as attribute of each contour line. Click OK.

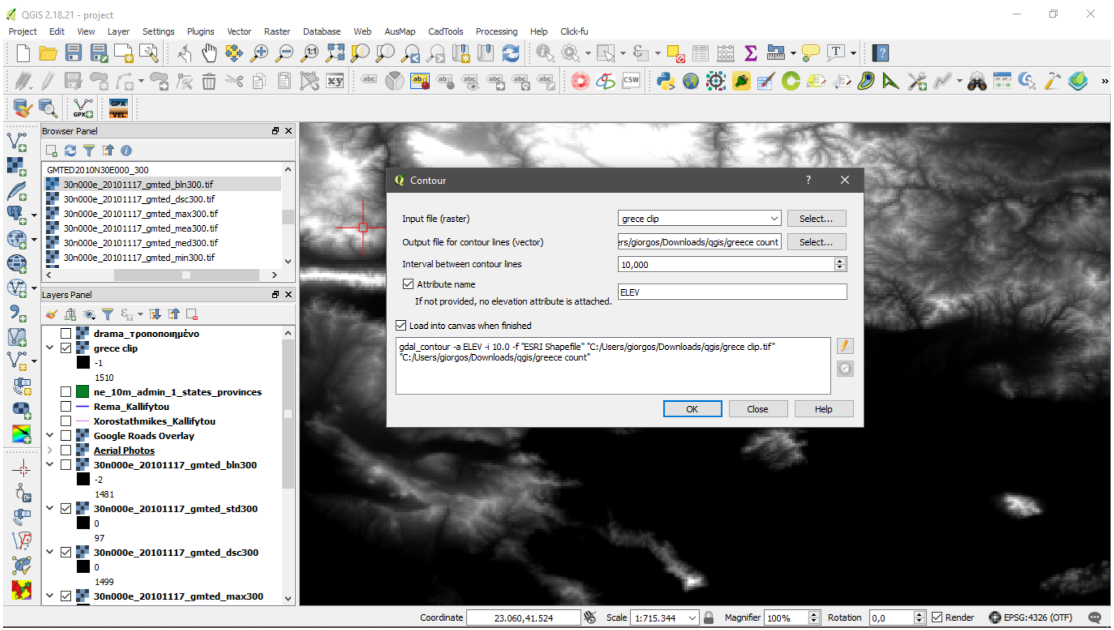


Figure 2.91 Creating contour lines

15. Once the processing is complete, you will see contour lines loaded into the canvas (see Figure 1.92). Each line in this layer represents a particular elevation. All points along a contour line in the underlying

raster would be at the same elevation. The closer the lines, the steeper the slope is. Let's inspect the contours a bit more. Right click on the contours layer and choose Open Attribute Table.

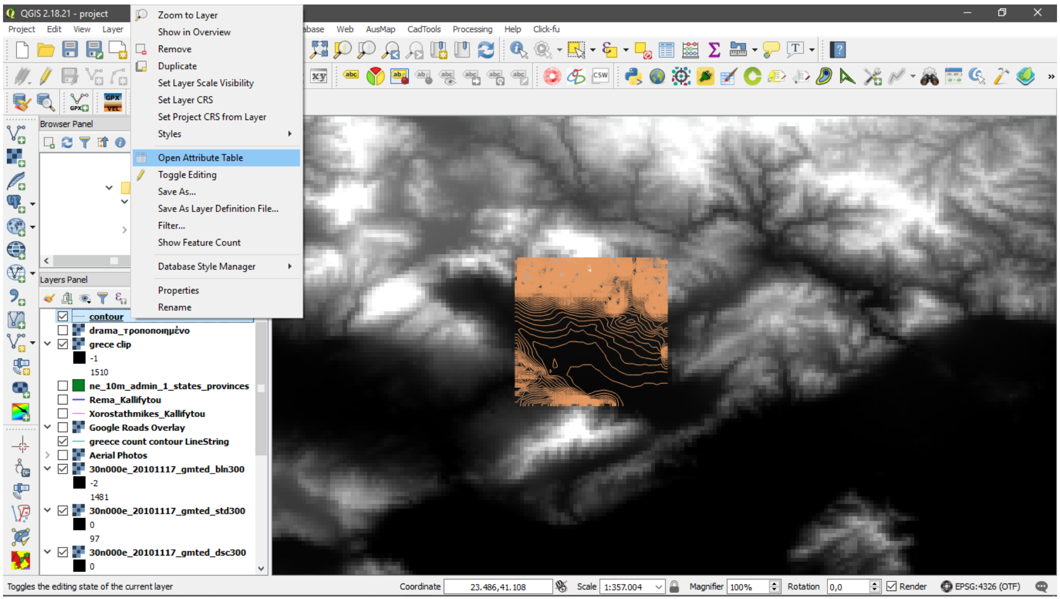


Figure 2.92 The contour lines loaded in the canvas

16. You will see that each line feature has an attribute named ELEV (see Figure 1.93). This is the height in meters that each line represents. Click on the column header a couple of times to sort the values in descending order. Here you will find the line representing the highest elevation in our data, i.e. Mt. Everest.

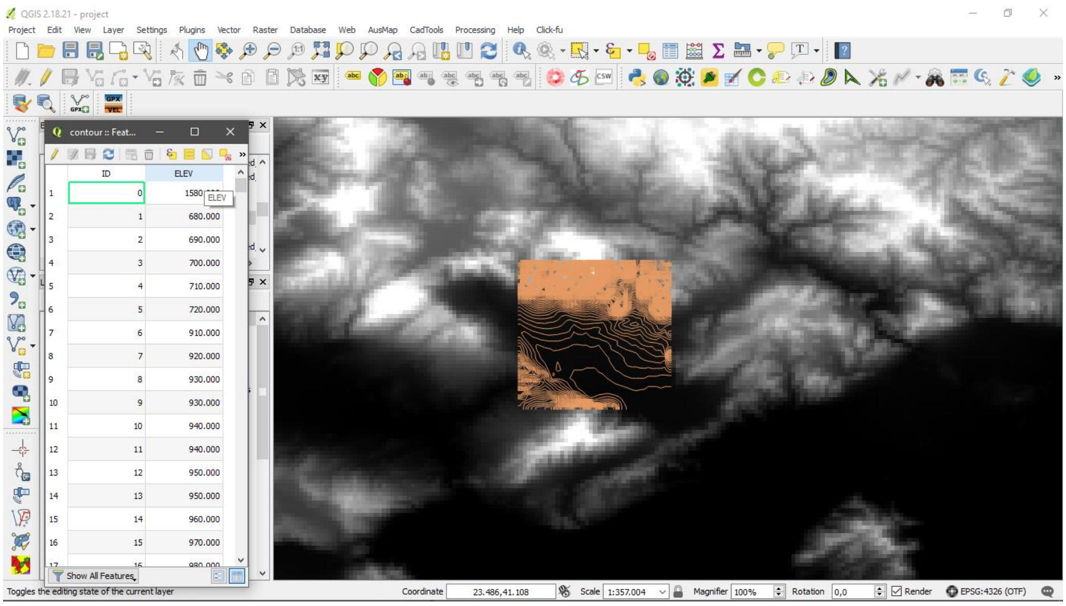


Figure 2.93 The attribute table of the contour lines

17. Select the top row, and click on the Zoom to selection button (see Figure 1.94).

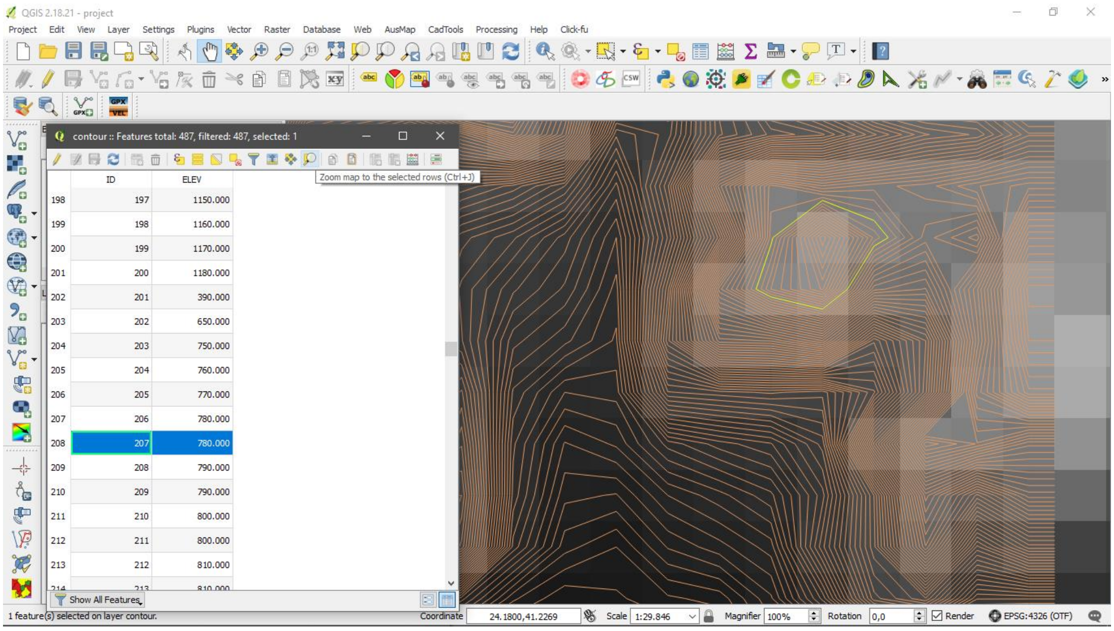


Figure 2.94 Zooming to your selection

18. Switch to the main QGIS window. You will see the selected contour line highlighted in yellow (see Figure 1.95). This is the area of the highest elevation in our dataset.

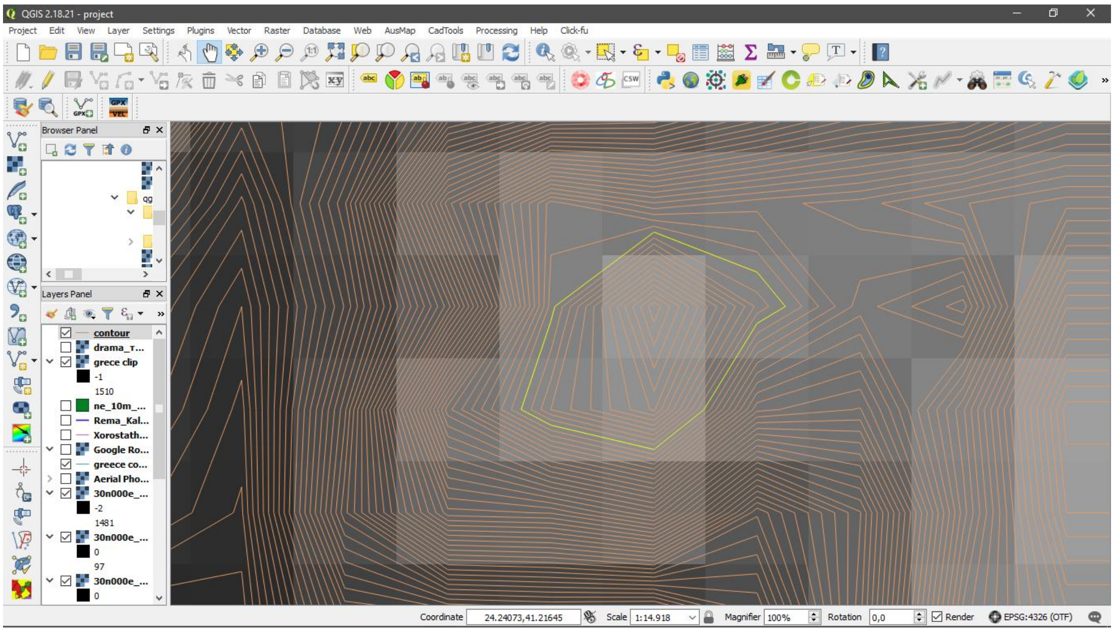


Figure 2.95 Seeing the selected contour line in QGIS

19. Now let us create a hillshade map from the raster. Select Raster ‣ Analysis ‣ DEM (Terrain Models) (see Figure 1.96).

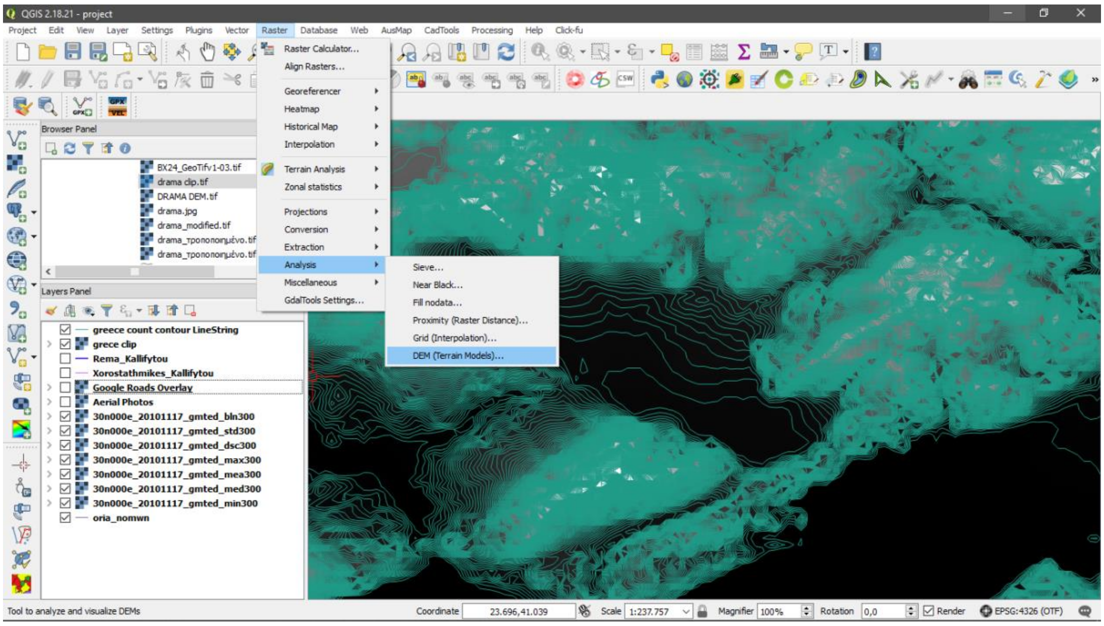


Figure 2.96 Creating the hillshape map in QGIS

20. In the DEM (Terrain Models) dialog, choose everest_gmted30 as the Input file (see Figure 1.97). Name the Output file as drama_hillshade.tif. Choose Hillshade as the Mode. Leave all other options as is. Make sure the Load into canvas when finished option is checked, and click OK.

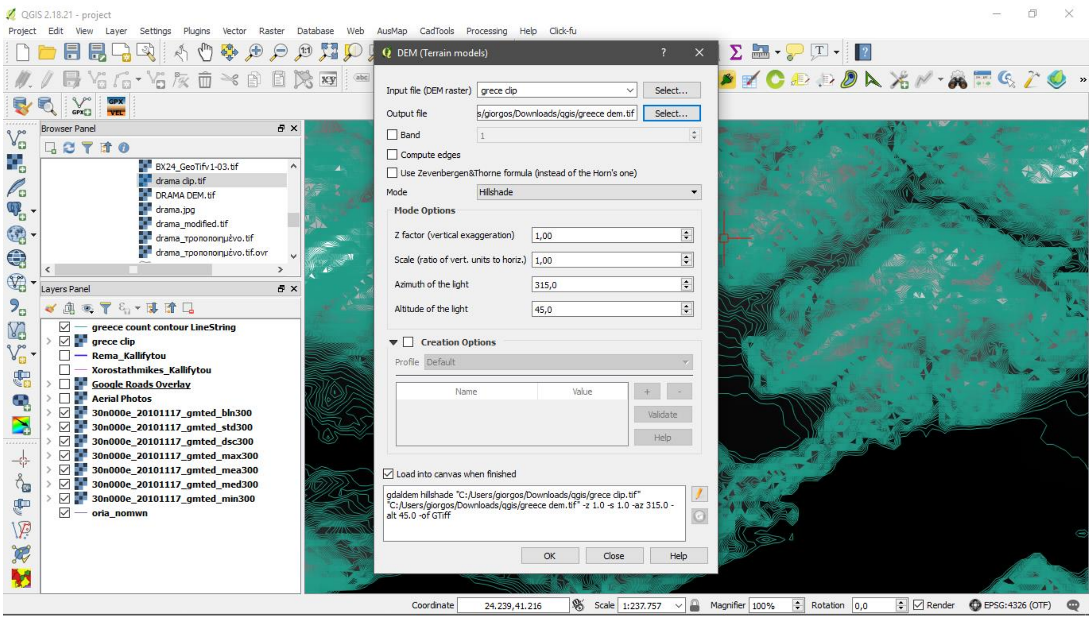


Figure 2.97 The DEM (Terrain Models) dialog

21. Once the process finishes, you will see yet another raster loaded into QGIS canvas (see Figure 1.98). Since you maybe zoomed-in near the Mt. Everest region, right click on the drama_hillshade layer and choose Zoom to Layer Extent.

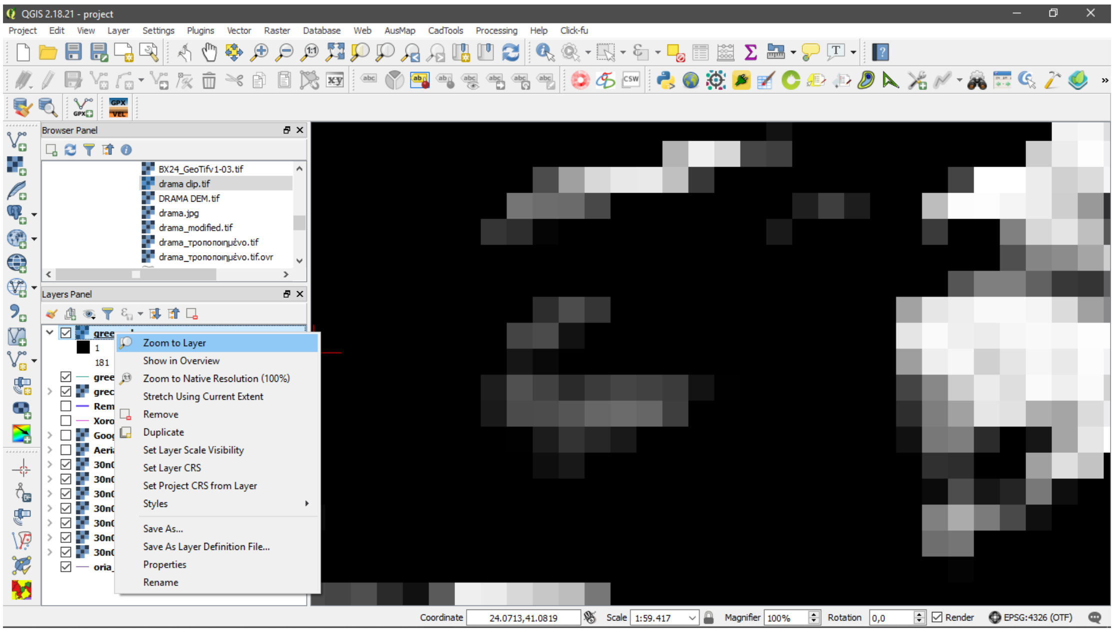


Figure 2.98 Another raster loaded into QGIS canvas after the Hillshade mode is complete

22. Now you will see the full extent of the hillshade raster (see Figure 1.99).

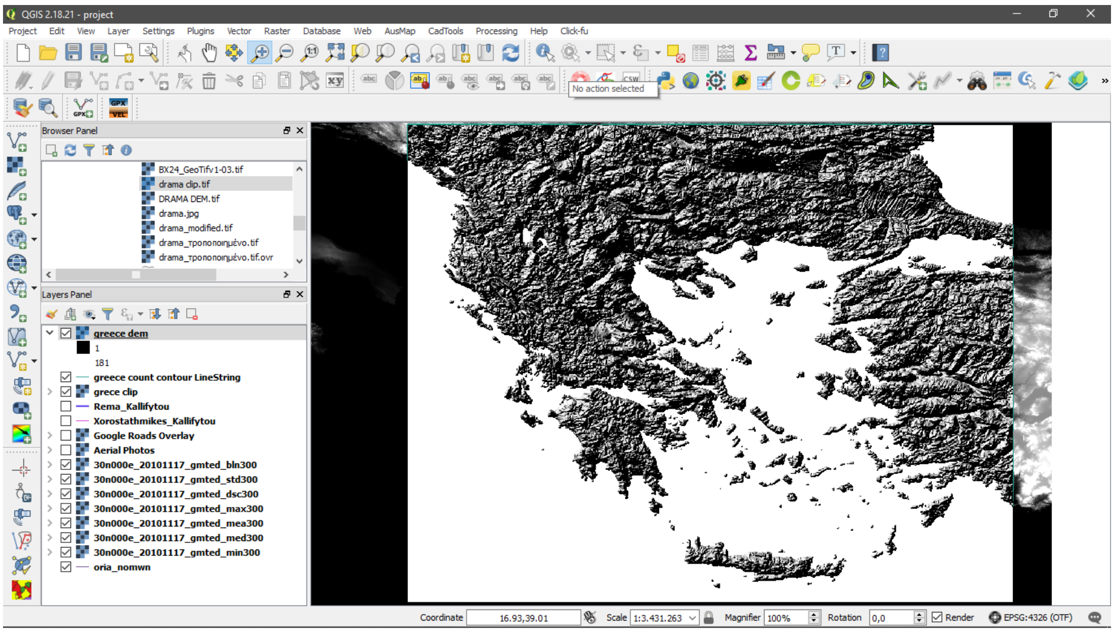


Figure 2.99 The hillside raster

23. You can also visualize your contour layer and verify your analysis by exporting the contours layer as KML and viewing it in Google Earth (see Figure 1.100). Right click on the contours layer, select Save as...

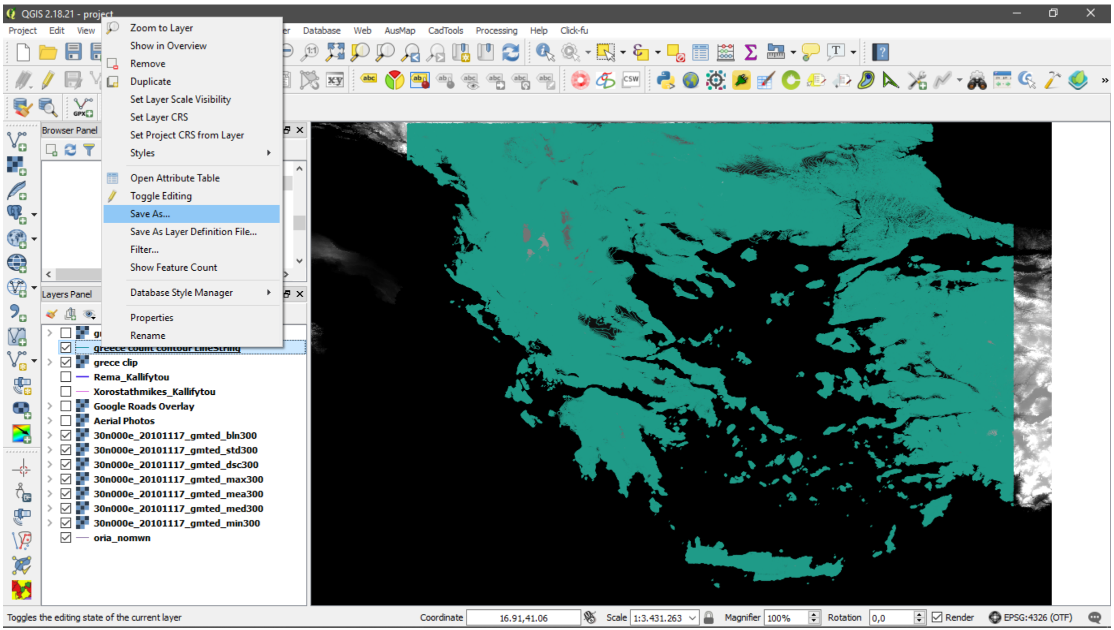


Figure 2.100 Saving the contour lines as a KML file (Google Earth)

24. Select Keyhole Markup Language [KML] as the Format (see Figure 1.101). Name your output as contours.kml and click OK.

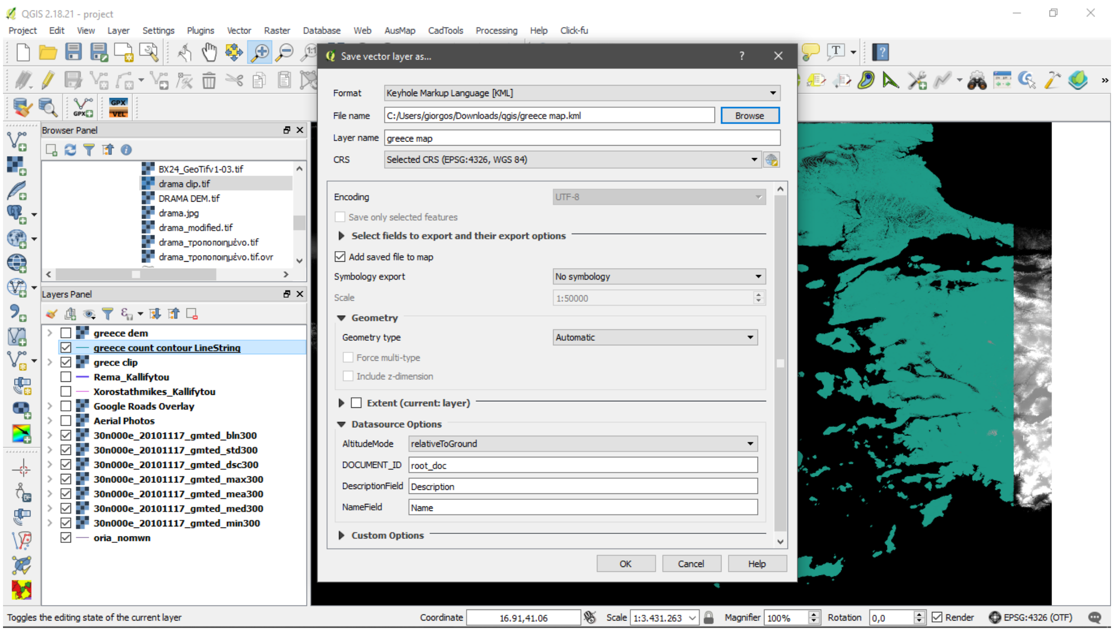


Figure 2.101 How to save in the Keyhole Markup Language [KML] format

25. Browse to the output file on your disk and double-click on it to open Google Earth (see Figure 1.102).

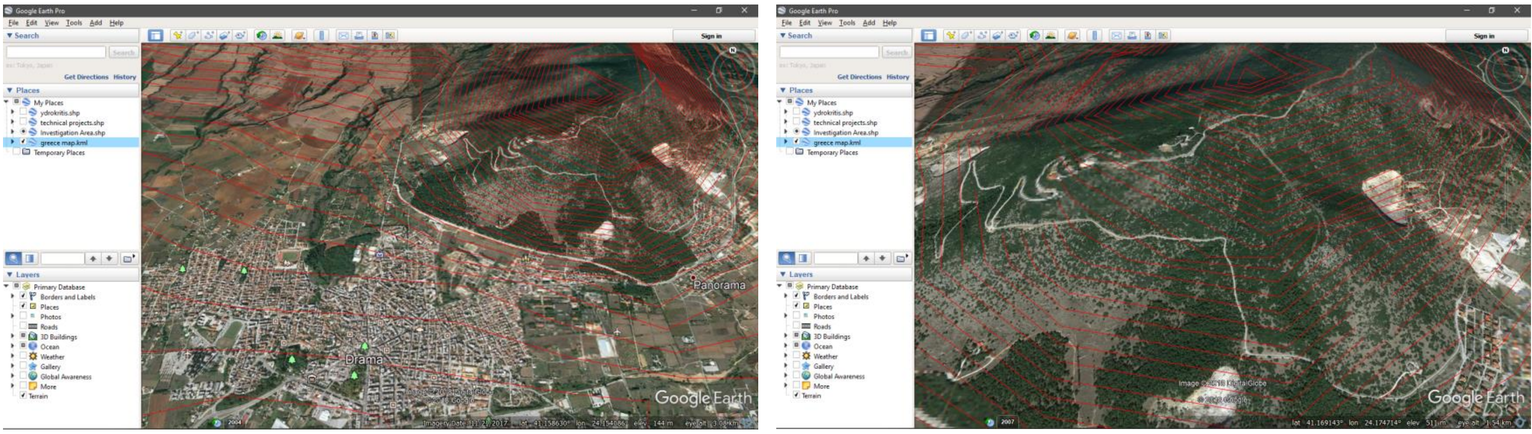


Figure 2.102 Opening Google Earth in the canvas

2.4.4 **Hydrologic analysis**

In this lesson, we are going to do some hydrological analysis. Starting with a DEM, we are going to extract a channel network, delineate watersheds and calculate some statistics.

1. The first thing is to load the project with the lesson data, which just contains a DEM (see Figure 1.103).

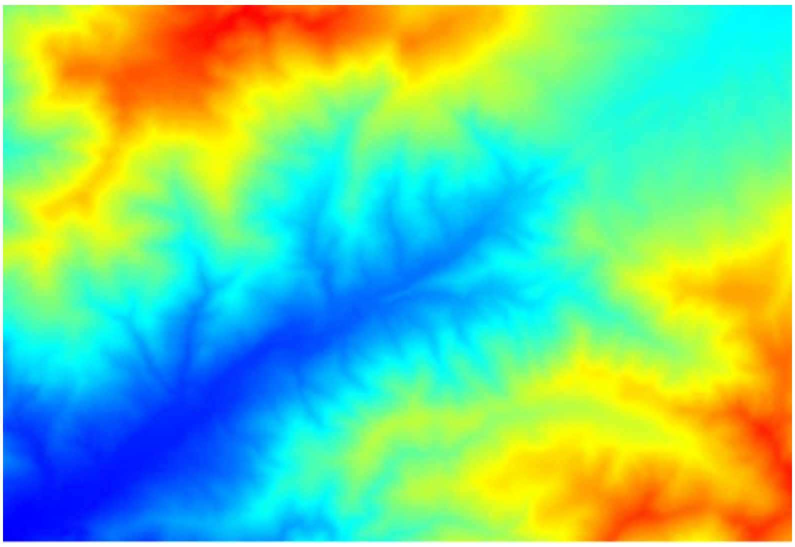


Figure 2.103 The DEM is loaded (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

2. The first module to execute is Catchment area (see Figure 1.104). You can use anyone of the others named Catchment area. They have different algorithms underneath, but the results are basically the same. Select the DEM in the Elevation field, and leave the default values for the rest of parameters.

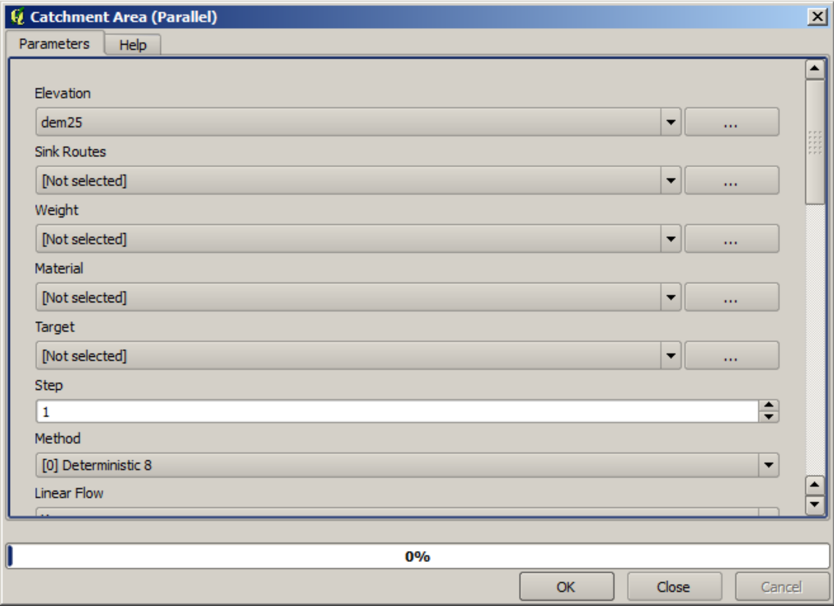


Figure 2.104 The Catchment Area Module (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

3. Some algorithms calculate many layers, but the Catchment Area one is the only one we will be using. You can get rid of the other ones if you want. The rendering of the layer is not very informative (see Figure 1.105).

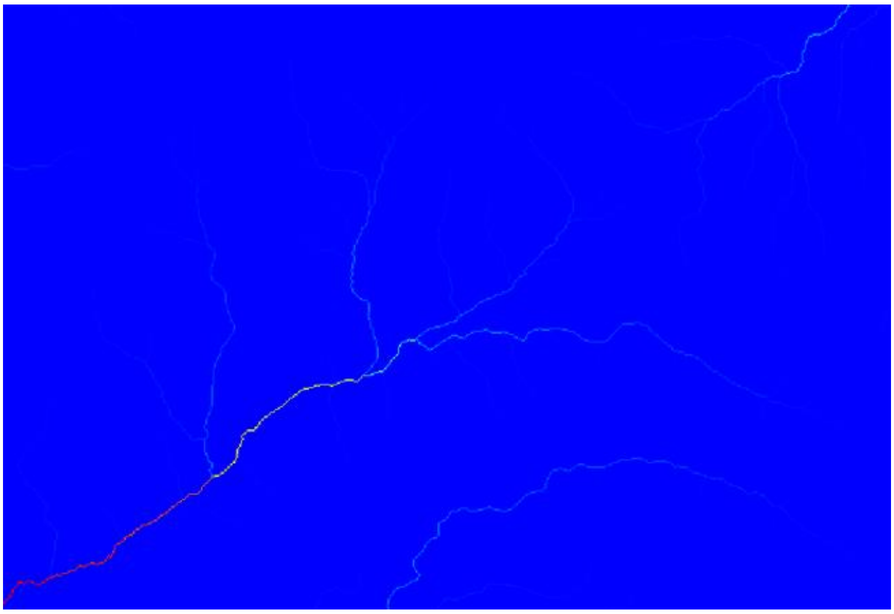


Figure 2.105 The channel network in the catchment (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

4. To know why, you can have a look at the histogram and you will see that values are not evenly distributed (there are a few cells with very high value, those corresponding to the channel network). Calculating the logarithm of the catchment area value yields a layer that conveys much more information (you can do it using the raster calculator) (see Figure 1.106).

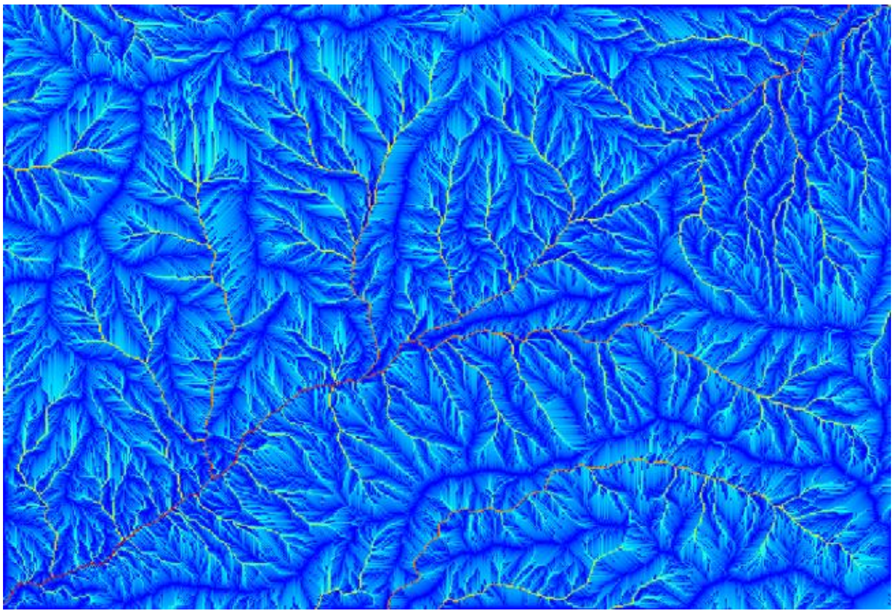


Figure 2.106 The topography and the channel network (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

5. The catchment area (also known as flow accumulation), can be used to set a threshold for channel initiation. This can be done using the Channel network algorithm. Here is how you have to set it up (note the Initiation threshold Greater than 10.000.000) (see Figure 1.107).

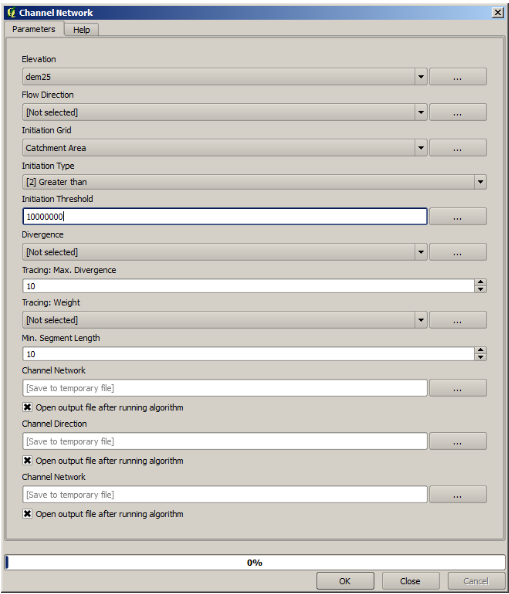


Figure 2.107 Setting up the Channel network algorithm (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

6. Using the original catchment area layer, not the logarithm one for the channel network (see Figure 1.108). That one was just for rendering purposes. If you increase the Initiation threshold value, you will get a sparser channel network. If you decrease it, you will get a denser one. With the proposed value, this is what you get.

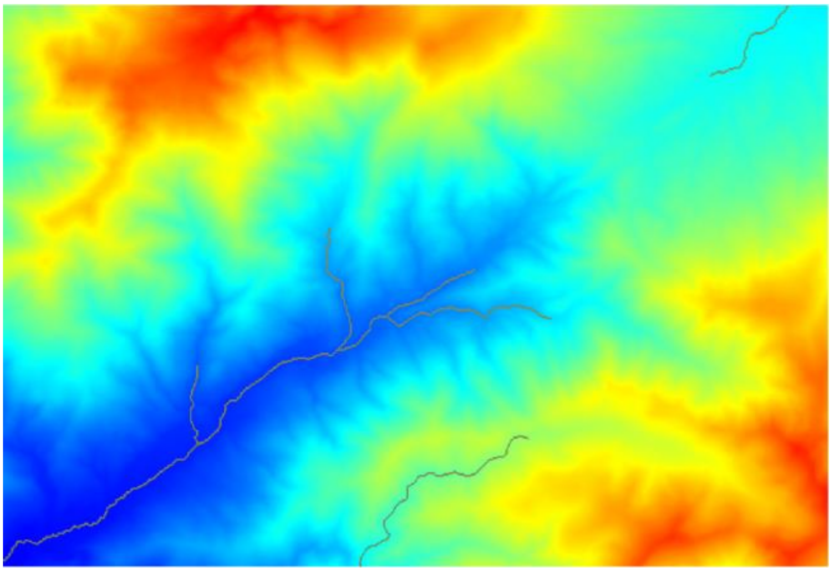


Figure 2.108 The channel network within the DEM (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

7. The image in Figure 1.109 shows just the resulting vector layer and the DEM, but there should be also a raster one with the same channel network. That raster one will be, in fact, the one we will be using. Now, we will use the Watersheds basins algorithm to delineate the subbasins corresponding to that channel network, using as outlet points all the junctions in it (see Figure 1.118). Here is how you have to set the corresponding parameters dialog.

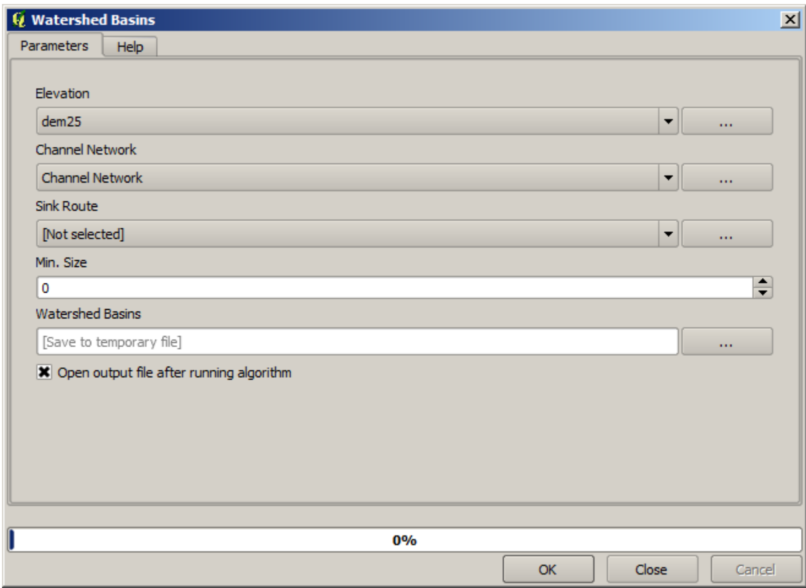


Figure 2.109 The Watersheds basins algorithm (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

8. Figure 1.110 is what you will get based on the Watersheds basins algorithm.

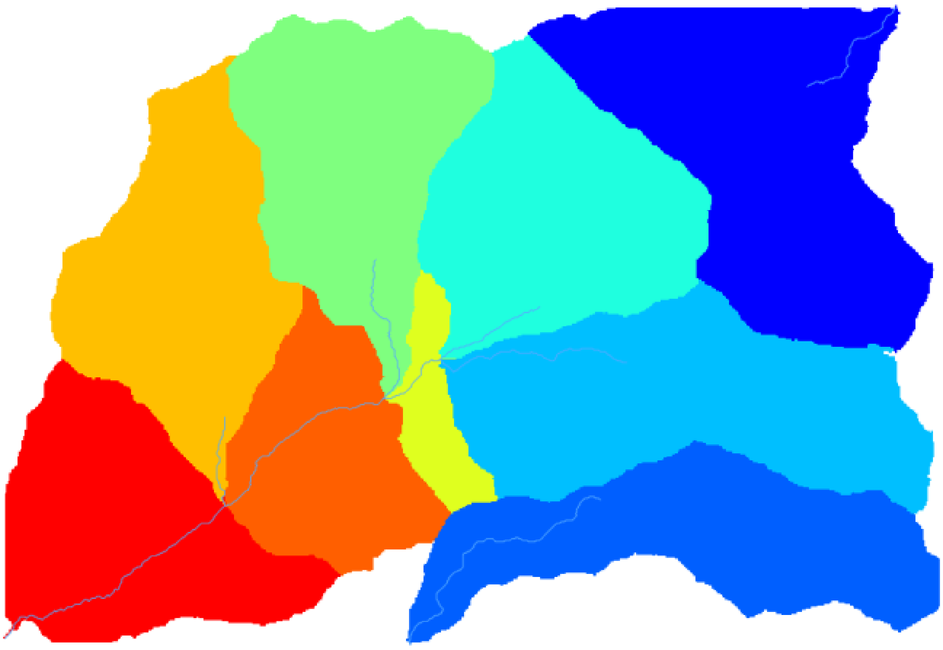


Figure 2.110 The results of the Watersheds basins algorithm (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

9. This is a raster result. You can vectorise it using the Vectorising grid classes algorithm (see Figure 1.111 and 1.112).

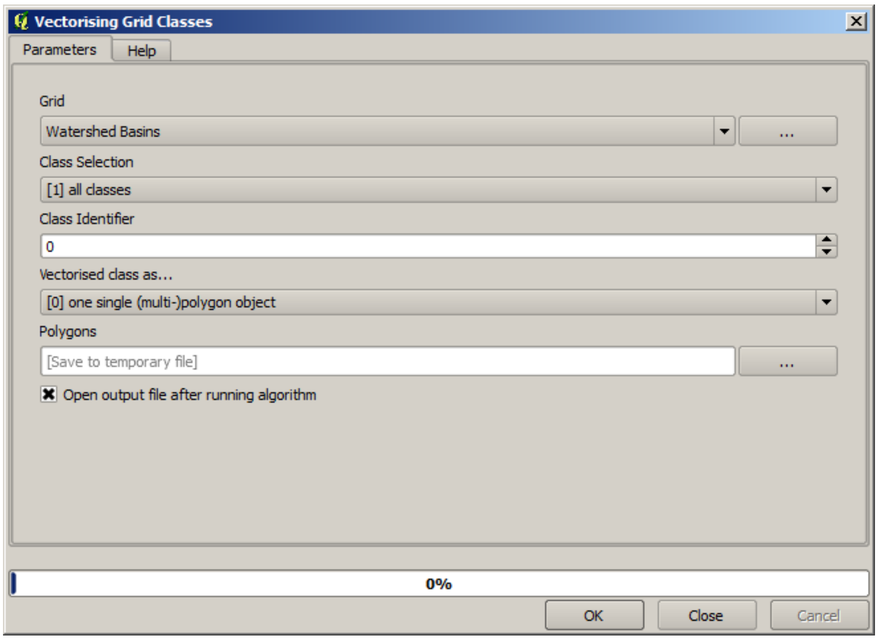


Figure 2.111 The Vectorising grid classes algorithm window (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

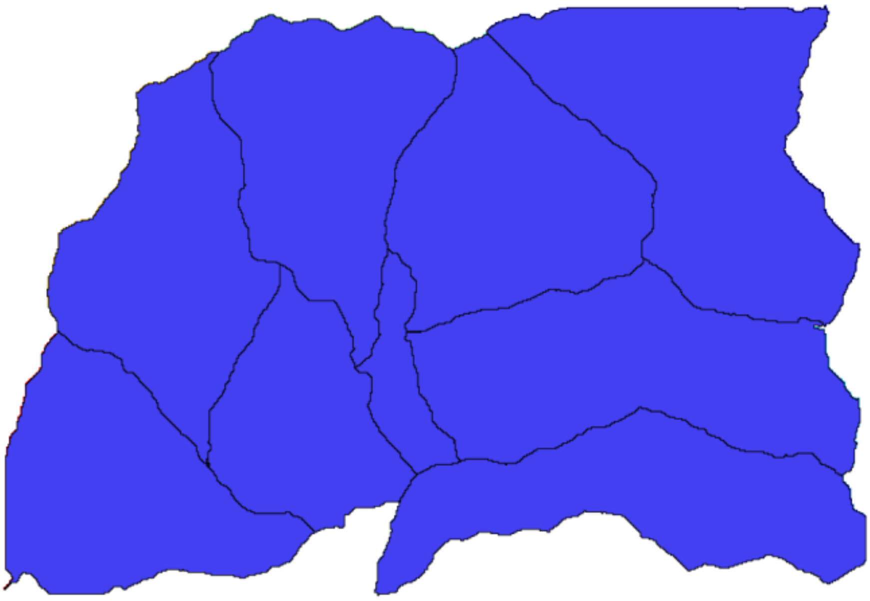


Figure 2.112 The results of the Vectorising grid classes algorithm (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

Now, let's try to compute statistics about the elevation values in one of the subbasins. The idea is to have a layer that just represents the elevation within that subbasin and then pass it to the module that calculates those statistics.

10. First, let's clip the original DEM with the polygon representing a subbasin. We will use the Clip grid with polygon algorithm. If we select a single subbasin polygon and then call the clipping algorithm, we can clip the DEM to the area covered by that polygon, since the algorithm is aware of the selection (see Figure 1.113).

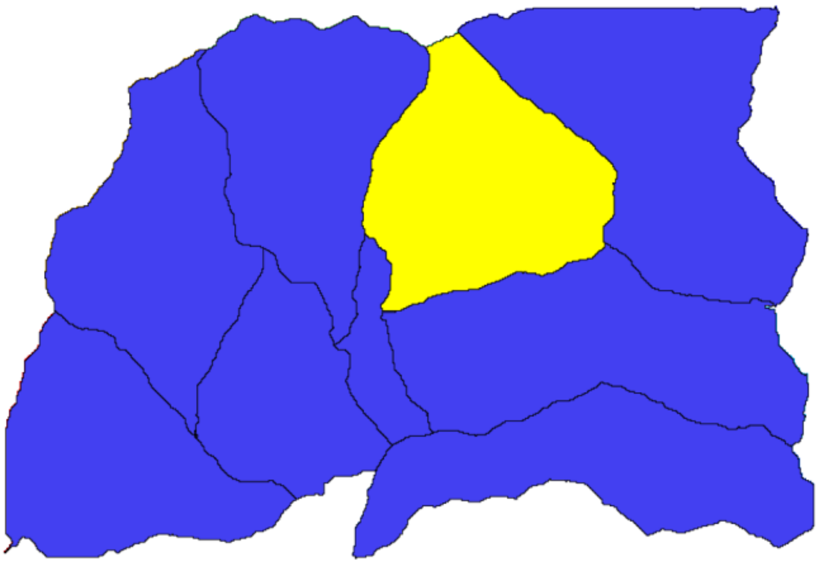


Figure 2.113 How to clip a selected subbasin (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

11. Next call the clipping algorithm with the parameters in Figure 1.114

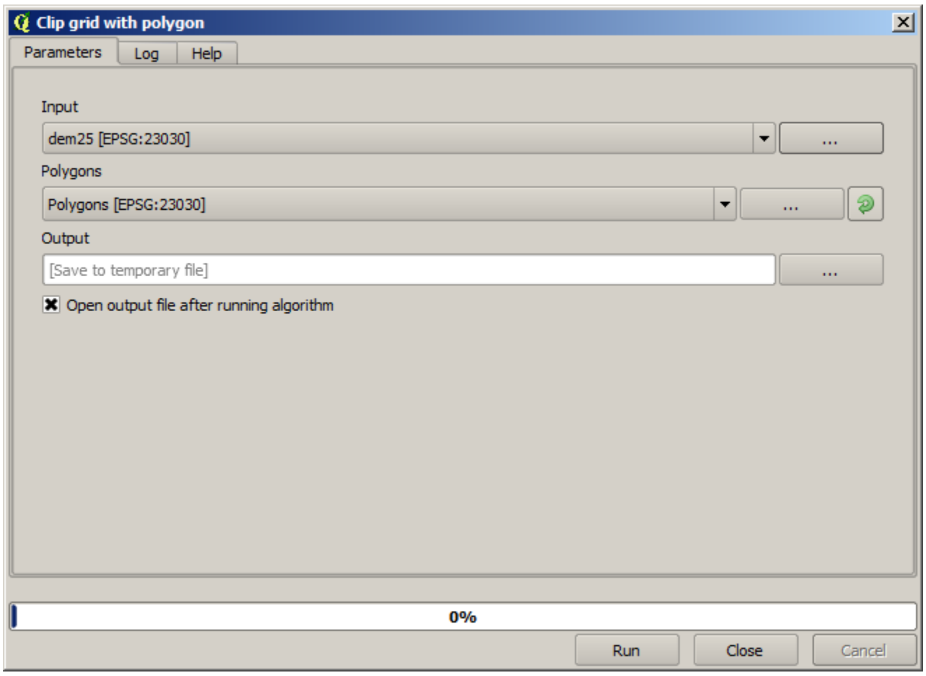


Figure 2.114 The parameters of the clipping algorithm (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

12. The element selected in the input field is, or course, the DEM we want to clip. You will get something like in Figure 1.115.

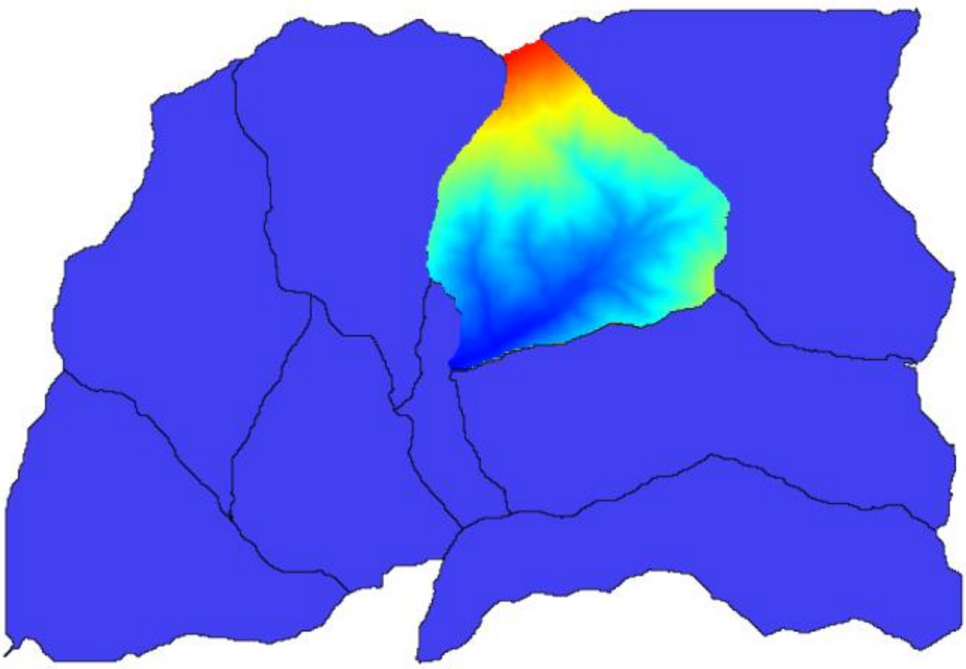


Figure 2.115 The selected subbasin with its DEM (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

13. This layer is ready to be used in the Raster layer statistics algorithm (see Figure 1.116).

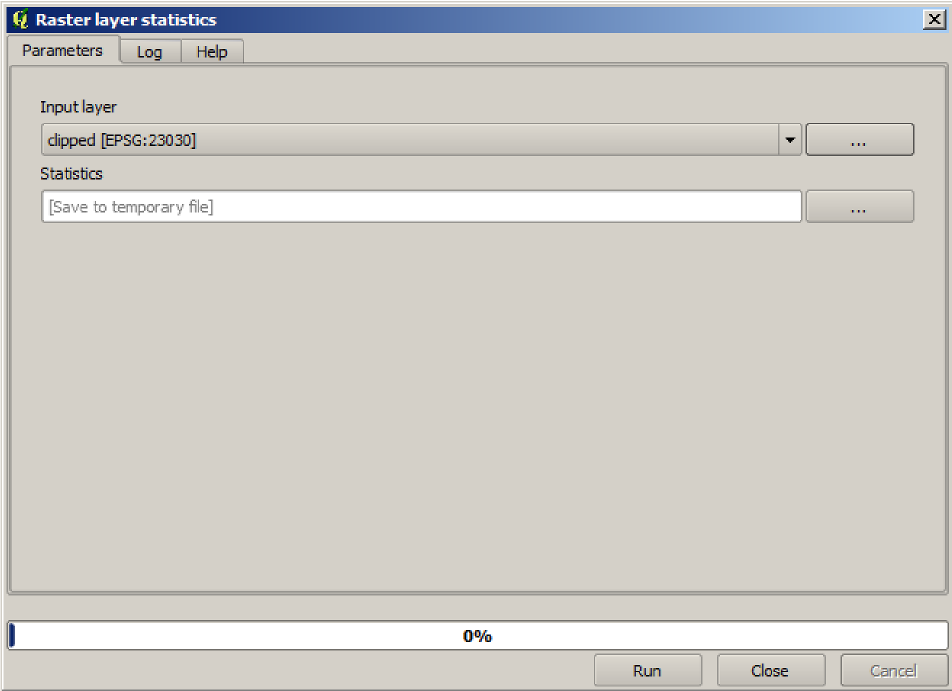


Figure 2.116 The Raster layer statistics algorithm window (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

14. The resulting statistics are the following ones (see Figure 1.117).

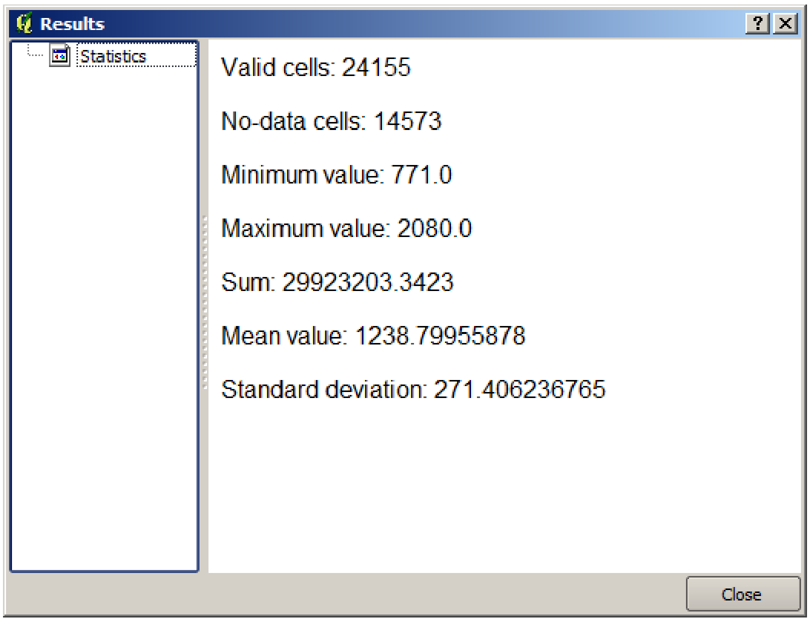


Figure 2.117 The Raster layer statistics algorithm results (source: https://docs.qgis.org/testing/en/docs/training_manual/processing/hydro.html?highlight=watershed)

2.4.5 Importing open data layer – (Corine land-use and FAO Soil data)

There are many different types of data sources you can import into QGIS. These steps will focus on the more commonly used data types including shapefiles, csv files, and raster files.

GIS data found online is often in a shapefile format. To import a shapefile follow these steps:

1. Click on the "Layer" menu, mouse-over "Add Layer" and click "Add Vector Layer..." (see Figure 1.118). You can also click the "Add Vector Layer" button in the left hand column of QGIS.

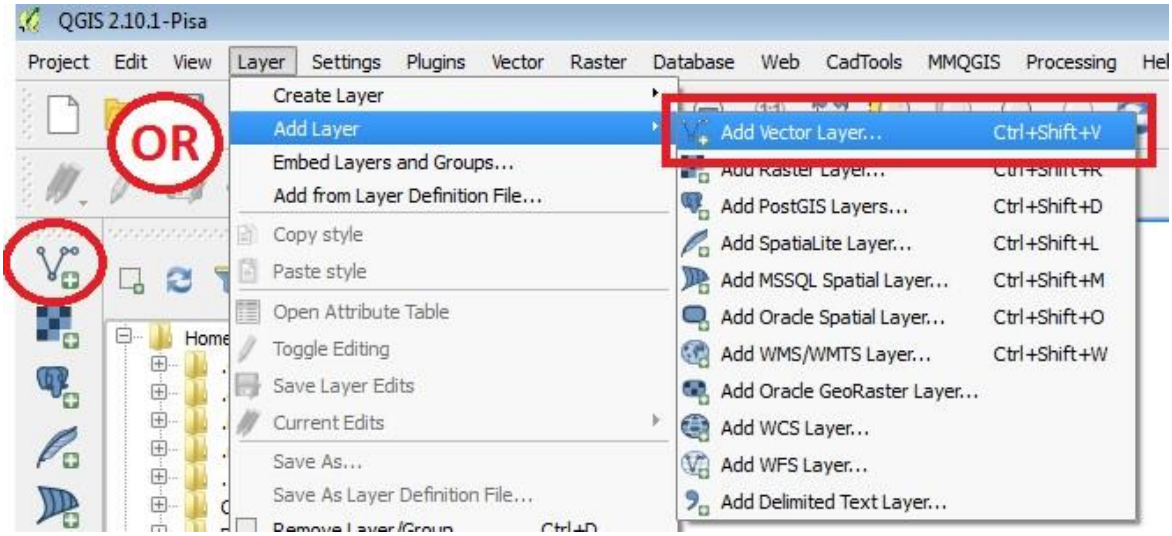


Figure 2.118 How to add a vector layer (source: https://guides.library.duke.edu/QGIS/ImportData)

2. If the shapefiles you have are on your local machine, all you need to do is click on the Browse button and navigate to the folder where your shapefiles are (see Figure 1.119).

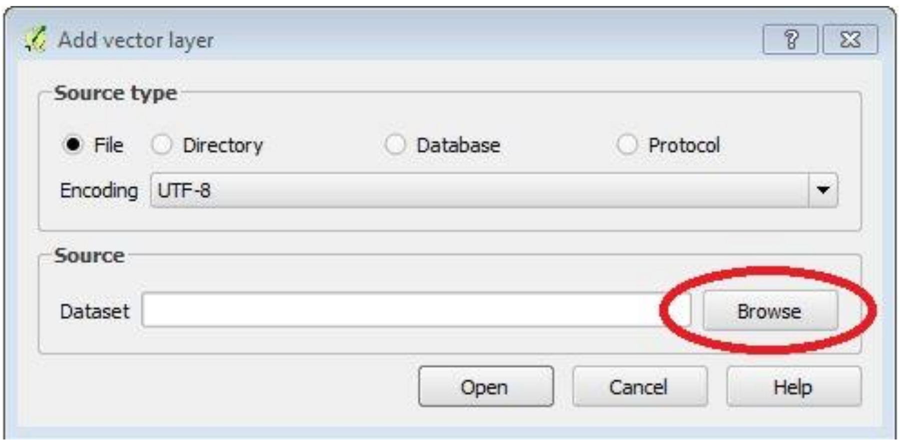


Figure 2.119 What to do when the shapefiles are on the local machine (source: https://guides.library.duke.edu/QGIS/ImportData)

3. After you find the folder with your shapefiles, you will need to be sure the data type is selected to shapefile (see Figure 1.120). Click on the drop-down box next to file name and select ESRI Shapefiles (.shp *SHP). You have many different vector data types to choose from if you have another data type.

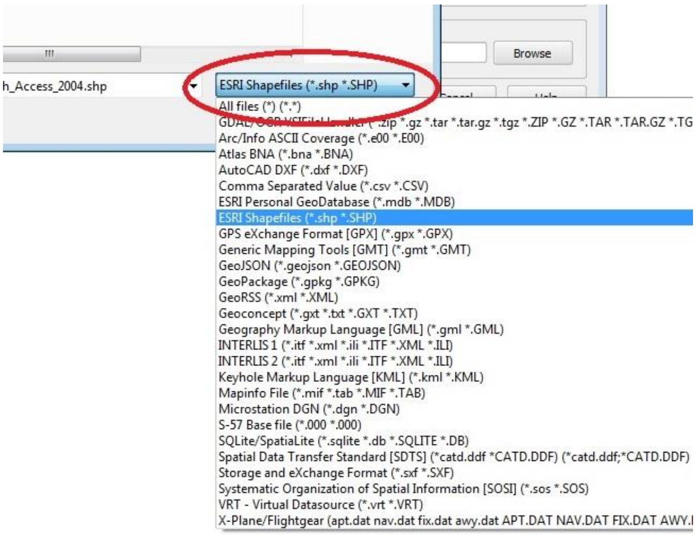


Figure 2.120 Selecting the correct vector data type (source: https://guides.library.duke.edu/QGIS/ImportData)

4. Click Open.

If you have a georeferenced image or aerial imagery, you will need to import them using the Add Raster Layer button. To import a raster file, follow these steps:

1. Click on the "Layer" menu, mouse-over "Add Layer" and click on "Add Raster Layer..." (see Figure 1.121) or click on the "Add Raster Layer icon in the left column of QGIS.

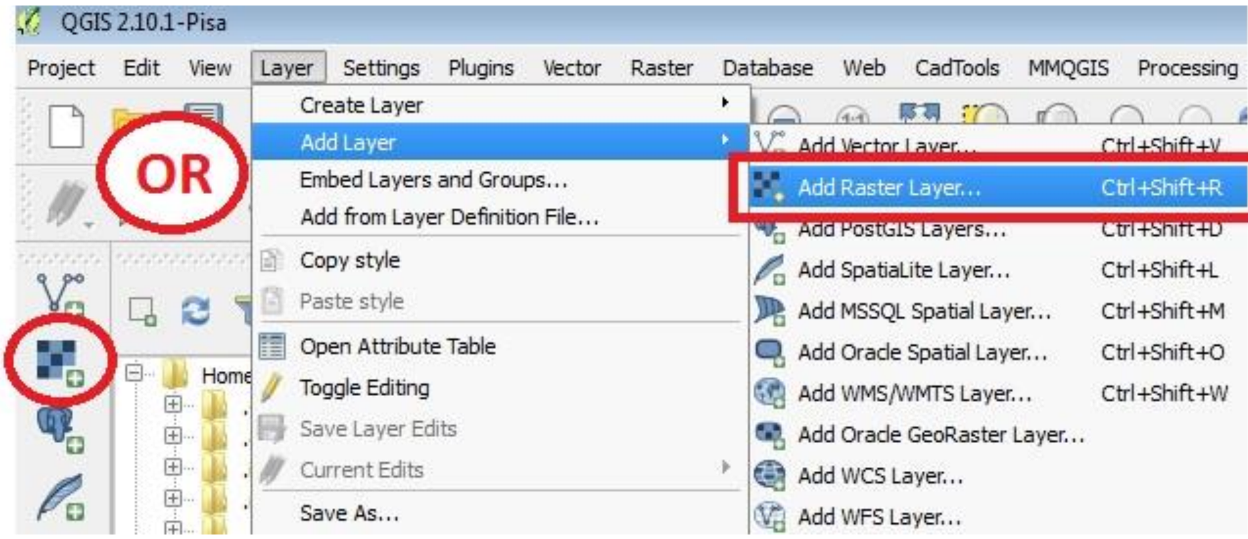


Figure 2.121 How to add a raster layer (source: https://guides.library.duke.edu/QGIS/ImportData)

2. You will automatically be directed to your folders. Go to the folder where your rasters are stored and change the raster data type if needed by click on the drop-down menu next to the file name (see Figure 1.122).

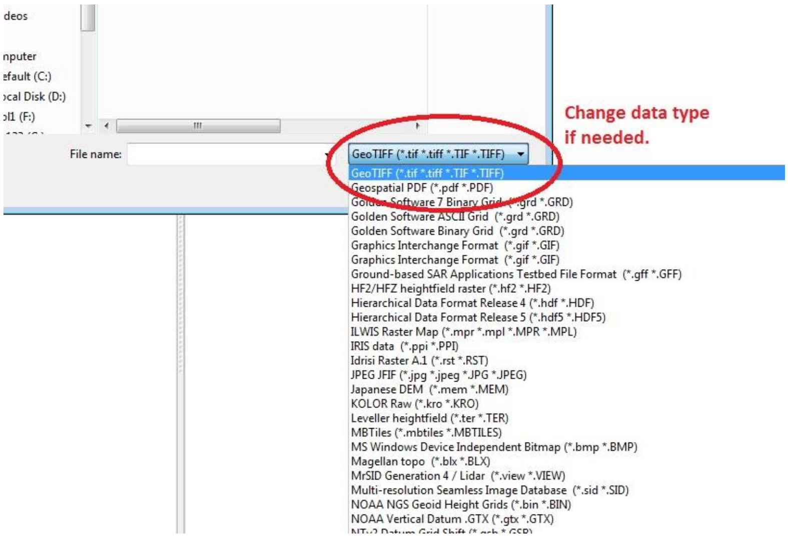


Figure 2.122 Selecting the correct raster data type (source: https://guides.library.duke.edu/QGIS/ImportData)

3. Click Open.

Once the csv files are formatted properly, you can add them into QGIS.

1.Click on the "Layer" menu, mouse-over "Add Layer" and click on "Add Delimited Text Layer..." (see Figure 1.123) or click on the "Add Delimited Text Layer" icon in the left column of QGIS.

2. The next GUI will have many different options you may need to change depending on the specific data set you have (see Figure 1.124). Here is an outline of the most common fields needed to be changed.

a. Browse - click on Browse and find the folder where the csv file is saved and open the file.

b. Layer name - the name of the CSV will show up here.

c. File format - depending on the version of QGIS you are using, you may need to verify the file format.

d. Geometry definition - If you have x, y coordinates you will choose the "Point coordinates" option. Verify the X Field is pointing to your Longitude field and the Y Field is pointing to your Latitude Field. If you have a table with no x,y coordinates you will choose the "No Geometry" option.

e. Layer settings - you will see a preview of the table. Verify that everything looks

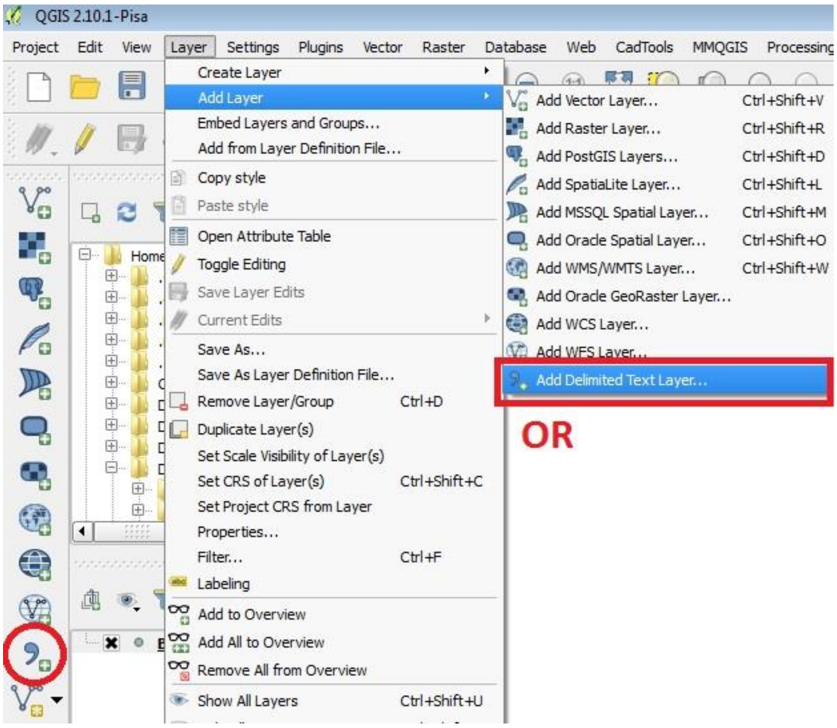


Figure 2.123 How to add a csv file (source: https://guides.library.duke.edu/QGIS/ImportData)

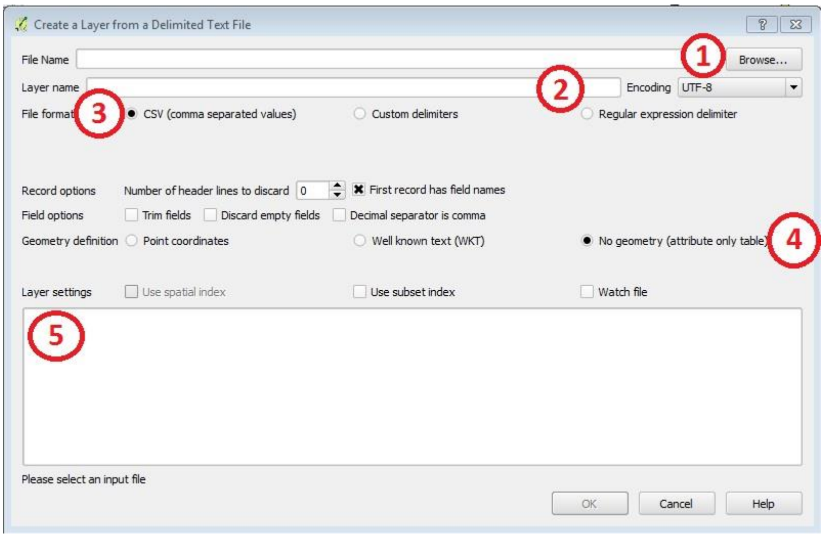


Figure 2.124 Options you need to change depending on the specific data set (source: https://guides.library.duke.edu/QGIS/ImportData)

3. Click OK.

4. If you have a field with no x, y coordinates you are done importing the csv file. However, depending on the version of QGIS you are using, you may be prompted to define the coordinate reference system (CRS) of your x, y coordinates. Longitude/Latitude coordinates are unprojected, and you should choose the CRS of WGS 84 (EPSG:4326) (see Figure 1.125). If you have coordinates using something else, like meters in a UTM zone, search for that using the filter box in the CRS Selector Dialog. For instance, type

in <utm 17> to get a short list that includes the UTM zone for Durham, 17N (e.g., NAD83 / UTM zone 17N, or EPSG:26917).

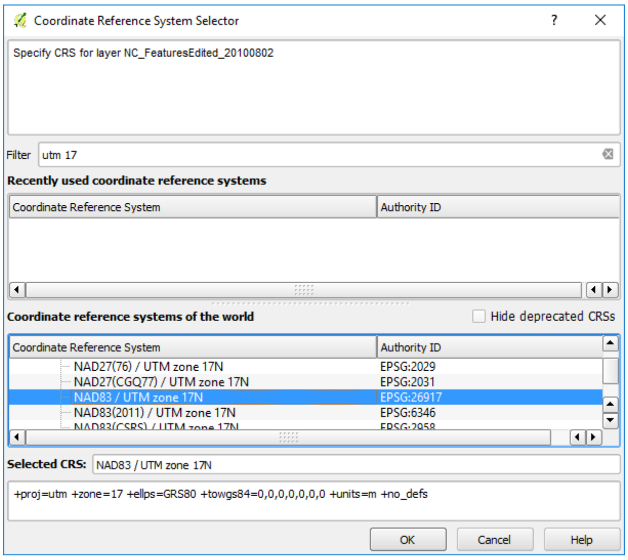


Figure 2.125 The Raster layer statistics algorithm results (source: https://guides.library.duke.edu/QGIS/ImportData)

2.4.6 Creating map with Corine land-use data and FAO Soil data

Corine Land Cover is a European program to create a land cover inventory of Europe. The data is freely available and a valuable input for many analyses and as vector files.

In the following steps we will show to use to create a physical map.

1. For the background a hillshade map can be used (see Figure 1.126).

Figure 2.126 The hillshade map (source: http://planet.qgis.org/planet/tag/corine%20land%20cover/)

2. A sand-colored color map that looks warmer and more natural is preferred instead of the standard grayscale (see Figure 1.127).

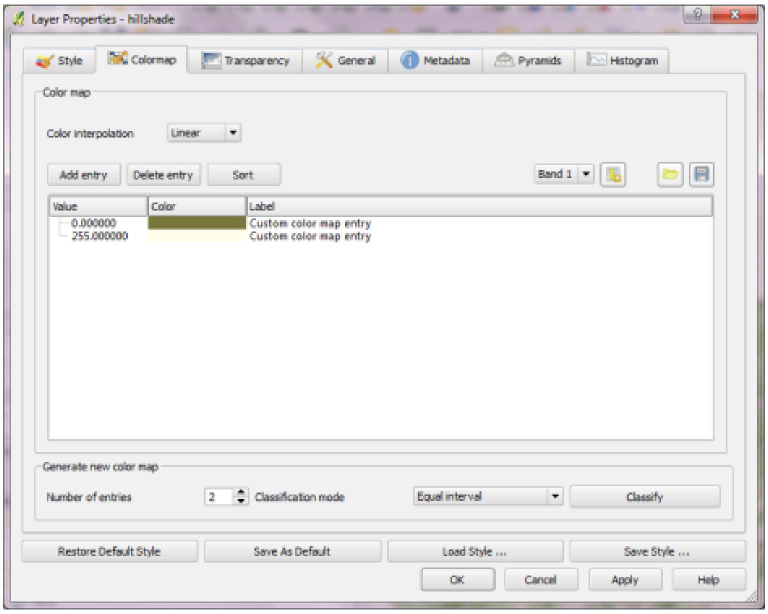


Figure 2.127 How to change the colors in a hillshade map (source: http://planet.qgis.org/planet/tag/corine%20land%20cover/)

3. On top of this hillshade, I put the Corine land cover layer (see Figure 1.128). Instead of the official bright colors we can select more neutral color palette and varying transparency values: Water areas are drawn with no transparency while forests are set to 50 % and built-up areas to up to 80 % transparency.

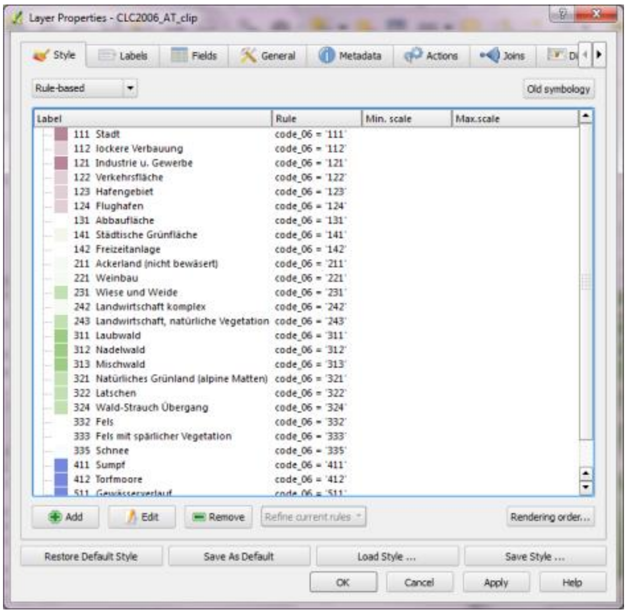


Figure 2.128 Changing the color of the Corine land cover layer (source: http://planet.qgis.org/planet/tag/corine%20land%20cover/)

4. On top of the land cover, I added a river dataset and styled it with the same color used for water surfaces in the Corine layer. Obviously, this is an optional step. Big rivers are visible within the land cover data too. After adding a mask and labels, the map is ready to add the finishing touches in Print

Composer: Title, explanatory text and a scale bar (see Figure 1.129). A legend was not added to this particular map since the color choices are intuitive enough.

Figure 2.129 The final land-use map built on the hillshade map (source: http://planet.qgis.org/planet/tag/corine%20land%20cover/)

Similarly to create soil maps from freely available data that can be retrieved from the European Soil Portal (European Commission 2012, available at http://eusoils.jrc.ec.europa.eu/library/esdac/index.html and the Harmonised World Soil Database Viewer 2012, available at http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/.

2.4.7 Case Study – Evaluating Riparian Areas Land-uses

In this case study we examine how GIS can be used for the initial assessment of the riparian areas of a studied reach. The use of GIS can provide preliminary data on the condition of the riparian areas that could be validated with field assessment tools.

1. The first step is to import that stream network and watershed boundary data (as seen in a previous section)

2. Next either the land-use data for the watershed from Corine can be imported (as seen in a previous section) or aerial photos can be imported and the different land-uses around the stream network of interest can be digitized (as seen in a previous section).

3. Buffering usually creates two areas: one area that is within a specified distance to selected real world features and the other area that is beyond. The area that is within the specified distance is called the buffer zone.

A buffer zone is any area that serves the purpose of keeping real world features distant from one another. Buffer zones are often set up to protect the environment, protect residential and commercial zones from industrial accidents or natural disasters, or to prevent violence. Common types of buffer zones may be greenbelts between residential and commercial areas, border zones between countries (see figure_buffer_zone), noise protection zones around airports, or pollution protection zones along rivers.

How to make buffers around point (see Figure 1.130), a line (see Figure 1.131) and a polygon (see Figure 1.132) in shown in the figures below.

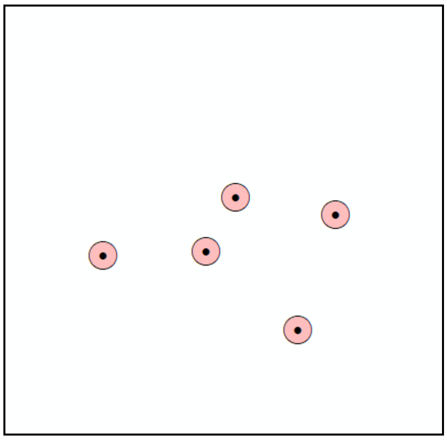


Figure 2.130 A buffer zone around vector points

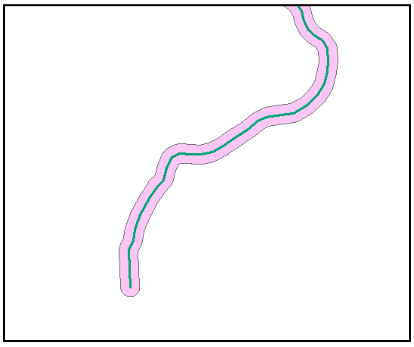


Figure 2.131 A buffer zone around vector lines

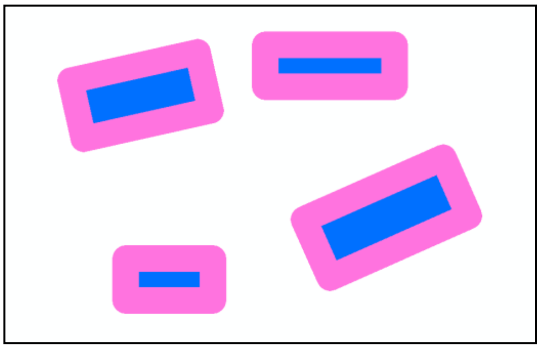


Figure 2.132 A buffer zone around vector polygons

4. There are several variations in buffering. The buffer distance or buffer size can vary according to numerical values provided in the vector layer attribute table for each feature. The numerical values have to be defined in map units according to the Coordinate Reference System (CRS) used with the data. For example, the width of a buffer zone along the banks of a river can vary depending on the intensity of the adjacent land use (see Figure 1.133).

In this case study we are looking at buffer zones around streams. These areas are typically the riparian areas. The buffers lengths used in this study were of 20 and 50 m from the stream bank, typical of the extents of riparian areas in s Mediterranean streams.

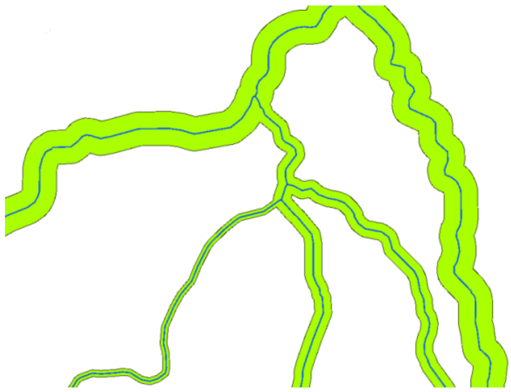


Figure 2.133 Buffering rivers with different buffer distances

5. Intersecting layers. This algorithm combines features from the Input layer and the Intersect Layer, resulting in features that cover both layers' features. Input Feature(s) that only partially lie within the other layer's feature(s) are split along the boundary of the other layer's feature(s). If any features are selected in the Input and Intersect Layers, then only those features are used in the operation. If no features are selected then the operation is performed using all features.

In this case the two buffers of 20 and 50 meters were intersected with the land-uses within these buffers. Specifically in this project the "buffer" and intersect function was used to estimate the area of the different land-uses/cover adjacent to the studied stream (see Figures 1.134-136)

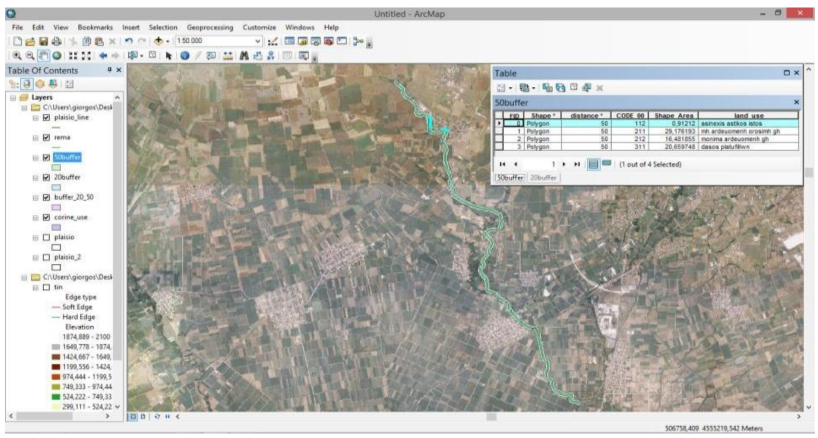
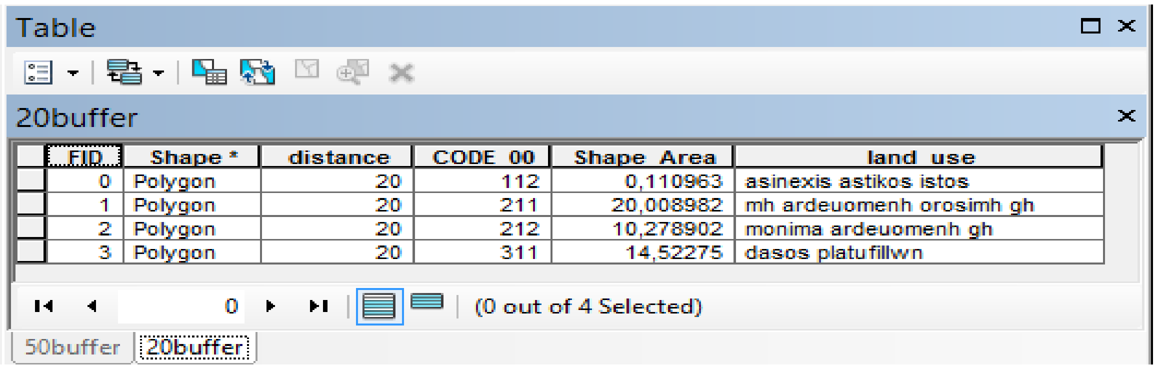
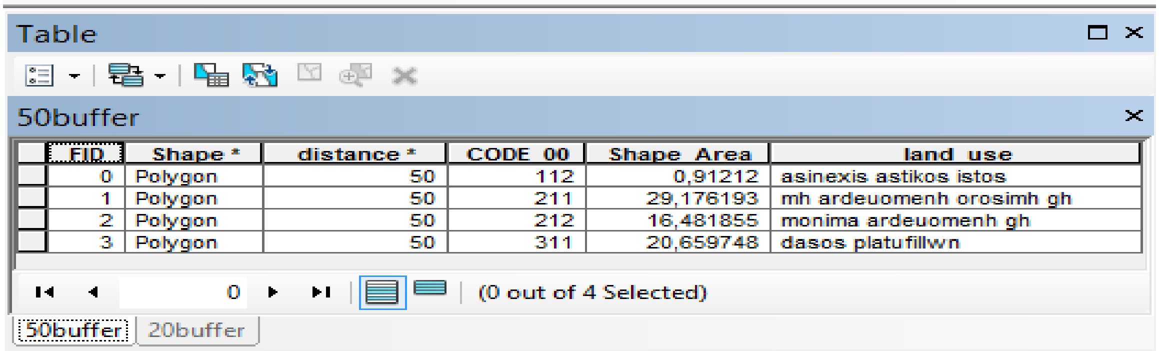


Figure 2.134 The buffer of the 50 meters intersecting with land-uses



FID	Shape *	distance	CODE_00	Shape_Area	land_use
0	Polygon	20	112	0,110963	asinexis astikos istos
1	Polygon	20	211	20,008982	mh ardeuomenh orosimh gh
2	Polygon	20	212	10,278902	monima ardeuomenh gh
3	Polygon	20	311	14,52275	dasos platufillwn

Figure 2.135 The table with area of the each land use at the 20 meters buffer



FID	Shape *	distance *	CODE_00	Shape_Area	land_use
0	Polygon	50	112	0,91212	asinexis astikos istos
1	Polygon	50	211	29,176193	mh ardeuomenh orosimh gh
2	Polygon	50	212	16,481855	monima ardeuomenh gh
3	Polygon	50	311	20,659748	dasos platufillwn

Figure 2.136 The table with area of the each land use at the 50 meters buffer

6. Overall this is an effective tool since it allows the quick assessment from the office of large lengths of riparian areas in regard to its land-uses.

3. ASSESSMENT AND FEEDBACK

This module is continuously assessed during the course of the semester. The assessment comprises coursework attendance, homework, practical (write up and presentation) and an exam. The pass mark for this module is 50% - you must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above.

Full details of the courseworks are contained in the Coursework Briefs which will be issued in due course.

Note: Failure to submit the coursework for the appropriate deadline without 'good cause' will be regarded as a non-submission, and hence will result in failure in this module. If you have a good reason for needing an extension to the deadline, you must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date.

To help you guide your development you will be provided with feedback on your performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort's overall performance will be provided. You will be given an opportunity to individually review your marked work to help you understand which aspects of your studies you are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. You are entitled to keep marked submissions for your review - however, you must return these when asked by the Module Leader or Module Tutor.

4. DIRECTED LEARNING AND PRIVATE STUDY

As you are expected to 'read' for your degree, you will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect you to be up to date with the current theme.

The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and you will be expected to demonstrate evidence of having sourced information from these in your coursework activities.

You should also make use of web-based materials and visit appropriate sites to develop a wider knowledge of the key issues and activities of not only your chosen discipline, but also in other related fields.

Please refer to the Module Descriptor for a detailed reading list. However, you may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section.

5. MODULE DIFFICULTIES AND EVALUATION

If you have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, you should speak with your employer or Academic tutor.

A module evaluation form will be made available to you on-line after the module is complete and you will be asked to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms are analyzed (anonymously) and the findings considered by the appropriate professional organization as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that you may have about the module in the first instance.

6. PERSONAL DEVELOPMENT PLANNING (PDP)

PDP is embedded within EFIB to assist you to develop as an independent and confident learner, not only during your time with us, but throughout your future career. It also allows more effective monitoring of your progress while undertaking your degree program studies. The process has been described as

"A structured & supported process undertaken by individuals to reflect upon their own learning and performance, and/or achievement, and to plan for their personal education and career development."

As a member of a professional graduate community, you will be required to undertake Continuing Professional Development throughout your career. Learning therefore must be seen as a lifetime activity, and the introduction of PDP at the early stages of your career prepares you for these future requirements. PDP provides an opportunity for you to develop your capacity for learning by getting you to reflect on why and how you are learning, and to become more capable of reviewing, planning and taking responsibility for your studies. All of the foregoing will of course be supported by staff, in particular your Academic Tutor. The key objectives of the PDP process can be summarized as follows:

- To help you become a more effective, independent and confident self-directed learner
- To understand how you are learning and be able to relate that learning to a wider context
- To improve your general skills for study and career management
- To articulate your personal goals and evaluate your progress towards these
- To encourage you to develop a positive attitude to learning throughout your professional life.

USEFUL LINKS AND USEFUL VIDEOS

Useful links

https://www.esri.com/en-us/what-is-gis/overview (accessed 24.09.2018)

https://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/index.html (accessed 24.09.2018)

https://www.ordnancesurvey.co.uk/support/understanding-gis/index.html (accessed 24.09.2018)

https://www.mathworks.com/help/map/the-three-main-families-of-map-projections.html (accessed 24.09.2018)

https://www.qgistutorials.com/en/docs/working_with_terrain.html (accessed 24.09.2018)

https://guides.library.duke.edu/QGIS/ImportData (accessed 24.09.2018)

https://opengislab.com/blog/2018/3/20/3d-dem-visualization-in-qgis-30 (accessed 27.09.2018)

https://www.igismap.com/download-digital-terrain-dem-digital-elevation-model-and-extract-contours-maps/ (accessed 27.09.2018)

http://www.webgis.com/ (accessed 27.09.2018)

https://ma.ellak.gr/documents/2015/07/grass-gis-for-geomorphologists-an-introductory-guide-2.pdf (accessed 27.09.2018)

http://qgiscloud.com/ (accessed 27.09.2018)

http://planet.qgis.org/planet/tag/corine%20land%20cover/ (accessed 27.09.2018)

https://www.eea.europa.eu/data-and-maps/data/clc-2000-vector-6 (accessed 27.09.2018)

http://eusoils.jrc.ec.europa.eu/library/esdac/index.html (accessed 27.09.2018)

http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ (accessed 27.09.2018)

Useful videos

https://www.youtube.com/watch?v=WAbOR_E2xtI (accessed 24.09.2018)

https://www.youtube.com/watch?v=bLbY3iMBW-A (accessed 24.09.2018)

https://www.youtube.com/watch?v=aLmMovuydqI (accessed 24.09.2018)

https://www.youtube.com/watch?v=5QIYZmysDNM (accessed 24.09.2018)

https://www.youtube.com/watch?v=r9Zy9XFOf9o (accessed 24.09.2018)

https://www.youtube.com/watch?v=JMbbm-X8fI8 (accessed 24.09.2018)

QUESTIONS, EXERCISES AND PROJECT

1. Questions

1. A geographic information system can

a. Interpret the data
b. Forecast data
c. Visualize the data
d. Make Decisions

2. Which of the following are key application disciplines for GIS?

a. Commerce and business.
b. Transport.
c. Physics and chemistry.
d. Environmental sciences.
e. Civil engineering.
f. Astronomy.

3. What are the main data representation forms in GIS?

a. pixel
b. vector
c. raster
d. sliver

4. What are the three features of vector data

a. Point
b. Color
c. Square
d. Polyline
e. Polygon
f. Polyshape
g.

5. What is the georeferencing process?

a. Your exact location Earth
b. The dimensions of a feature
c. The construction of the attribute table
d. Digitizing raster data

6. What are the three families of map projections are?

- **a. cylindrical**
- **b. conical**
- c. spherical
- **d. planar**
- e. polygonal
- f. orthogonal

7. Which of the following statements for map projections are incorrect?

- a. Conformal or orthomorphic map projections maintain correct distance properties.
- **b. When the map projection goal is to accurately measure distances, you should select a projection that is designed to preserve distances, planar**
- **c. Map projections are never absolutely accurate representations of the spherical earth orthogonal**
- **d. Equal area map projections are best used to calculate areas**
- e. There are few different map projections available

8. What does QGIS stand?

- a. Quick GIS
- **b. Quantum GIS**
- c. Quest GIS

9. What is QGIS main advantage?

- **a. Free and open-source cross-platform desktop**
- b. Most accurate and user friendly GIS software
- c. Most used GIS software

10. What are QGIS main components?

- **a. Menu Bar, Tool Bar, Map Legend, Map View, Status Bar**
- b. Menu Bar, Tool Bar, Map View, Status Bar
- c. Menu Bar, Tool Bar, Graphics Bar, Map View, Status Bar

11. GPS is (please circle the correct statements):

- a. Software that are freely available to manage data
- b. All GPS data are stored in one file formats
- c. GIS data cannot be upload to a GPS
- **d. GPS data can be uploaded on GIS**
- **e. A satellite-based system to find your exact position anywhere in the world.**

2. Exercises

1. Import the provided map into QGIS

2. Georeference the map

3. Digitize the hydrologic network, the watershed boundaries and the main roads.

3. Project

The goal of the project is to implement of soil and water bioengineering for sites that are facing one of the following scenarios: a) Fluvial, b) Coastal or c) Slope. This should be done on the sustainable and cost-efficient way.

1. Review on the problem that your assigned site is facing
2. Collection of data of the study site (google maps, DEMs, land-uses etc.)
3. The data that is not spatial form should be developed.
4. Digitize for a) FLUVIAL the hydrologic network and watershed boundaries, b) COASTAL the coastline and the area of interest and c) SLOPE, the study area.
5. Insert land-use, soil, climatic, geologic, roads, urban areas etc. that you need are appropriate for your study
6. Develop a map with the areas with the highest risk (erosion, flood, landslide etc.) that should be the priorities for soil and water bioengineering works
7. Suggest the type of soil and water bioengineering works that should be implemented
8. Finally do a cost analysis

Each team will write a report that will be at least 20 pages and have 10 references from scientific journal. The team will also present their report to their classmates (the presentation will be 15 minutes).

MODULE 5.

ENVIRONMENTAL IMPACT ASSESSMENT AND PLANNING

Module 5

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

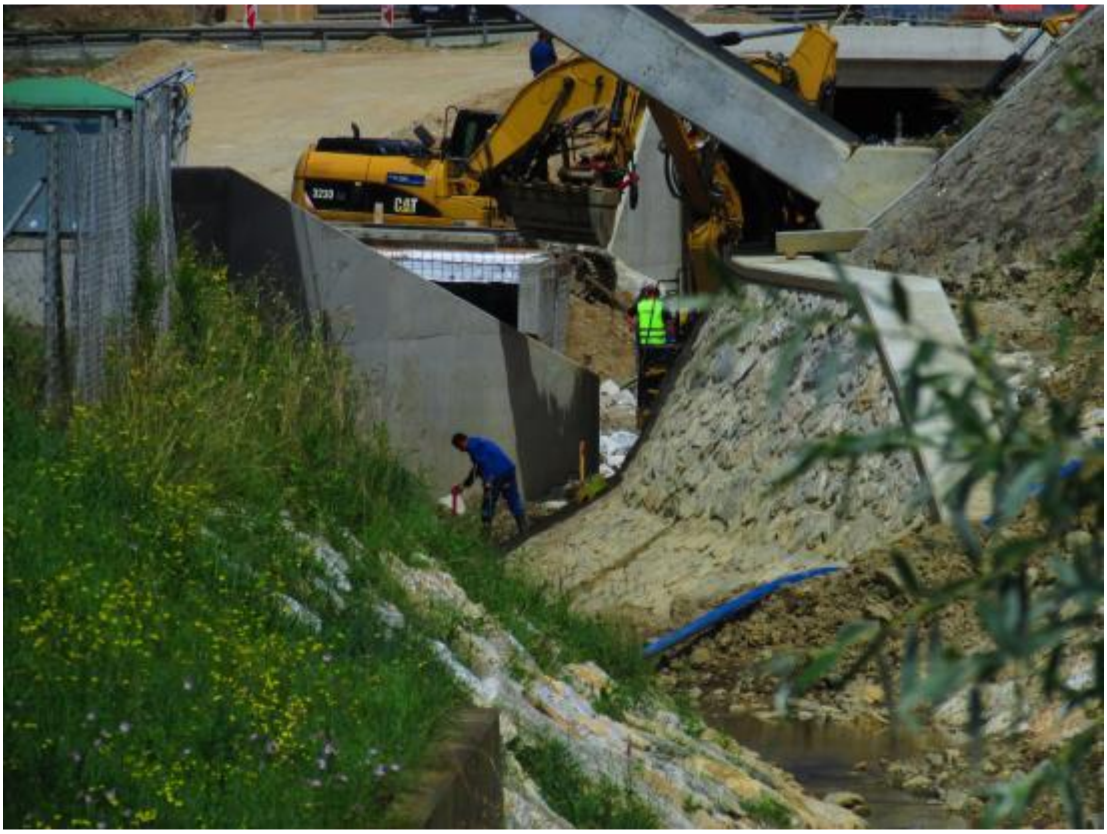


Photo: S. B. Mickovski

Module 5

ENVIRONMENTAL IMPACT ASSESSMENT AND PLANNING

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

ENVIRONMENTAL IMPACT ASSESSMENT AND PLANNING

Authors:

Mickovski S.B., Thomson C.S., Monterrubio G. Gallagher C.E., Sorolla A.,

Glasgow Caledonian University, Naturalea.

Co-funded by the Erasmus+ Programme of the European Union

September, 2018

TABLE OF CONTENT

1. MODULE DESCRIPTOR

Status: core

Credit Points (ECTS): 3

Pre-requisite knowledge: Module1, Module 2, Module 4

Module structure:

Activity	Total Hours
Lectures	20
Tutorials	5
Seminars	10
Practicals	5
Independent learning	30
Assessment	5
Total	3 (1ECTS=25hrs)

Summary of module content:

This module examines the types of planning system used across the Mediterranean region in context of soil and water bioengineering (SWB) works. The role of sustainability in planning systems, in plan making and in implementation is investigated within a risk-based framework. The use of Environmental Impact Assessments (EIA) to protect the environment and the promotion of project sustainability through strategic environmental assessment (SEA) are demonstrated.

Learning outcomes:

On successful completion of this module students should be able to:

- Evaluate the various planning procedures and mechanisms in light of SWB works in the Mediterranean.
- Relate the generic project lifecycle to SWB works stages
- Create a project management framework for application in the soil and water bioengineering sector
- Apply the principles of risk assessment/control/management to SWB works
- Identify and appraise the principle planning regulations and guidelines, particularly relating to the need for EIA and SEA
- Carry out a screening and scoping exercise on a "live" project (case study) to determine the level of detail of the EIA or if it is necessary at all

- Use techniques such as overlay to compare combinations of environmental impacts from various different project options
- Critically appraise both EIA and SEA as tools to aid in the pursuit of sustainable development in terms the triple base line for SWB case studies.
- Evaluate the importance of public participation and consultation for both SEA and EIA processes
- Describe the application of BIM methodology at different stages of SWB works.

Teaching/Learning strategy:

Teaching will follow novel methods derived through the ECOMED project: lectures for imparting fundamentals of module and tutorials and practicals for application of the fundamentals. These will be supplemented with virtual learning content, case study analysis, site visits and work placements.

The delivery of the module is through lectures, seminars and case studies. The students will gain hands on experience of the process of EIA and learn the importance of public consultation through group discussion and presentations. Case studies will show the students real life planning applications, particularly in relation to restoration, regeneration and sustainability. Guest speakers will be used as appropriate.

Other learning and teaching strategies will be developed and implemented, appropriate to student needs, to enable all students to participate fully in the module.

Syllabus:

- Types of planning system in use across the World, focus on the Mediterranean region
- Basis of project management for SWB works
- Introduction to environmental risk (environmental, societal, financial), risk control and management, the nature of environmental risk
- Environmental risk assessment including environmental impact assessment (EIA) and strategic EIA (SEA)
- EIA and the planning system, environmental management systems
- Structure and background to EIAs, risk control, environmental audit and monitoring
- Environmental assessment, EIA and project management, action plans
- Stakeholder engagement and public participation
- Project sustainability assessment
- Building Information Modelling for SWB works

Indicative reading:

Bloemer, S. et al 2015. European Guidelines for Soil and Water bioengineering. EFIB

Carrasco García, M.J and Salamanca Sánchez-Cámara, A.E 2010. Evaluación de Impacto ambiental de infraestructuras. Redacción y tramitación de documentos, ISBN 978-84-8143-710-2

Design Manual for Roads and Bridges, Vol 11, Section 4. HD44/09. Assessment of implications (of highways and/or roads projects) on European sites (including appropriate assessment). http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol11/section4.htm

Glasson J and Therrivel R 2011. Introduction to Environmental Impact Assessment, Routledge

Gray, D. H., Sotir, Robbin B. 1996. Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. Wiley-Interscience, ISBN 10: 0471049786 ISBN 13: 9780471049784.

Norris, J.E.; Stokes, A.; Mickovski, S.B.; Cammeraat, E.; van Beek, R.; Nicoll, B.C.; Achim, A. (Eds.) Slope Stability and Erosion Control: Ecotechnological Solutions. 2008, VI, 290 p., Hardcover. Springer.

Schiechtl, H. M., Stern, R. 1996. Ground Bioengineering Techniques: For Slope Protection and Erosion Control. Wiley-Blackwell, ISBN 10: 0632040610, ISBN 13: 9780632040612.

Schiechtl, H. M., Stern, R. 1997. Water Bioengineering Techniques: for Watercourse Bank and Shoreline Protection. Wiley-Blackwell , ISBN 10: 0632040661, ISBN 13: 9780632040667.

Studer, R, Zeh, H., De Cesare, G. 2014. Soil bioengineering – construction type manual. vdf Hochschulverlag AG der ETH Zürich, ISBN: 978-3-7281-3642-8

Therivel and Chadwick. 2005. Introduction to Environmental Assessment, Routledge, London

Morris and Therivel. 2009. Methods of Environmental Impact Assessment, Routledge London.

Therviel 2004. Strategic Environmental Assessment in Action, Earthscan 2004.

Jones Carys; 2005. Strategic Environmental Assessment and Landuse Planning, Earthscan, 2005.

Ficher, T. 2007. The Theory and Practice of Strategic Environmental Assessment-towards a more systematic approach EARTHSCAN 2007.

Watt, A. 2014. Project Management. https://open.umn.edu/opentextbooks/BookDetail.aspx?bookId=456

Journals: Journal of Environmental Management, Environmental Impact Assessment Review, Journal of Environmental Planning and Management, Journal of Environmental Policy and Planning

Transferable skills development:

- Setting personal targets and time management.
- Learning skills will be enhanced by use of open-source information and IT skills to research and collate information for case studies.
- Communication skills will be enhanced by requiring the use of appropriate language when writing and speaking to fulfil assignments and when making presentations in seminars.
- Group-work skills will be developed to address case study problems including the taking of initiative and assuming responsibility in carrying out agreed tasks.
- Critical thinking and problem solving
- Practical application of EIA tools
- Group Working skills

Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Coursework 1	2.5	50	50	EIA and SEA for SWB works incl. risk assessment
Coursework 2	2.5	50	50	Practical sustainability Assessment (case study)
Total	5			

Module contacts:

Module leader: Mr A. Sorolla, Dr Gallagher

Module tutor (academic): Dr Mickovski, Dr Thomson

Module tutor (industry): Ms. G. Monterrubio

2. PLANNING SYSTEMS

The Royal Town Planning Institute (2001) describe planning as "… a management process which can deliver the spatial aspects of sustainable development, integrated agendas and inclusive communities anywhere in the world." Planning is therefore concerned with how decisions are made in relation to the future of cities, towns, villages and countryside. The emphasis, globally is how can we ensure that the planning approach adopted is one that proves to be sustainable and helps to mitigate the effects of climate change.

The planning system profiles new developments across a country, ensuring that the development is in the public interest, while weighing up its economic, environmental and social benefits and drawbacks. It plays a key role in making sure the developed land is safe, well designed, and attractive. The planning also ensures that development will support regeneration which meets the needs of local communities. It should make sure that new development in protected areas takes into account its surroundings but also prevent development where it would cause unacceptable environmental harm. The planning system aims to ensure that all views on the new development are taken into account.

It is important to realise that planning *per se* is not dictated by the EU through regulations or directives, EU legislation and case law impacts upon the planning law of member states. Each country and region has its own planning systems and organisation covering: national, sub-national, local planning, neighbourhood planning, and major infrastructure projects. In general terms it can be said that there is a previous project, the project itself, the executing works and monitoring. A planning permission from a local planning authority usually starts the planning process with the person or organisation that wants to carry out the development submitting a planning application.

The main elements of any planning system are plans and policies to guide the future development of land. Planning acts as a system to control the use of land by evaluating proposals in relation to the plans and polices of a country and region. There are 4 categories of planning:

- Planning by Statute – Plans as a Rule Book (Town and Country Planning Act (UK), Land use planning and Appraisal Law (Spain))
- Discretionary Planning – plans as guidelines (can be seen as good practice)
- Pretend planning – Plans with no influence
- No planning

There is a hierarchy of plans across member states:

- National – these plans and polices provide information on how to do things
  - Development plans
  - Development management
  - Community engagement
  - Sustainable economic growth
  - Sustainable development – this places a duty on the local planning authorities to promote sustainability in their area
- Regional –addresses the national plans in a regional context and will include both towns and cities. They are concerned with broad development projections and should be updated on a regular basis (5 years is the norm)with an accompanying Consultation Statement
- Local – are sites specific plans which give details of the allocation of land in the area for particular uses. In line with regional plans they should be updated (again 5years) and a

consultation statement is also required, but should also have an Action Plan (every 2 years) to allow for timeous response to any issues.

When starting a new project, a previous study of the area that wants to be analysed has to be done. It implies doing a hydraulic study of the river where fluvial works would be done, as well as a geotechnical study for an unstable slope. Besides, a study of the potential vegetation and the already existent vegetation should be done for a better knowledge of the area and an adequate writing project.

For the final project, a detailed report of the actions and works that will be done have to be described. While writing the report, it also has to be mentioned the soil usage of the surrounding area to minimize the direct and indirect impacts. Moreover, in the case of river works they have to be treated as the whole basin and not just the section of the river where the works would be done to take into account the inputs or outputs coming from upstream. For the field work period, it is important to notice if there would be potential material close to the working area, such as stones or pruning material, for their usage instead of bringing materials from further areas.

Afterwards, when executing the works according to the plan, keep in mind the detection and protection of cultural heritage and ta

rget species for a better work execution. In addition, there have to be a plan for the waste management or specify what is done with the soil waste in the works.

Question: How is planning law implemented in your own country? At what level(s) of the planning hierarchy would a SWB have most influence and why?

3. INTRODUCTION TO PROJECT MANAGEMENT

3.1 Key definitions

3.1.1 Project

The project is a unique process which starts with inception and follows through to completion. However, this is often fragmented and it is important to note that with few exceptions no two projects are the same. Projects are described as “a temporary endeavour undertaken to create a unique product, service or result”.

In the construction industry environment, where the soil and water-bioengineering is included, the key stages of a project involve Design, Procurement, Construction and Handover; and can be large and small and can take a short or long time to complete (either its objectives have been met or the project is terminated).

3.1.2 Project Management

Project management is defined as the application of processes, methods, knowledge skills and experience to achieve the project objectives (APM, 2018).

Project Management can be described as the art of managing all the aspects of a project from inception to closure through the application of a formal approach using a scientific and structured methodology which brings control to complex environments. It is an art and science which seeks to convert vision into reality in a context which is complicated by issues related to technological, inter-dependent tasks, or geographical spread of team and stakeholders (Naybour 2014).

Key aspects of project management are:

- Defining project goals & objectives
- Developing a project plan
- Specifying tasks or how goals will be achieved
- Identifying needed resources
- Associating budgets and timelines for completion

Associated with this comes:

- Planning what needs to be done, when, by whom and to what standards
- Co-ordinating the work of different people
- Monitoring work being done
- Managing any changes to the plan
- Delivering successful results

3.2 Project team

	Role	Responsibility	Skills
Project Manager	Authority, responsibility, and accountability, and who has been assigned to achieve the project objectives within an agreed period of time, cost and quality/performance. They are responsible for managing project stakeholders and appointing team members who will be required to aid the completion of the project.	Resource management: time (schedule), manpower, money, facilities, equipment, material and information/ technology. Interface management: customer relation, management (functional and upper level), product interface, material interfaces (inventory control), and information flow. Planning and control management: increase equipment utilisation, increase performance efficiency, reduce risks, identify alternatives to problems and identify alternative resolutions to conflicts.	Team building Leadership Conflict resolution Technical expertise Planning Organisation Entrepreneurship Administration Management support Resource allocation
Engineer / Designer	Design and physical integrity of SWB structures	Duty to ensure the safety and durability of the project on which they are working. Solve technical problems to achieve project vision.	Multi-disciplinary technical expertise, Investigation, communication, management, training
Site Supervisor	Ensure there is a safety programme/routine in place and everyone knows the precautions and actions to take in case of an accident. Ensure everyone knows of this, and determine the effectiveness of the controls in place.	assessing various safety hazards, and determining the likelihood of an accident occurring; coach, help or guide workers to become and remain competent in these areas, as well as others; motivate and, in some, cases even discipline staff;	Technical expertise Planning Organisation; Capable of performing emergency first aid at work;

		mentor and encourage members of the team	
Client / Owner	Ensure that suitable management arrangements are made for the project; Select & appoint a competent and resourced Designer/Contractor. Notify the relevant enforcing authority of certain projects (notifiable). Ensure sufficient time and resources are allowed for all stages of the project. Ensure co-operation and co-ordination between the client's employees and client contractors	Provide the pre-construction information (PCI) to the designers and contractors. Verify the sufficiency of the construction phase plan (CPP) prior to construction commencement. Verify that suitable welfare facilities are in place prior to construction commencement. Contractor training - Ensure the necessary information, instruction and training is received and appropriate supervision is provided to comply with the regulations. Subsequent to receipt of the health and safety file from the Principal Designer, maintain the information up to date and provide access to any person who needs to see it for health and safety purposes.	Planning Organisation Entrepreneurship Administration Management support Resource allocation
Contractor / Subcontractor	Responsible for the overall coordination of a project, with site safety as priority	providing all of the material, labour, equipment (e.g engineering vehicles and tools) and services necessary for the completion of the project; responsible for the quality of all work performed by any and all subcontractors; applying for building permits, advising the person they are hired	Good communication skills. Problem solving skills. Decision-making ability. Commercial awareness. Ability to motivate others. Teamworking skills. Good knowledge of planning/building

		by, securing the property, providing temporary utilities on site, managing personnel on site, providing site surveying and engineering, disposing or recycling of construction waste, monitoring schedules, and cash flows, and maintaining accurate records	methods and regulations.

Table 1 shows a summary of the profiles in a project team.

Exercise: read PMI and APM definitions online and discuss potential hard and soft skills needed for each key project team member role.

3.3 Project lifecycle

The project lifecycle relates to the sequence of phases through which a project will evolve. The process of planning, organising and managing resources to achieve the objectives of the project across its lifecycle is what represents project management.

Phases of the project lifecycle: The RIBA (Royal Institute of British Architects) provide a Plan of Works (**Figure 1**) which is developed around a set of work stages to aid the process of briefing, designing, constructing, maintaining, operating and using building projects. It provides details around tasks and outputs required to each stage which may vary or overlap. The Plan of Works is designed to act across a range of sectors and project sizes and sees to allow for the mapping of all forms of procurement.

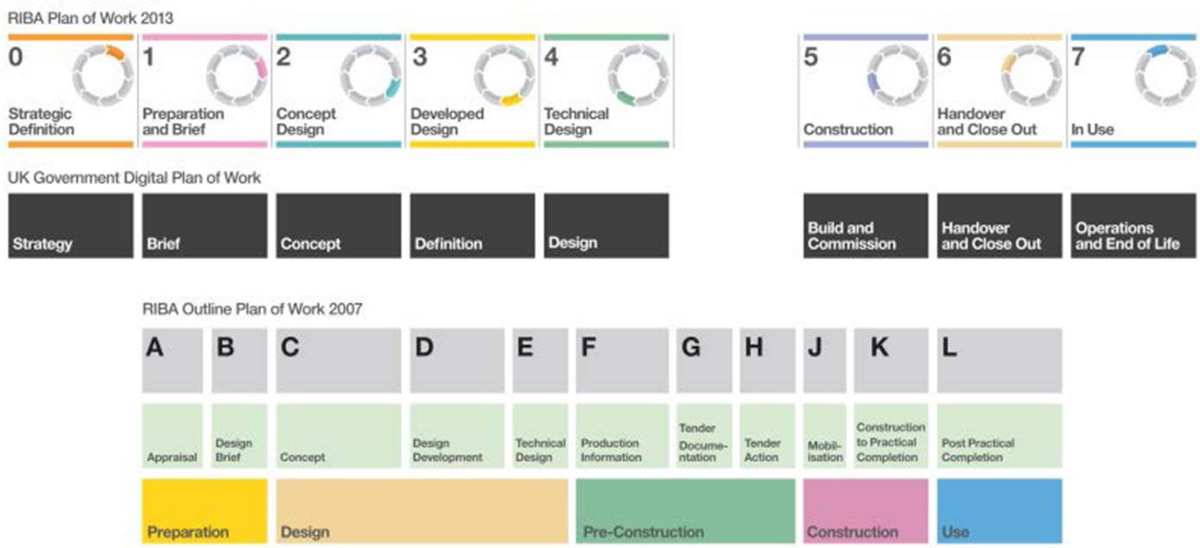


***Figure 1** RIBA plan of works (Source: RIBA, 2013)*

Exercise: Select one of the ECOMED case studies and analyse a selected workstage. Can you identify the activities fitting in the RIBA plan of works? Can you identify gaps in the activities/processes? Research the online resources for other sources detailing project lifecycle stages. How do these differ from RIBA's? Are there any specific Soil and Water bio-engineering stages/processes that are not covered in these systems? Can you identify any overlap in the stages?

Figure 2 reflects another structure presented for project lifecycle but reflects the overlapping nature of these stages often and the varying levels of effort which the project manager requires to display in realising the activities which represent these phases.

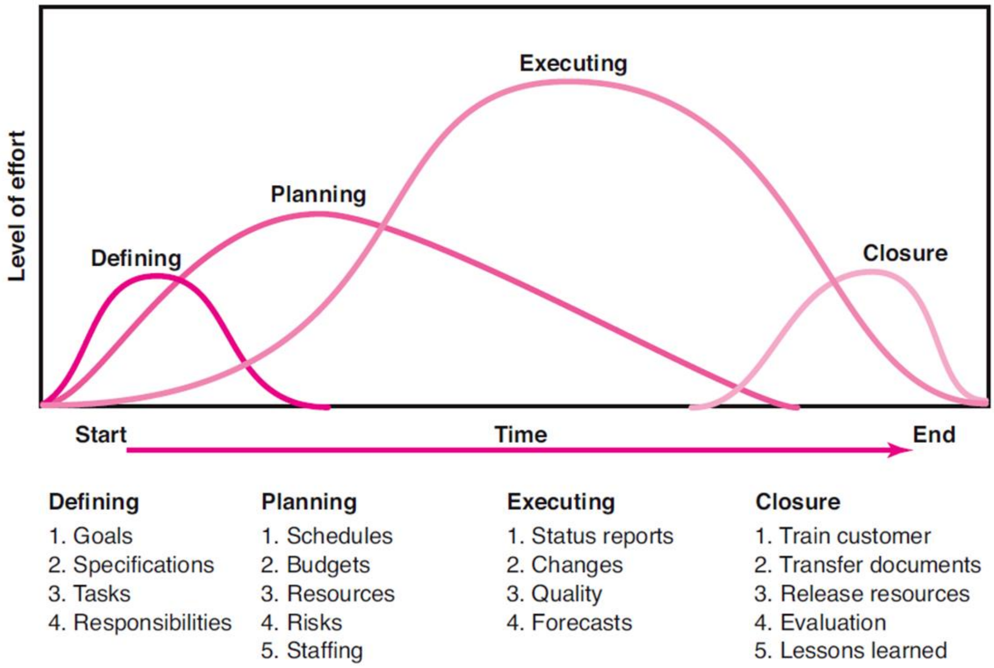


***Figure 2** Project phases relating to the duration of the project and the level of effort (source: XXX)*

3.4 Project methodology

A project methodology is a framework with specified deliverables for management.

Figure 3 shows a basic example reflecting the project lifecycle phases with the methodology phases and illustrates the approach of identifying tasks, signoffs, and the gates. The PMBOK Guide (PMI) is process-based, meaning it describes work as being accomplished by processes. Processes overlap and interact throughout a project or its various phases. This approach is consistent with other management standards such as ISO 9000.

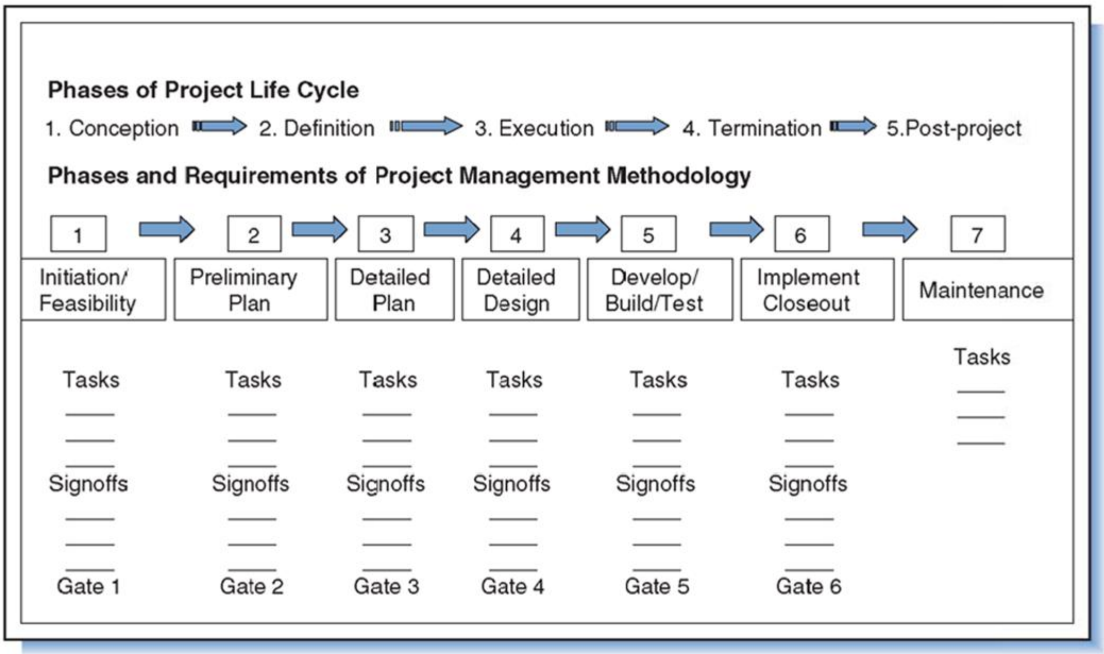


Figure 3 *PMBOK Guide (PMI) http://www.cs.bilkent.edu.tr/~cagatay/cs413/PMBOK.pdf*

Processes are described in terms of:

- Inputs (documents, plans, designs, etc.)
- Tools and Techniques (mechanisms applied to inputs)
- Outputs (documents, products, etc.)

PMI identify Specifies Tasks and Deliverables for:

- Project initiation/proposal
- Project selection
- Proposal development
- Project planning
- Requirements/specifications
- Work definition
- Resource needs
- Time and cost estimating
- Budgeting/accounting
- Risk analysis
- Contract management

Other Project Methodologies are provided by organisations such as PRINCE 2.

Exercise: select an eco-engineering process within a case study and detail the inputs, tools and outputs within.

3.5 Project execution plan (PEP)

A PEP is a core document which the project manager has as part of their toolkit. It provides a fixed point of reference for project stakeholders including 1) project information, 2) lines of communication and authority and 3) key project procedures.

In developing the PEP specific for the project the project manager will need to involve stakeholders and those with responsibility, get agreement from them as to its contents, and reflect key concepts such as the size of the project (minor works, major new build), complexity- phases, timing and interfaces, procurement route and the nature of the works i.e. engineering.

Usually, the PEP comprises:

I. project definition and brief
II. roles, responsibilities and authorities
III. project cost plan and cost management procedures
IV. risk and sensitivity analysis
V. programme management
VI. contracting and procurement
VII. administrative systems and procedures
VIII. safety and environmental issues, such as the construction design and management regulations;
IX. quality assurance
X. commissioning; and
XI. post project evaluation

3.6 Scope management

3.6.1 Managing project scope

At the start of a project, problems tend to be associated with resource issues. As the project nears completion, obstacles tend to be clustered around two issues: first, last-minute schedule and technical changes, and second a series of problems that have as their source the uncertainty surrounding what happens to members of the team when the project is completed. **Figure 4** shows the importance of planning to ensure that changes are restricted to the early phases of the project when they are manageable.

The project manager key task is to make sure that the scope is managed, and that sufficient planning and detail is provided in order for the stakeholders to agree around the scope and for any problems to be identified early.

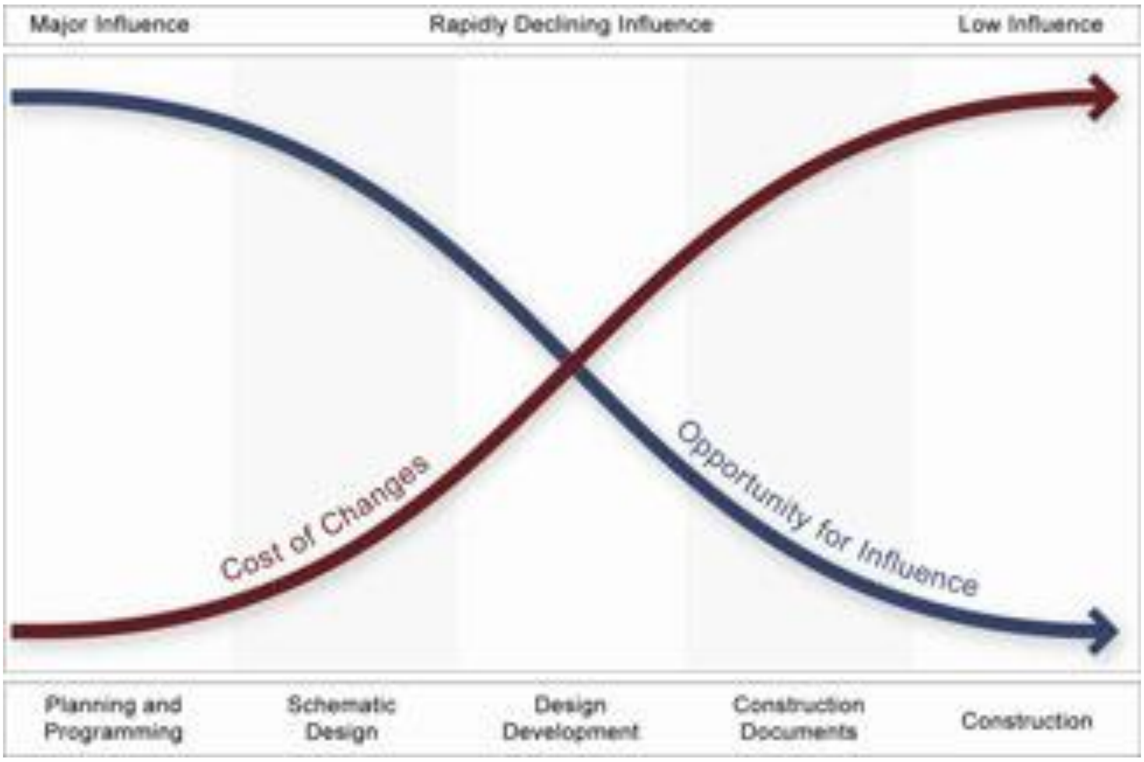


Figure 4 *Opportunities to influence change vs the cost of change across the project process. Source: https://www.wbdg.org/design-disciplines/architectural-programming*

3.6.2 Change management

Change control is the process through which all requests to change the baseline scope of a project, programme or portfolio are captured, evaluated and then approved, rejected or deferred.

The process must allow all stakeholders to submit their suggestions for changes to scope and typically comprises five steps: *Request, Review, Assessment, Decision and Implement*. The request is entered into a change register which records all requests and their status (e.g. pending, approved, rejected or deferred). If an unauthorised or emergency change is identified, it should be retrospectively put through the change control process.

3.6.3 Monitoring and control

Planning is a key activity that produces a plan, which then forms the basis of monitoring. Monitoring and control is key to effective project management as it provides the process for monitoring and controlling the processes used to initiate, plan execute, and close the project to meet the performance objectives defined in the project management plan (PMBOK3, p78). Monitoring is the term which refers to collecting, measuring and disseminating performance information and assessment measurements and trends to effect process improvements.

3.7 Project closure

The closing process of the project is very important to the project's success. It requires planning and resource to ensure that it is effective. Key activities surrounding project closure:

- Gain client acceptance

- Transition of deliverables to owner
- Close out contract obligations
- Capture lessons learnt
- Close accounts
- Update resources schedules
- Financial accounts
- Performance evaluations
- Market success
- References
- Update CV
- Celebrate!

Types of project closure

- Normal
- Premature
- Failed project
- Changed priority

When is a project closed?

- Practical completion
- Non-completion
- Making good defects
- Final accounts
- Final certificate
- Reviewed

How do you terminate a contract?

- Successful performance
- Mutual agreement
- Breach

Group exercise

As a group, explore the following questions in relation to projects which you are familiar with:

- What dangers do you think come from not closing a project effectively?
- If you are going to terminate a project, as a Project Manager, what factors would make it easier to manage this process?
- What do you think are some of the key steps in a post project review?
- For a project you are familiar with (you can choose one of the ECOMED case studies), can you determine the key characteristics for project success, and reflect on how you could judge whether the project achieved this or not?
- Please identify any barriers which may restrict the development of post project lessons? and then the implementation of post project lessons?
- For a project you are familiar with (you can choose one of the ECOMED case studies), can you

establish post project lessons, and how you would carry these forward to inform a future project?

4. INTRODUCTION TO RISK, ASSESSMENT, CONTROL, AND MANAGEMENT

4.1 Risk

Risk is an event that is likely to occur in the future and this would prevent or delay the accomplishment of a planned objective/target.

4.2 Risk Management

Risk Management (RM) is a process to: Identify all relevant risks, Assess/quantify these risks, Address the risks in order of importance, Monitor them and report on their management.

The RM cycle comprises:

- Confirming strategy (define purpose, plan and targets),
- Identification and Assessment of risks (explore threats, causes and effects, likehood and impact, prioritise),
- Challenge and evaluate risk controls (the efficiency of policy, actions, procedure, processes in place to mitigate against risks; measure residual risk)
- Take action (for serious risks with no/low controls, where risk appetite is exceeded, where costs>benefits): tolerate, treat, substitute, terminate
- Monitor and Report (use standard format e.g. Risk Register, review all risks regularly and the serious ones more often, report to senior level but make the assessments available to the stakeholders).

Group exercise: Discuss application of the RM cycle in a typical eco-engineering project from the perspective of a a) Client/Owner and b) Contractor. Identify actions that bring value to each of these stakeholders and contrast them to the perceived benefits for the wider environment.

4.3 Risk categories

Risk management is usually a legal requirement in construction/environmental sector, it promotes good management and needs to be focussed due to usually limited resources. To improve focus, risks should be categorised (clustered) into standard and actionable groups such as:

- Environmental: air pollution, soil contamination, water pollution, reduction in biodiversity, noise, vibrations, fire, flooding, earthquake, landslides, erosion, etc.
- Financial: change in funding, failure to safeguard assets, Poor cash flow management, Lack of value for money, Fraud / theft, Poor budgeting, etc.
- Operational: low staff skills levels, poor quality of work delivered, lack of succession planning, health and safety risks on site, failure in the supply system, poor project management process
- Reputational: poor stakeholder relations, poor partnership relations, criminal and or unethical links
- Governance and compliance: poorly defined duties, disregard to terms and conditions of funding, safeguarding of vulnerable individuals, taxation, data protection, health and safety law, etc.

- Strategic: activities contradict stated objectives, failure to engage in processes/activities that support the objectives

4.4 Risk Assessment, Monitoring and Reporting

Risk Registers (RR) are used to monitor and qualitatively report on the risks throughout the project life. They are databases of information on risks and they are 'live' documents that need to be reviewed and updated regularly.

RR comprises: Risk description, Controls in use, Impact (1-5), Likelihood (1-5), Impact (likelihood x impact; 1-25), Risk owner, Residual risk/Further actions needed, Date. RR helps in prioritising based on usually colour-coded matrix.

Specific quantitative risk assessment (QRA) methods exist for different risk categories and types. QRA methods and examples for slope stability related problems can be found at: http://hkss.cedd.gov.hk/hkss/eng/qra.aspx.

4.5 How to succeed with risk management

The risk has to be accepted in all works and be integrated during the whole process as soil and water bioengineering deals with dynamic ecosystems. Once the works are in progress, although everything is planned and organized, some unpredictable problems before the proposal of the project can happen. It has to be taken into account the days and season of the executing works as some actions can't be done out of season as it could be planting or using the stakes technique. In addition, when working in a river basin, the works have to be stopped when there have been heavy rains or during snow melting time. For a more precise works, it is essential having a good topography of the riverbed and its margins in order to achieve the same river levels previous to the works. To diminish the environmental risk it is important to use products of good quality. When having to do soil movements, do it with soil of quality so as to diminish the risk of not structured soil or intrusive seeds mixed in it. In the same way invasive plant species represent a risk when planting autochthonous and endemic species.

Soil and water bioengineering has a social risk in the sense that the society is reluctant to these kind of works. The concept that concrete can be a better solution is still widely spread and thus in some regions the works of this discipline can be difficult to impulse and explain to the society. For this reason, there have to be proposed more dissemination activities among the stakeholders and society in general. It is highly recommended to propose dissemination activities before, while and after the works as the perception of the society improves and there is a more reliable feeling in these kind of works. In order to achieve success, the RM process needs to involve all levels of stakeholders, review effectiveness of controls regularly, ensure risk owners take responsibility, focus on causes rather than symptoms. RM process can fail if it is limited in scope, limited in support from management/stakeholders, is not transparent, is not embedded within the planning/management systems.

As there can be some unexpected changes during the execution of a work due to administrative factors, changes in the due dates, last minute actions cancellations or additions, there is also a financial risk. It has to be keep in mind that some projects are finally executed years after their proposal and thus there can be changes in the budget. For all these cases, it is essential having meetings and agreements with the clients, as well as a good knowledge of the area and techniques for an adequate and realistic budget.

Group Exercise: Work in small groups (3-5 persons). Choose one of the ECOMED case studies and create a risk register for Planning, Construction, and Maintenance/Monitoring stage. Highlight the highest risks for each of the stages, propose control measures, and analyse the roles of different risk owners.

4.6 Risk management frameworks

Existing relevant risk management framework (e.g. geotechnical; HD 22/08) provide advice on what constitutes hazards that pose risks and will need to be considered when developing the risk registers for a project. This framework proposes certification at a number of critical stages:

- Key Stage 1 Initial review of project and risks to determine its classification and thus the requirement for certification
- Key Stage 2 Preliminary assessment including preliminary certification
- Key Stage 3 Design and Construction Certification
- Key Stage 4 Feedback.

Expanding this framework to include the effect of soil- and water bioengineering strategies and structures can lead industry- specific framework such as the one below:

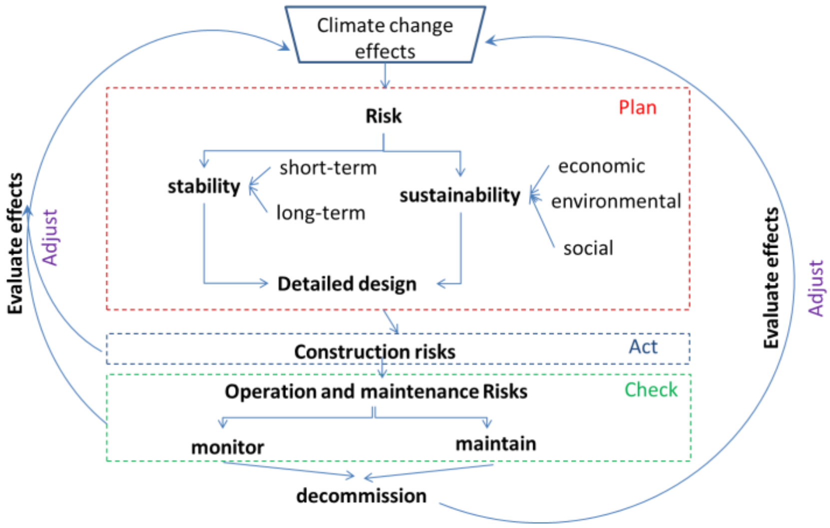


Figure 5 *Proposed risk-based framework for analysis and integration of vegetation-related parameters in geotechnical design and construction (Mickovski, 2018)*

5. ENVIRONMENTAL RISK ASSESSMENT

5.1 European EIA Directive

The EIA directive (85/337/EEC) has been in force since 1985 and as almost all projects involve landuse, the planning system of all member states (MS) acts as the main mechanism for the implementation of the directive. Under the directive projects will require an EIA if they are listed in Annex I, whilst for those listed in Annex II, it is at the discretion of the MS whether or not a full EIA is required. The process of EIA should result in an Environmental Impact Statement and a Non-Technical Summary.

- Annex I (Mandatory EIA): These are considered to have signification effect on the environment and include: motorways, long distance railway lines, installations for the disposal of hazardous waste etc.
- Annex II (Discretion of Member States); for projects listed in Annex II, it is up to the national authorities (which will include planning officials) to determine as to whether or not an EIA is needed. This process is known as **Screening**. Key issue to consider here is the fact that projects listed in this Annex II specifically mention flood relief projects which is highly applicable to SWB. Additionally it is increasingly important to assess the environmental impact of a project, regardless of whether mandatory or not so understanding the process of EIA is essential to all those working in the area of SWB.

EIA Directive amendments:

- Directive 97/11/EC – updated the Directive to consider transboundary aspects of EIA and widened the scope by increasing the type and number of projects requiring a mandatory EIA.
- Directive 2003/35/EC –incorporated the importance of public participation to align with the Aarhus Convention on public participation in the decision –making process. This amendment is important for SWB as involvement with the public may make the eco engineering alternative the more attractive option and therefore raise the profile of such projects.
- Directive 2009/31/EC – amended Annexes I and II – of specific interest is projects relating to capture and storage of CO_2
- Directive 2011/92/EU – original directive and amendments codified
- Directive 2014/52/EU – to simplify the rules for assessing the potential effects of projects on the environment – aim to improve the level of environmental protection and promoting sustainable development. Of key interest to SWB professionals is the greater need for monitoring of the impacts of the project.

Key Questions: How is the EIA directive implemented in your own country? Who decides whether a project can go ahead or not?

5.2 The process of EIA

EIA should begin when project is initiated and continue right through to monitoring the impacts of the development. It should include mitigation measures and details regarding site restoration. Monitoring is considered to be one of the weakest parts of the EIA process and the new revision (2014/52/EU) aims to improve this. The following flowchart summarise the main issues of the EIA Process:

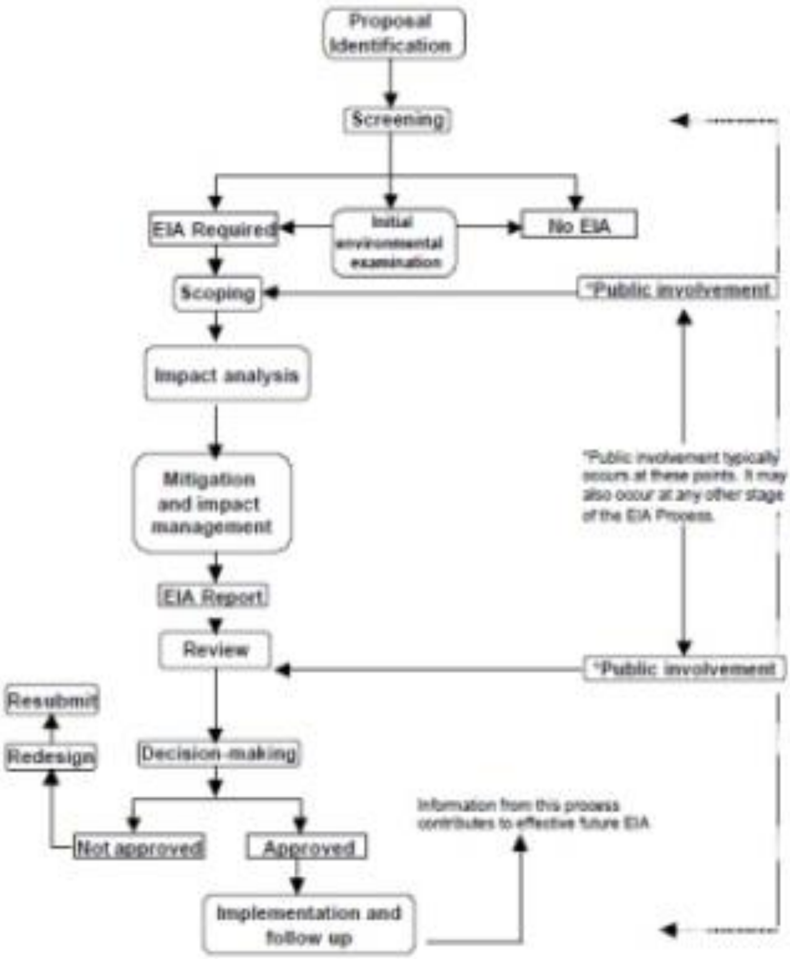


Figure 6 *EIA Process (source: UNEP, https://unep.ch/etu/publications/EIA_2ed/EIA_E_top2_chart.PDF)*

An environmental statement must accompany the planning application that is then sent to the relevant decision making authority (normally related to planning).

The specific requirements for an EIA depend on each country and region. In the case of Spain, the information has to be based on the environmental assessment legislation law 21/2013 of December 2013. According to this law, the article 7.2 specifies the type of evaluation (either ordinary or simplified) according its suitability in the annex I or annex II. In addition, the document has to include all the basic information required in the article 45.1 of this law 21/2013 and present the application in the regional environmental office of the Government attached with the project that want to be executed.

5.2.1 Screening

The first consideration is whether or not it is mandatory for the project to have an EIA – Annex I yes, Annex II at the discretion of the competent decision making authority but it is seen as good practice to identify the main impacts of a project and make every attempt to either eliminate them (very rarely possible) or mitigate and manage them.

5.2.2 Scoping

The scoping aspect is carried out to establish what the significant issues are – ideally these issues should be established in conjunction with the developer, any relevant agencies who may be affected by the project and the public. Good scoping is central to identifying the key aspects, minimising them and creating the Environmental Statement. It also allows for the adequate allocation of resources for the project.

Guidelines for Good Scoping Practice (source: http://www.snh.org.uk/publications/on-line/heritagemanagement/EIA/a.1.shtml)

- Make early site visits in order to ensure that matters of concern are identified at an early stage;
- Establish appropriate consultation arrangements with interested parties including the Competent Authority;
- Conduct the scoping exercise in a systematic manner using scoping matrices and producing a Scoping Report where appropriate; and
- Agree baseline survey requirements, prediction methods and evaluation criteria with appropriate bodies, including non-governmental bodies where they have expertise.

Any potential impacts of a project are measured against what the present and likely future state of the environment without the project (both natural events and human interaction should be included) across the same timescale of the proposal. This baseline assessment should focus on the significant issues

5.2.3 Question of Significance

It is often difficult to find any definition on what a significant impact actually is. There are however guidelines that may help in identification.

- Is the impact in question likely to threaten the attainment of existing or proposed environmental quality standards?
- Is it likely to conflict with the objectives, policies or plans of the authority competent to authorise the project?
- Is it likely to be an issue of concern to an environmental control authority because it may conflict with its environmental objectives, policies or plans?
- Is it likely to be an issue of concern either to national environmental interest groups or the local community in which the project would be located

When considering what significant impacts are the following need to be considered:

- The receiving environmental media (air, water and land)
- The living receptors occupying those media (humans, flora, fauna)
- The Built environment

These impacts can then be classified in 3 main categories

- FIRST – impacts relating to the project at any stage: exploration, planning design initial construction, operation and modification, termination and de-commissioning
- SECOND – impacts that occur from abnormal working conditions- frequency and probability is linked with risk analysis and assessment
- THIRD – stimulation of other projects

To carry out the scoping aspect of the project the contractor needs to be familiar with various methods of identification. There are a number of main approaches that can be considered but it is important to appreciate that the increasing use of GIS in this as a means to reduce subjectivity amongst assessors.

5.2.4 Public Participation

The process of EIA is also based on public participation but there has been criticism that they have little voice in affecting any change. The public should be consulted at the scoping stage and the prediction and mitigation stages prior to the creation of the draft environmental statement. The draft EIS is then reviewed taking into account the feedback from the public. It is important to realise that public participation covers a range of both professionals (scientific community, decision makes, regulatory bodies etc.) and the general public (normally those who are directly affected by the project will be more vocal). More detail on public participation can be found in the section on Stakeholder Engagement.

5.2.5 Methods of Identification

- Overlay technique – increasingly with the use of GIS – allows for layers of different themes to be overlay to identify impact – this approach will be the most accurate method if impact identification and SWB professionals should become confident in its use
- Matrices (Leopold is the oldest one in use) – this approach can be a good means of identifying what the key significant impacts are and develop the appropriate mitigation strategies to reduce them. The impacts are judged on magnitude and importance but it is importance to appreciate that this relies on a degree of subjectivity. The figure below illustrates a simple matrix:

Comparing Options – Matrix comparison

	Do nothing (baseline)	Option 1	Option 2	Both
Air Quality	-	--	+	-
Water quality	-	--	--	---
soil	0	-	-	--
Social/economic	0	+	++	++

Figure 7 *An example of a simple matrix identifying what the key significant impacts are and developing the appropriate mitigation strategies to reduce them*

- Environmental evaluation system – quantitative method attempts to give weightings to an impact based on relative importance
- Checklists lists aspects of the project can be descriptive, questionnaire type or relate to threshold values of concern
- Networks – this approach is based on the recognition that environmental systems consist of complex interaction and relationships and aims to try and reproduce this web:

Impact → Impact A → Impact B → Impact c etc

***Figure 8** An example of networks approach including interactions*

5.2.6 Predicting and assessing impacts

When predicting and assessing any potential impacts the possible interactions between the proposed development and both existing and future site conditions should be considered. It is important that both the positive and negative impacts are considered in relation to source of the impact (pollution), the pathways which it may travel and finally the receptor that will experience the impact (SPR).

When considering the mitigation strategy the following hierarchy should be adhered to:

- Prevent – can the impact be prevented (consider alternative method etc.)
- Reduce – consider minimisation at source, abatement at site and/or abatement at receptor
- Offset

5.2.7 Monitoring of Impacts

The latest amendment of the directive 2014/52/EU highlights the need for improvement monitoring which has been considered a shortcoming of the process. When creating a monitoring strategy for a project, the following aspects should be considered:

- What is to be monitored;
- The standard or parameter to be achieved;
- Who will carry out the monitoring;
- How will the monitoring be funded;
- Who will receive the results and be responsible for any necessary action

In theory the process of monitoring will provide feedback for future EIAs.

5.2.8 Environmental Auditing

EIA is an anticipatory tool, whilst environmental auditing is a tool that measures the effects of certain activities on the environment. To measure the effectiveness of the project, environmental auditing should therefore be carried out to provide feedback and enable suggestions for improvements to be made. However as it follows the weakest phase of the EIA (monitoring), auditing is not always well reported or acted on. However this is expected to change as there are greater drivers for sustainability so it is important that SWB professionals are familiar with the process. This also links to the wider concept of environmental management systems which is based on the principles of continuous improvement through the Plan, Do, Check, Act cycle (**Figure 9**).

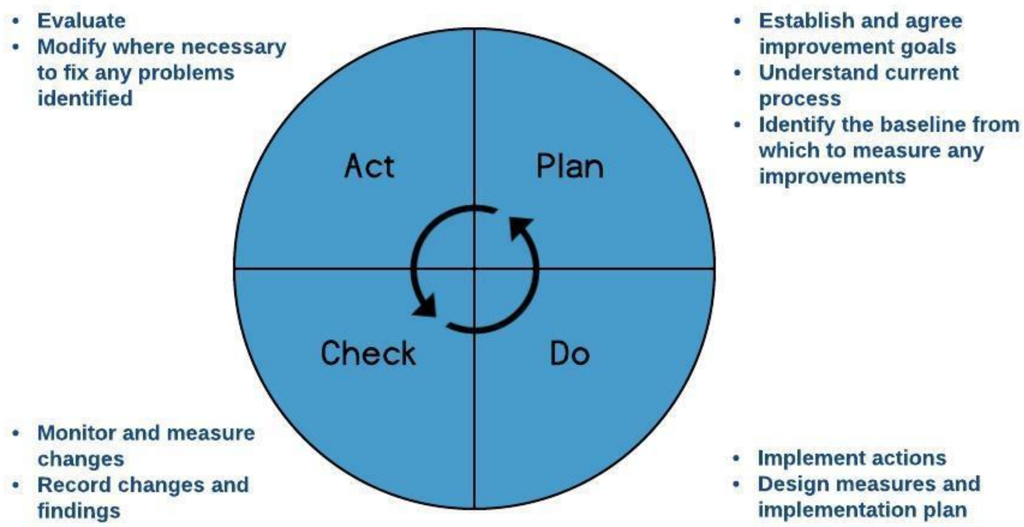


Figure 9 *PDCA diagram for Continuous Improvement (source: https://www.sheffield.ac.uk/piu/how)*

According to the European standards, for the works and processes it is important to mention the ISO 14001. Then, each organization is responsible to achieve and fulfil its requirements and is assessed once a year to evaluate the procedure.

When executing a SWB work, the project has to include a detailed description of the working area (from atmosphere, soil, landscape, vegetation, fauna to population) and the negative impacts it can present. In order to reduce the impact on the physical, biological and socio-economic environment, specific preventive and compensatory measures can be proposed when writing a proposal of works. These measures will be proposed taking into account the current state, the impacts that are predicted and what would be the state of reference with special attention to the protection and improvement of the biological environment. More information about how to take measures and procedures during field work for the description of the EIA can be found in the protocols of the ECOMED project.

Exercise: Consider how the principles of Auditing and PDCA can result in improved methods of eco-engineering solutions. Considering one of the SWB projects carry out a create a scoping matrix to identify what the key environmental impacts are and identify the appropriate monitoring and mitigation strategies to manage and minimise them.

5.2.9 Strategic Environmental Assessment

EIA is often referred to as Project EIA, with the type of project perhaps being a new road, a coal power station etc. The criticism that has been levelled at project EIA is that it comes too late in the process and the type of project has already been decided on which may not be the most environmentally friendly option. There were also a number of EU and UN initiatives that were developed in light of the following

- Climate change and global warming
- Loss of Biodiversity
- Cumulative effects – project EIA is about the project – there is little considering of the cumulative impacts of a number of similar type projects on a wider area

The EU responded with the SEA directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. The aims of SEA are:

- Improve strategic action (therefore should come much earlier in the process than EIA so as the influence the type of projects
- Promotes participation of shareholders in the decision making process (a criticism of EIA as claims that the participation is too late and therefore the type of process cannot be influenced. This is a key aspect for SWB practitioners to consider as eco engineering interventions could be highlighted.
- Focus on key environmental and or sustainability constraints, therefore good scoping is also key to the success of SEA
- Identify the best option, i.e. what is the best environmental option?
- Minimise negative impact, optimise positive ones and compensate for loss (based on the precautionary principle)

Although the SEA directive does not refer to policies, good practice should consider the ethos of SEA when developing them. It does however apply to a wide range of public plans and programmes. There are 11 key sectors that SEA applies to: Agriculture, **Forestry**, Fisheries, Energy, Industry, **Transport**, Waste, **Water**, Telecommunications, Tourism, **Land use planning**. Of key relevance to SWB professionals are those highlighted in bold.

The process of SEA is similar to that of EIA with environmental considerations being a main feature of the stages. There are a few key diiferences in that the SEA requires the environmental authorites to be consulted at the screening stage. It is based on a tiering approach (**Figure 10**) which means that aspects of the decision making carried out at one level do not need to be revisited at a later one. This should result in the best environmental option being chosen.

Policy - what is the policy under consideration? E.g. a sustainable energy policy

↓

Plan - what is the masterplan to deliver this? would potentially rule out coal fired power stations as they would not be considered he BPEO

↓

Programme – what series of programmes to consider? Renewable energy, energy efficiency , etc.

↓

Project - at this level the type of project is already based on what is considered the most environmentally friendly option, therefore there will be **NO** project EIAs for coal power stations

***Figure 10** An example of tiering approach for SEA*

5.2.10 Process of SEA

- Stage A: setting the context and establishing the baseline – if it falls into one of the 11 sectors then SEA mandatory, if not then Screening in consultation with the environmental authority must be carried out to establish if needed.
- Stage B: deciding the scope of SEA and developing policy alternatives
- Stage C: assessing the effects of the plan
- Stage D: consultation on the draft plan and environmental report
- Stage E: monitoring the implementation of the plan.

Who to involve in the process:

- The responsible decision maker (policy may be devised by SE or equivalent) and consultants (local authority and consultants)
- Environmental and Sustainability Organisations (both Gov and NGO's)
- The public (early in process – may lead to more socially and politically acceptable decisions)

A key aspect of the process of the creation and publication of an environmental report. This report should contain the following information:

- Outline of the contents, main objectives of the plan or programme and how it relates to other areas
- Relevant aspects of the current environment – how they will change without pp (Baseline)
- Environmental characteristics of areas likely to be significantly affected
- Existing environmental problems/issues (i.e. are there any designated areas)
- Any environmental protection objectives (at any level)
- Likely significant effects -not just local but large scale issues (impact of new coal power stations and global warming etc)
- Reduction and off setting of any adverse effects
- Outlines of alternatives
- Monitoring
- Non-technical summary

There are number of key benefits of the SEA process that should aid in the promotion of sustainability. These include:

- Impacts considered early on, therefore can influence type of projects undertaken
- Assess cumulative and synergistic impacts which are difficult to assess at project level
- Large scale impacts (e.g. global warming and impacts on biodiversity)
- Better consideration of alternatives
- Clear requirement to monitor the impacts

Question: Consider how the process of SEA can be used as a vehicle to promote the uptake of eco engineering solutions on a wider scale.

6. SUSTAINABILITY AND PROJECT MANAGEMENT

6.1 Recognising the role of project management to deliver sustainable construction

Recognising that project management has a role to play in the delivery of sustainability within construction projects provides the opportunity to move away from viewing sustainability as something a project reacts to due to a traditional approach focused on compliance with planning requirements and building standards. Traditional concerns around moving beyond compliance were that it presents t associated costs and presents additional risks to the project. However, increasingly it is recognised that this doesn't need to be the case especially if the whole life cycle benefits of sustainability are recognised. Sustainability has traditionally been viewed in construction as being linked with a technical solution which can be seen as expensive or represent a risk to the delivery of the project. Recognition in recent years has seen it increasingly being linked to softer issues as well as a broader perspective related to social and economic considerations, and also that it can be enhanced through management solutions. The growing awareness of the lifecycle of a project and that considering sustainability up front in the planning, design and construction, can have significant sustainability benefits during its operation realised through maintenance savings, extended lifespan as well as a lower impact on society.

6.2 Conceptual tensions between project management and sustainable development

Project management	**Sustainable development**
Short term orientated	Long term orientated
Sponsors: narrow stakeholders	Current and future generations
Deliverable/ results orientated	Lifecycle orientated
Scope, time and budget	People, planet and profit
Reduced complexity	Increased complexity
Top down management	Consensus/ bottom up
Fact based	Precautionary
Linear and mathematical analysis	Systematic approach
Net present analysis	Triple bottom line

Table 2 conceptual tensions between project management and sustainable development

6.3 Two lifecycles to consider for project management

Releasing the potential for sustainability depends on the ability for those managing the project to recognise the two important lifecycles which need to be considered 1) the project and asset lifecycle and 2) the construction component lifecycle, and these are show in **Figure 11**. The first lifecycle relates to the planning, design, construction and asset management, and significantly when reflecting sustainability asks that project managers consider the demolition, waste removal and disposal of the asset should it not be able to be modified or maintained any further. The second lifecycle relates to the eco-engineering construction components and highlights that it is necessary to consider the sourcing, transport and processing of components with a view to their impact, and to recognise that this lifecycle integrates to the project and asset lifecycle physically during realisation (construction phase) but that the full component lifecycle needs to be considered during the early stages of the project and asset lifecycle as this is when the decision making takes place.

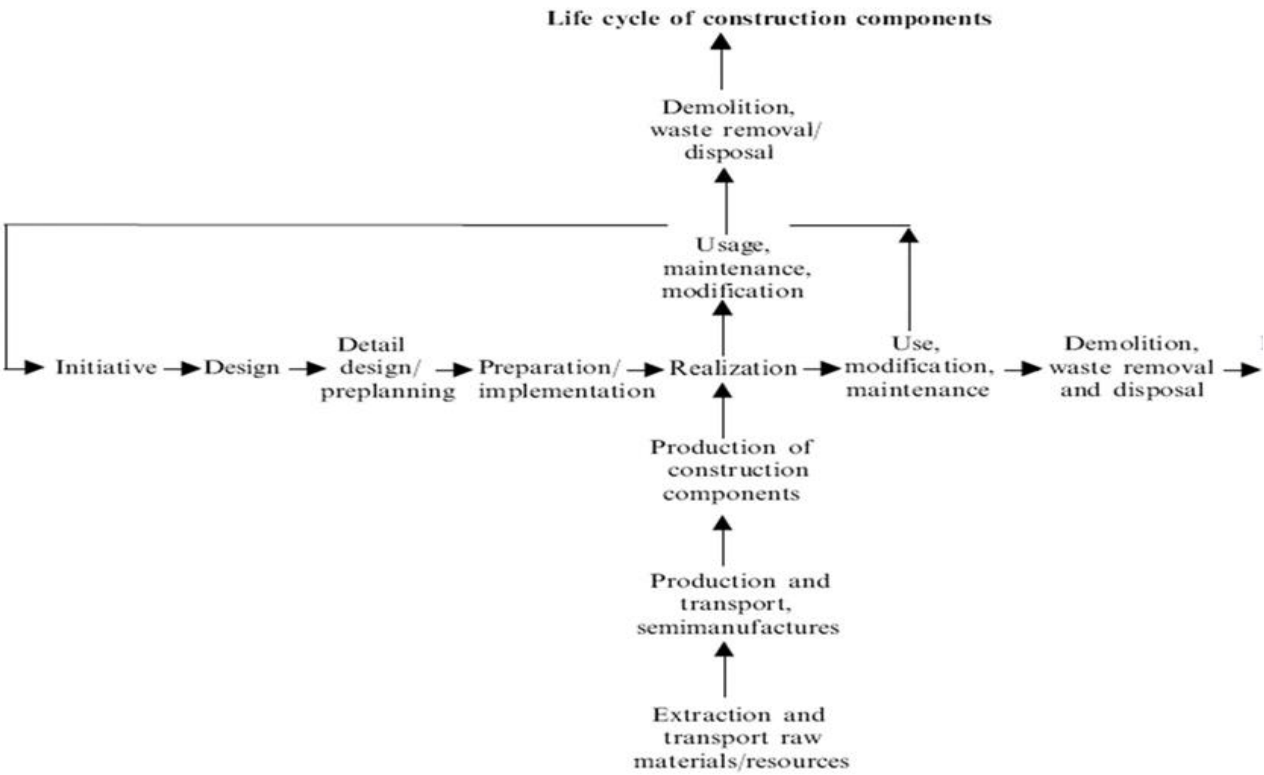


Figure 101 *Integration of the project and asset lifecycle and construction component lifecycles*

Points to consider when managing a project:

- The need to consider decisions across the whole life of a project and not in isolation
- Do decisions have sustainability consequences?
- How will different stakeholders values relate to sustainability within the project context?
- The need to understand the implications for assessing and monitoring sustainability

6.4 Embedding sustainability within the project process

The RIBA produced their Green Overlay to their Plan of Works in (2011) which outlined the points in the project process when it was optimal to consider sustainability (and specifically environmental) issues. Khalfan et al. (2006; 2002) attempted to embed sustainability within project management protocols by identifying the key activities and stakeholders involved in a Sustainability Management Activities Zone and presented using PMI's PMBoK project process (Aouad et al., 1998). This protocol makes a start at understanding the generic activities required across the different phases of a project, however a need exists to develop a framework with greater practitioner focus and that responds to the changing policy context and the evolution of good practice.

Sustainability Management Activity Zones within Process Protocol (Khalfan et al. (2006)

- Prepare sustainability mission statement for the project
- Scope sustainability issues
- Prepare sustainability matrix for the project
- Prepare sustainability action plan
- Revise sustainability action plan
- Undertake sustainability pre-assessment of outline concept design
- Undertake sustainability assessment of the full conceptual design
- Revise sustainability plan
- Monitor production information against sustainability plan
- Monitor construction against sustainability plan
- Complete post construction review against sustainability targets

6.5 Emergence of the sustainability action plan

Inspired by the Agenda 21 Plan for Action (UNCED, 1992), the sustainability action plan has emerged and is utilised in the delivery of policy and in promoting industry initiatives for sustainable construction. The plan provides an agreed shared vision reflective of context, with a framework of objectives, targets and KPI's and a planned delivery process which is agreed and provides focus on assessment and feedback to decision makers. These are principles which are common to project management and could play a pivotal role in embedding sustainability as a core project consideration. The potential is provided for a framework to guide and support its delivery across the project phases, ensuring it is assessed and that the plan is updated and revised as the project progresses. Such an action plan has the potential to move away from viewing sustainability as a project add-on, and instead to view it as an integrated element of management practice (Chance, 2009; Khalfan, 2006).

The plan will outline for each sustainability issue:

- an outline of established standards and targets (regulations, building standards)
- baselines and targets that can be potentially achieved
- the agreed target set for the project
- outlined methods for achieving these
- identify responsibilities for its delivery

Steps to develop an action plan

- Visioning and scoping project sustainability issues
- Target setting and base lines
- Developing a sustainability (action) plan
- Developing a sustainable design checklist
- Developing a sustainable construction plan
- Developing a sustainable asset management plan
- Development of a sustainability assessment plan (outlining assessment and monitoring regime across project and asset lifecycle)

6.6 Sustainability decision-making

It is widely appreciated that during the early stages of the project, the key decisions which affect sustainability will be taken. It is possible to map out key decisions in relation to a traditional project process reflecting when final decisions are required and when it is possible to start considering them. Below is a list of key design considerations for sustainability, and **Figure 12** maps when they require to be taken (d) against (c) when they can be considered from.

The key decisions that impact on sustainability are associated with:

- Location
- Project scale (size)
- Use/ function
- Site layout
- Orientation
- Form
- Structure
- Processes and equipment (including materials)
- Construction (techniques)
- Operating conditions
- Eventual demolition/decommissioning

	Design considerations										
RIBA phases	Location	Project scale	Use	Site layout	Orientation	Form	Structure	Processes and equipment	Construction (techniques)	Operating conditions	Eventual demolition
Inception	D	D	D	C	C	C	C	C	C	C	C
Feasibility				D	D						
Outline proposals											
Outline proposals						D					
Scheme design							D				
Detailed design								D			
Detailed planning											
Production information											
Bills of quantities											
Tender action											
Project planning									D	D	
Operations on site											
Handover											
Completion											D
Feedback											
C- consideration	D- decision required										

***Figure 112** Key design considerations against RIBA plan of works project stages*

What this shows, is the need to ensure that sustainability is embedded within the scope of the project and that it is aligned with its objectives and therefore reflected in the key decisions taken. Another way to look at this can be in **Figure 13,** where Vivacity2020 (2008) outlined the key decision making stages associated with the planning and design of a project and aligned sustainability tasks and then regular reviews around each.

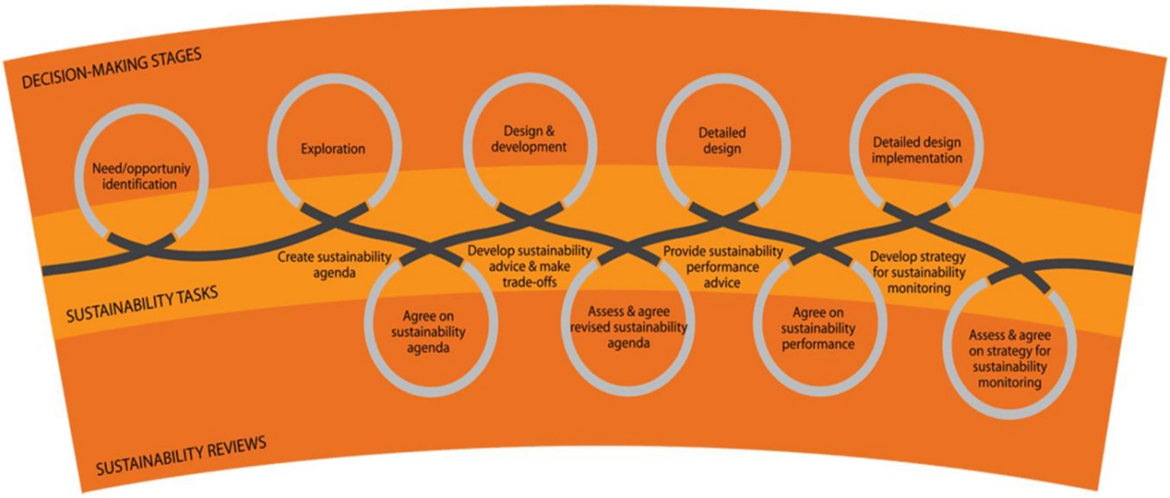


Figure 12 *Key decision making stages associated with the planning and design of a project and aligned sustainability tasks. Source: Vivacity2020, 2008 source: http://www.vivacity2020.co.uk/story/detailed-decision-making/index.html*

There are two clear benefits of ensuring that sustainability is incorporated in to a project in the early stages:

- Ensures needs and requirements of project team/ stakeholders are considered
- Enables environmental, social and economic to be considered and followed across project (TBL)

Role of the project manager in promoting project sustainability

- Leadership (providing vision and championing sustainability)
- Instilling sustainability as a requirement (i.e. during team selection process)
- Ensure procurement route matches the sustainability requirements
- Ensure project hierarchy is not a barrier to managing sustainability
- Knowledge management (need to facilitate flow and sharing of knowledge between individuals and projects)
- Change management (facilitate a change in thinking and practice)
- Integrate sustainability within all decisions taken (i.e. budget and need for WLSV)
- Promote innovation and enterprise culture
- Facilitate learning and education
- Facilitate inclusion and participation of team members
- Ensure engagement with stakeholders throughout

6.7 Sustainability and environmental assessment

The sustainability action plan provides a framework around which the project managers can utilise sustainability assessments where appropriate across the project phases. The sustainability assessment should provide in its coverage the three pillars of sustainability (environmental, social and economic criteria). The assessment should provide a framework around which traditional project assessments are covered such as traditional environmental assessments ensuring that the project aligns with environmental legalisation and standards but also to ensure that the project goes beyond compliance when appropriate. Project planning needs to consider also the economic and social assessments to ensure that the full sustainability picture is captured to aid decision making regarding its viability and whether mitigation measures are required. Project managers need to have access to tangible data and information at an appropriate point in the process to support their decision making. The assessment process should be viewed as involving five phases which should sit across the project process.

1) Scoping (where indicators are identified for environmental, economic and social criteria)
2) Planning (where individual assessment methods are identified across the project process and their implementation resources and planned)
3) Assessing (application of the assessment, collection of data and evidence and presentation)
4) Evolution (consideration of assessment outputs)
5) Monitoring (establishment of a monitoring regime over lifecycle against indicator criteria)

The action plan provides the framework around which the assessments to support the projects delivery and long term monitoring can be delivered to ensure it continues to perform.

Benefits of Sustainability Action Plans:

- Establishes sustainability as a project aspiration
- Provides a clear framework and assessment methodology across project phases
- Encourages a holistic view of sustainability and promoting achievable targets
- Encourages the use of experts to guide project sustainability
- Facilitates the flow and sharing of knowledge
- Provides leadership for sustainable practice
- Promotes aligned environmental monitoring aligned with long term maintenance programme

Common practice within construction and engineering tends to focus on the triple bottom line approach which is focused on communicating sustainability performance to stakeholders to support their development of project goals and in helping shape project outcomes. In this context, the effectiveness of a sustainable assessment method (SAM) will depend on the consideration of the three dimensions (or pillars) of sustainability (economic, social, and environmental), identification of the overlapping zones and solution to the conflicts and trade-offs that exist between the dimensions therefore tending to align with the more pragmatic weak sustainability definition. This approach seeks to present alignment with standards and best practice but not to pass a judgement on whether the project has breached resource limits as would be the case with a method such as ecological footprint which follows a strong sustainability definition.

Eco-engineering measures are considered to be a more sustainable alternative to traditional hard engineered solutions due to their greater alignment with natural systems. Traditionally, eco-engineering works would take place either very early in the project to allow for vegetation establishment or very late to allow for monitoring of the performance. Eco-engineering practices can significantly help in reducing costs and risks while, at the same time, achieving the sustainability credentials of the project both from a biomimicry perspective but increasingly from its contribution to society through its aesthetics, potential for resilience and whole life value. However, not unlike the concept of "fitness" in evolutionary biology, the determination and quantification of sustainability can only be made after the measure has been put in place and only with an appropriate structured set of performance criteria applicable to eco-engineering practices. Eco-engineering systems include the environment (soil, water, air, flora/fauna, society), inert and live construction materials and the interactions between these. The main purpose of these systems is the stabilization/reinforcement of the soil or to avoid major disruptions and collapses while hedging against instabilities and discontinuities, thus seeking to ensure physical resilience and long term sustainability of the system. While the biological and ecological aspects of ecological engineering have been extensively studied, the technical (including longevity) aspects and the socio-economic issues associated with soil bioengineering are not usually quantified in practice.

Once the precedents of the project are explained and the environment and its factors are detailed, the project also has to include a plan for the waste management, quality control, maintenance plan, monitoring plan and communication plan. More in depth with the environmental management, while doing land movements and during the work, but also afterwards there are some materials and waste that will not be used anymore and so it has to be managed properly. For the case study of Santa Eulàlia de Ronçana, the reed (*Arundo donax*) that was removed from certain places of the river basin had to be treated as waste and was ground and sent to a waste treatment plant, according to the waste management plan.

When the works are finished, there have to be a minimum maintenance in order to grant the viability of the actions that have been done and control that the function they are designed for is accomplished. With the maintenance plan the client and the enterprise can check if all the measures are working as they should for the next three years after the works are finished. Besides the maintenance plan, the monitoring plan pretends to monitor and assess the results and discuss if the aims of the project have been achieved after certain period of time since they were executed. The monitoring plan supports the improvement of the professionals as it helps to evaluate the success or failure of the project design, techniques used and asses the environmental indicators described in the diagnosis done previously in the EIA. The monitoring plan is related with the communication plan in order to let the society and the stakeholders know the results of the project.

Whilst it is possible to assess various aspects of the long term performance of soil bioengineering measures and the relevant projects in their delivery through risk assessments and environmental impact assessments, there should be standardised means of assessing the sustainability performance of such measures in an integrated framework which captures the environmental, social and economic dimensions of sustainability.

Different assessment methods are applied at different scales of the project lifecycle:

- Strategic planning (Strategic Environmental Assessment)
- Appraisal of planning proposals (Environmental, Social and Economic Impact Assessments, Risk Assessment, Sustainability appraisal by local authority and compliance with regulator)
- Construction performance and monitoring (predication and actual); CEQUAL, Environmental management systems, monitoring for maintenance programmes
- Component levels (i.e. materials, lifecycle analysis)

The assessments are split into two dominant types Objective based and Impact based assessments as displayed in **Table 3**:

Objective based assessments	**Impact based assessment**
Evaluate the extent to which the proposals align with best practice or priorities advocated by the tool developer. Against thematic criteria, credits are awarded depending to what extent practice	A base line based assessment of the impact of the proposals, reflecting on a set of thematic indicators, targets set and then actual performance (predicted and actual depending on

relates to best practice and move beyond compliance.	project stage).
Examples: strategic assessments such as Strategic Environmental Assessment (SEA), project level environmental appraisals such as CEQUAL	Examples: environmental impact assessments (EIA), economic impact assessments, social impact assessments.

Table 3 The two dominant types of sustainability assessment

The sustainability benefits of eco-engineering measures have not been quantified in the past, perhaps due to, a lack of awareness of the sustainability agenda or its value; lack of an agreed means of interpreting it in the context, lack of mechanisms and frameworks for quantification of these benefits and lack of emphasis on long-term monitoring. These challenges have contributed to the dominance of the objective-based assessments such as BREEAM (http://www.breeam.com/), LEED (https://new.usgbc.org/leed) and CEEQUAL (http://www.ceequal.com/) which are sustainability assessment methods (SAMs) developed for the wider built environment and focus on benchmarking sustainability performance of construction projects. They reflect a mix of quantifiable and subjective indicators with the aim of providing stakeholders a holistic view of a construction project's sustainability performance whilst acknowledging the difficulties of providing accurate measures which engineers would otherwise rely on.

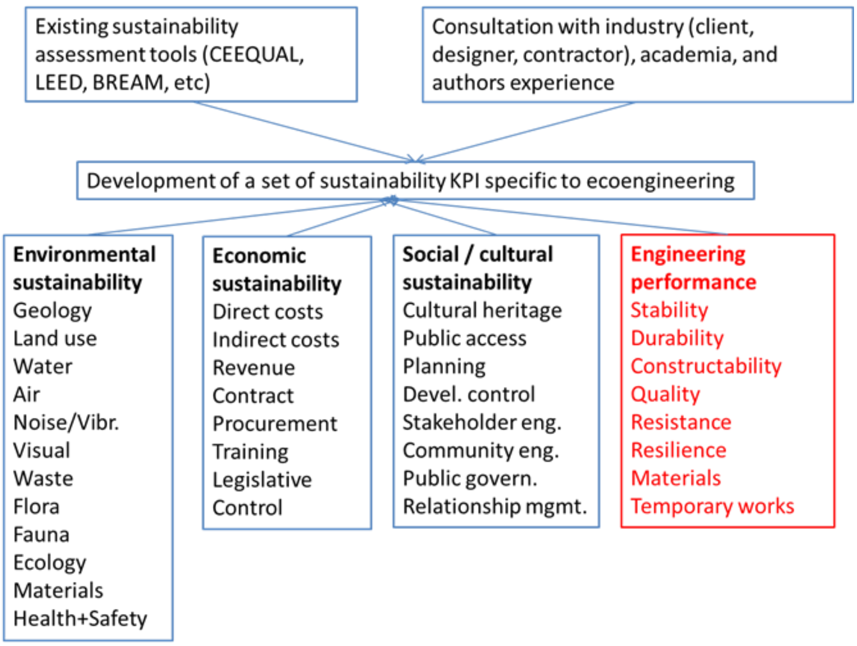


Figure 14. *Conceptual framework for eco-engineering sustainability KPI (Mickovski and Thomson 2017). The Engineering Performance KPI set is a novel addition to the traditional sustainability KPI sets*

Group exercise: Select one existing SAM (BREEAM, LEED, CEEQUAL) and discuss the pros and cons of its application to eco-engineering. Analyse the procedures and critically evaluate the relative weighing of the sustainability pillars in each.

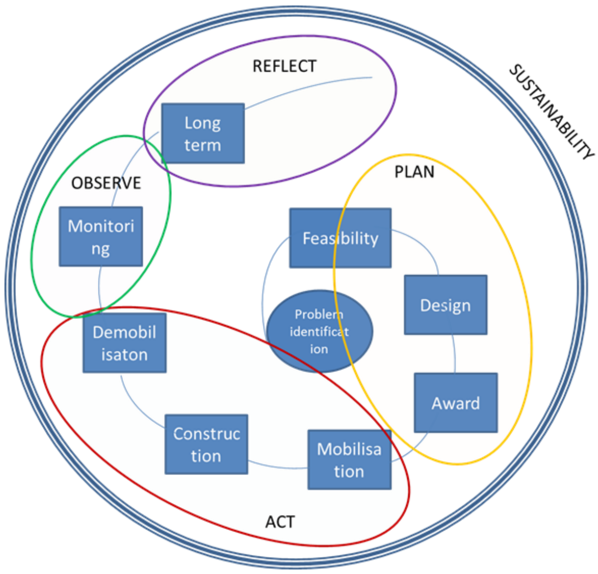


Figure 13 Eco-engineering project phases where sustainability needs to be taken into account (Mickovski and Thomson 2017)

Seminar/wiki: Discuss how assessments relate to project phases on a SWB project. Use one of the ECOMED case studies as an example.

6.8 Key Performance Indicators (KPIs)

KPI are part of the benchmarking process commonly used in the construction industry and are an important basis for establishing an objective based SAM. A benchmark is a level of performance that allows comparison between projects in order to achieve 'best practice' through continuous improvement of the performance. KPI is the measure of a process that is critical to the success of the project and a common set of KPIs within an industry based on best practice and regulations allow benchmarking of an organization or a project against the standards achieved within industry. While KPI benchmarking systems relating to sustainability have been introduced to the construction industry as a whole in the last decade, there is a lack of KPIs and benchmarking systems for the eco-engineering industry which would enable knowledge acquisition and transfer and promote the best practice within the practitioners' and managers' community. Such a system would also demonstrate compliance with internal/external reporting regulations (e.g. ISO 2004, ISO 9000 and ISO 14000 series) and facilitate transparency for information sharing. This would increase the visibility of eco-engineering as a specialist and multidisciplinary branch of the construction industry. For this, a comprehensive set of KPIs are essential to underpin an objective based assessment seeking to enable the measurement of accomplishments, demonstrate transparency to stakeholders and build a knowledge base for the professionals involved.

An example of such KPI set can be found in Mickovski and Thomson (2017), which results in a relatively clear reporting format (**Figure 14-16**) and allows monitoring and planning of the sustainability actions throughout the lifetime of the project.

Group exercise: Select a case study from ECOMED library and assess the sustainability performance for a selected project stage (Feasibility, Design, Mobilisation, Long-term). Propose measures for improving the sustainability performance in each stage.

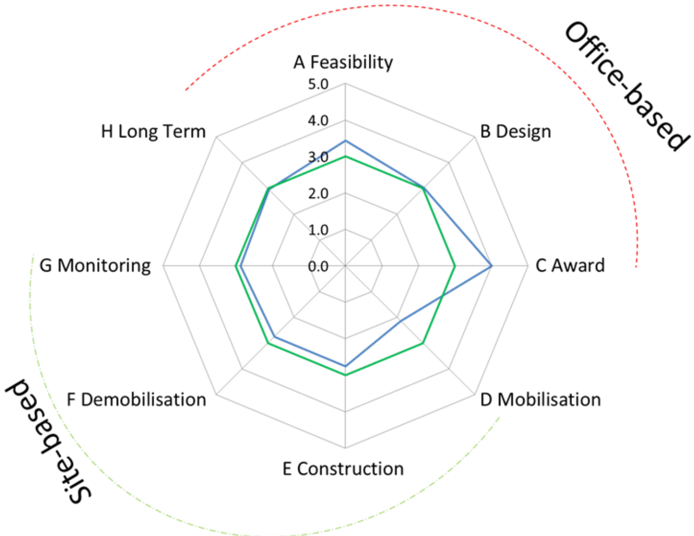


Figure 146. *Sustainability performance of the project through different project phases (blue line) compared to the 'neutral' sustainability performance (green line). Sustainability ranking: 1- Harmful; 2- Reduction; 3 – Neutral; 4- Improved; 5- Significantly improved (Mickovski and Thomson 2017)*

Questions

- What role does the project manager play in facilitating sustainability?
- In groups, can you identify any characteristics they should display?
- Reading exercise
- Looking at the definition and principles for sustainability in project management
- Consider what is meant by sustainability as both a short and long term objective
- Is the PM best positioned to bring sustainability aspects to the table? (relation to process and deliverable)
- Based on your experience to what extent do current projects relate to these principles?
- How would you facilitate the change required within projects?

7. STAKEHOLDER ENGAGEMENT

Stakeholders are defined as individuals or groups that can influence or are influenced by organisational activity. They will not act as uniform groups and display different priories and relationships to the company.

Figure 17 reflects that stakeholders can be placed in a hierarchy of interests in relation to the project, from those who are core to its function, to those who represent interests through the competitive environment, to those who are part of the external environment.

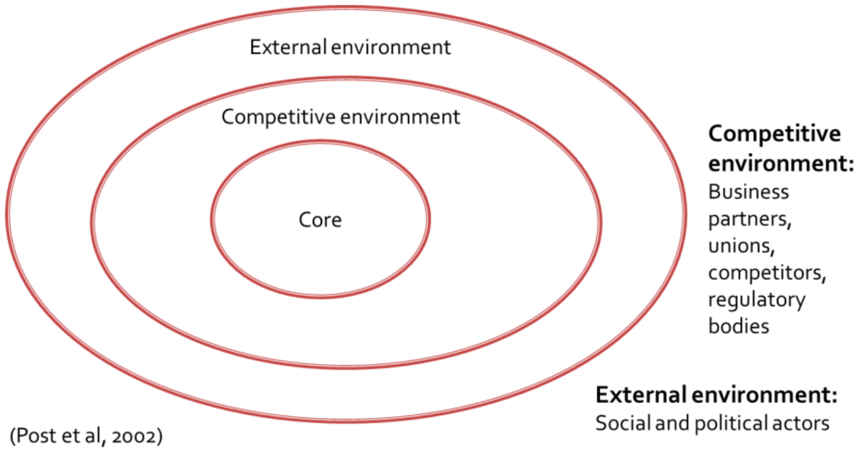


***Figure 15** Stakeholder landscape*

7.1 Principles and benefits of quality stakeholder engagement

Approaches to stakeholder engagement have been variable, but in recent years it has become clear that effective stakeholder engagement needs to follow a common set of principles such as:

- clearly define the scope
- have an agreed decision making process
- focus on issues material to the organisation and/or its stakeholders
- create opportunities for dialogue
- be integral to organisational governance
- be transparent
- have a process appropriate to the stakeholders engaged
- be timely
- be flexible and responsive

The benefits of stakeholder engagement include:

- Equitable and sustainable social development by giving those that need to be heard the opportunity to be considered in decision making
- Better management of risk and reputation
- Allowing pooling of resources to solve problems (knowledge, people, money and technology)

- Understanding of complex operating environments (markets, cultural dynamics)
- Learning from stakeholders (products, process)
- Inform, educate and influence stakeholders to improve their decisions and actions (on organisation and society)
- Develop trust and transparency with stakeholders

Exercise: Access Stakeholder Engagement Standard AA1000 (https://www.accountability.org/wp-content/uploads/2016/10/AA1000SES_2015.pdf) and map different stakeholders for the different project stages of an Ecomed case study.

The key stakeholder engagement activities related to each of the project stages (**Figure 18**) are shown below:

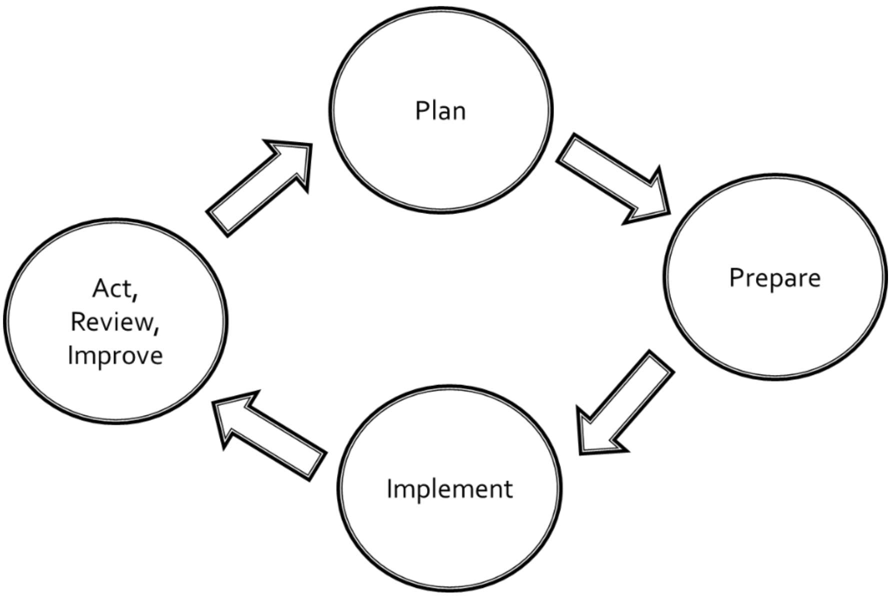


***Figure 16** Stages of Stakeholder Engagement Process for AA1000*

A purpose (Source: AA1000 STAKEHOLDER ENGAGEMENT STANDARD 2011, p27)

First action should define a clear purpose for the engagement as there is no point engaging if you don't have a reason. Two categories for engagement

- Engagement for strategy (engagement to help shape strategic decisions)
- Engagement for operations (engagement at an operational level to help shape practice based decisions)

Plan

- Profile and map stakeholders (stakeholder analysis)
- Determine engagement levels and methods
- Establish and communicate boundaries of disclosure

- Draft an engagement plan (documents full process considers limiting factors)
- Establish indicators

Prepare

- Mobilise resources
- Building capacity (increase preparedness to engage)
- Identify and prepare for engagement risks (develop contingency plans such as promoting balance between stakeholders, motivate etc)
- Invite stakeholders to engage
- Brief stakeholders
- Engage
- Document the engagement and its outputs
- Develop action plan (responding to outputs)
- Communicate engagement outputs and action plan

Act, review and improve

- Monitor and evaluate engagement
- Learn and improve
- Follow up on action plan
- Report on engagement

7.2 Stakeholder Analysis

Key to effective stakeholder engagement is the foundation that stakeholder analysis can provide and this requires further exploration. There are four common steps which can be identified in relation to stakeholder analysis (**Figure 19, Table 4**):

I. Identify your stakeholders
II. Prioritise your stakeholders
III. Understand your stakeholders
IV. Plan your engagement with stakeholders

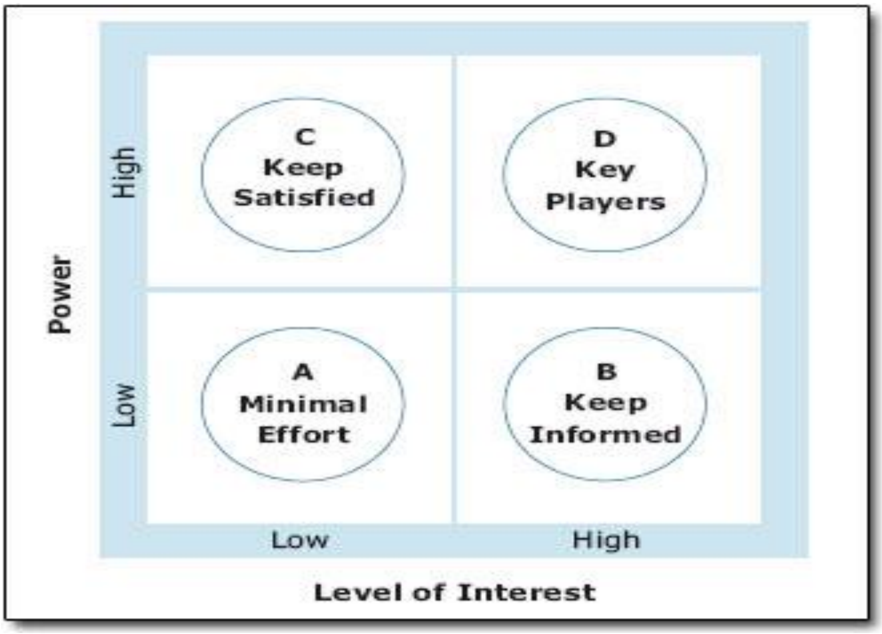


Figure 179 Power/ Interest Grid http://labspace.open.ac.uk/file.php/7722/b324_1_004i.jpg

Stakeholder group	Characteristics	Engagement
Group A low interest/ low power	The project may require little or no effort to be focused on this group. The stakeholders pose no threat due to a lack of both interest and power.	Monitor these people, but do not bore them with excessive communication
Group B high interest/ low power	This group, although having a high interest, has little power to exercise control so they can be maintained through the management of information to keep them informed of project events.	Put enough work in with these people to keep them satisfied, but not so much that they become bored with your message.
Group C low interest/ high power	This group may or may not realise the degree of effect they have over the project and therefore must be kept satisfied. However, because of their low interest in events, they are unlikely to cause significant disruption.	Keep these people adequately informed, and talk to them to ensure that no major issues are arising. These people can often be very helpful with the detail of your project.
Group D high interest/ high power	The project must try to satisfy this group first and foremost as they have the power to affect the company and a high degree of likelihood that they will use their power.	Monitor these people, but do not bore them with excessive communication.

Table 4 Stakeholder groups with characteristics and resultant engagement approach

Group activity: For a chosen project case study, place your stakeholders on the matrix provided to explore the power/ interest relationship. Develop a simple engagement plan. Discuss your choices with other groups.

7.3 Public consultation

Essentially the target stakeholders in SWB types of works are the local authorities and communities that want to solve a specific problem or repair certain parts of their properties and territories. Before the works are executed some dissemination activities such as expositions of the projects are done for these target groups for a major communication and understanding of the processes and works. Thanks to these activities other organisations worried about the landscape managing like NGOs are aware of the projects and can share and improve their knowledge. Afterwards, once everything is finished, more informational activities like visits to the places of interest are done for a better approach of the works to the stakeholders and all publics.

In cases where the works are more complex and need a general view, such as a river basin, other stakeholders that can be interested in the works can be the consortiums. In the study case of Santa Eulàlia de Ronçana, the main targeting groups where the Municipal Council and the Consortium of the Besòs river basin, among the great support of the local organisations and neighbourhood associations of Santa Eulàlia.

More stakeholders that can be interested when writing complex SWB project can be regional agencies managing topics of soil and water, knowing the complexity and administration organization of the country the works will be done. Important for eco-engineering construction projects due to their nature is to ensure that the public (community) are engaged sufficiency in their development as they have the potential to exert power through the planning process by objecting or stalling the projects progress if they aren't happy with it. It is recognised also that whilst some members of the public may not be able to stop the project if they are unhappy with it, it is important to try and work with them to take on their views and see if it can be mitigated. Public consultation is a regulatory process where the public's input on matters affecting them are sought. It is a process which seeks to improve the efficiency, transparency and involvement of the public in the development of the project. There are a number of different levels involved:

1) Notification (which seeks to publicise the proposals)
2) Consultation (which seeks to provide a two-way flow of information and to exchange opinions)
3) Participation (where interest groups are involved in drafting and developing the proposals)

There are a number of ways to categorise the levels of consultation, but a common one in relation to public consultation is the Citizen Participation ladder by Sherry Arnstein (1969). She identified eight different types of consultation around three higher level categories.

1) Citizen Power: Citizen Control, Delegated Power, Partnership.
2) Tokenism: Placation, Consultation, Informing.
3) Non-participation: Therapy, Manipulation.

7.4 Citizen science and empowerment

Citizen science is the involvement of the public in scientific research – whether community driven or global investigations. There are different types of activities from participation, to collaboration through to co-created projects, where the public work alongside scientists to contribute ideas, questions and methods to the research projects. It is also known as community science, crowd science, crowd-sourced science, civic science, volunteer monitoring or networked science). Often it can be referred to as public participation in scientific research, participatory monitoring and participatory action research. The key aspect of the definition is that it represents scientific research being conducted with amateur scientists.

In the context of projects, it is apparent that citizen science has the potential to make a contribution as communities are influenced or impacted by it. If there is a science element to the project (i.e. slope stabilisation) then engaging the community with the project will help to promote understanding and this can be facilitated through a structured community education programme. However, it is the potential to get the community involved in the monitoring and long term maintenance of the project which presents the potential through citizen science.

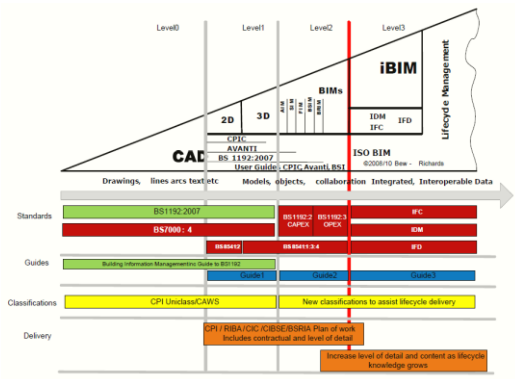
8. BUILDING INFORMATION MODELLING FOR ECO-ENGINEERING

The origins of BIM are in the 1960s when Building Description System was invented as a complete virtual representation of a building within a computer system. While traditional Computer-Aided Draughting (CAD) uses lines to represent the building's features, BIM uses virtual objects with attributed properties to describe its geometry, materials, performance requirements, etc. With the advent of the World Wide Web in the 1990s, web-based document management systems became common which enabled distributed teams to collaborate and share documents electronically. These become known as Common Data Environments.

The combination of the Building Information Model with a Common Data Environment became known as Building Information Modelling, BIM. To achieve the maximum benefits, projects needed to adopt processes for specifying the information uses, standards, software, hardware and management systems, prescribed through a BIM of different maturity level (**Figure 20**):

- as a technology supporting a task within the project, such as the use of simulation to verify construction schedules;
- as a project delivery methodology facilitating the delivery of a project by providing a means of collaboration between all project team members, providing project information in the right format for those who need it;
- as a lifecycle asset and facility management approach to the creation and exploitation of information supporting operations, maintenance and decision making as well as optimising the project phase.

It is important to adopt a whole-life view of an eco-engineering structure and the need to realize value from it; not solely its design and construction or upgrading. From this aspect, it is important to recognize that a large amount of information and data about an asset is generated and exchanged (https://www.thenbs.com/knowledge/what-is-cobie) during its lifetime and that a security-minded approach to the handling of such information and data will need to be adopted (http://bim-level2.org/en/).



Level 0 'Just get on with it'	In a pre-BIM world we use CAD simply as a means of drawing production. Drawings, whether in PDF or printed, are used as the basis for communication and collaboration across teams. Companies may use internal standards for the authoring, management and sharing of information internally, but these are often ad-hoc and may vary by discipline and supplier.
Level 1 'Collaborate'	BIM Level 1 introduces standards for consistent approaches to CAD and 3D model authoring, and sets management practices for collaboration. BS 1192 provides the basis for BIM Level 1, documenting processes for quality control, information sharing, document naming and CAD naming – the basis of the Common Data Environment.
Level 2 'Coordinate'	Coordinating the creation of an information model which combines the geometric elements of an asset in three dimensions with the attribute information usually stored in schedules, bills of materials and specifications, BIM Level 2 provides a methodology for asset owners and suppliers to collaborate through information rather than documents. BIM Level 2 applies equally during capital projects and throughout operations with processes defined for the Project and Asset Information Models and an emphasis on the handover, the 'information exchange', between the two.
Level 3 'Integrate'	The vision for BIM Level 3, is a completely integrated approach to the management of asset and project related data. Information will be seamlessly available to those who need it in a format that allows different stakeholders to reuse information for different purposes. BIM Level 3 starts to make links with other digital innovations like Building Management Systems, Smart Cities and the Internet of Things[3].

Figure 20 *BIM maturity levels (adapted from BSI, 2017 (BSI/UK/1054/ST/0328/EN/HL)*

8.1 Constructability and operability

The principle of constructability is widely applied in design. However, the principle of operability has not historically been considered to the same extent. Design decisions have to be based upon accurate and relevant information and data, and their impact on operational needs has to be understood before they are committed to construction. The most effective time to comment on the suitability or effectiveness of design is before it is finalized. Testing assumptions during design is necessary to understand how the asset will perform in operation. Whilst it is too late to comment on the design of the asset once it is operational, systematic measurement, analysis, comparison and feedback can be useful in informing the design of future assets.

Existing standards (BS 8536:2, 2016) complement and strengthen briefing practices and procedures:

- By promoting the early involvement of the operator, operations team or asset manager
- By extending the commitment on the part of the delivery team to aftercare post-handover of the asset and its safe, secure, efficient and cost-effective operation in line with environmental, social, security and economic performance outcomes and targets.

The requirements of inclusive design and of managing design in construction have been incorporated to anticipate the implications for managing assets and their environments inclusively and effectively when they become operational. The above standard outlines the primary activities, information, questions and deliverables to be addressed by the designers, constructors and other specialists to support their work and so ensure that the asset owner and the operator, operations team and asset manager, as appropriate, are provided with as much certainty as possible in regard to the required operational performance of the asset throughout the project lifetime (**Figure 21**)

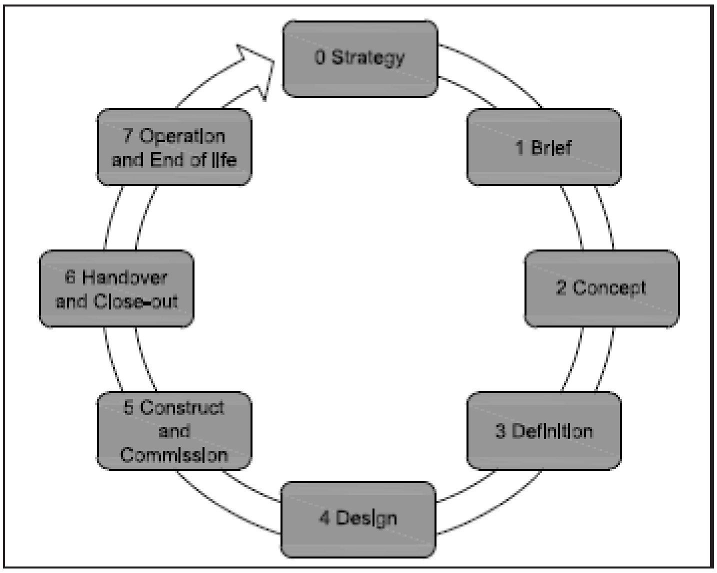


Figure 18 Project work stages Plan of work: 0-7 Strategy, Brief, Concept, Definition, Design, Construction/commission, Handover/close-out, Operation/End-of-Life

Examples of employment of BIM in eco-engineering can include:

- integrating analysis and drawing production to improve efficiency;
- 3D modelling to improve quality in terms of coordination and communication;

- a common data environment to improve collaboration within and across teams;
- using visualization to engage non-technical stakeholders during design reviews;
- improve confidence in the design and use the model for prefabrication;
- planning and optimizing the project schedule through simulation;
- monitoring project budgets and spend through linking activity with components;
- using the 3D model to improve site inductions, making safety and risk management tangible;
- maintaining inspection records to monitor asset performance.

8.2 Evidence based approach

The design and construction decisions should be based on the best available information from multiple sources, including but not limited to the owner's business objectives, current operations, the lessons learned from previous projects, design modelling and simulation, and performance evaluations. This approach should be extended to include the provision of evidence to support proposals and recommendations prepared by the delivery team (**Figure 22**). Information and data for these purposes should be handled, stored and protected in accordance with the owner's security requirements (e.g. PAS 1192-5).

Each stakeholder has a part to play in the delivery of a project and therefore has a different role in the BIM process. The existing roles and responsibilities on a project can be improved by adopting BIM and the types of tools which can support the project delivery throughout its lifecycle. A list of roles and tools can be found in BSI, 2017 (BSI/UK/1054/ST/0328/EN/HL)

Group exercise: Review the ECOMED protocols for a selected stage and critically assess the data and information that feeds into and out of this stage from a) Owner's and b) Designer/Contractor's perspective. Which datasets are critical to the stability and security of the eco-engineering structure? How can the role of designer and site supervisor on an ecoengineering project be enhanced by adopting BIM approach?

8.3 Outcomes

These should be set at the Strategy stage, and monitored during each subsequent work stage up to and including Operation and End of life, with post-implementation review (PIR) at prescribed intervals during a defined period of extended aftercare which should be used as the basis for measuring operational performance. The outcomes should be defined as environmental (energy use, greenhouse gas emissions, water, soil, landscape, etc. see Sustainability), social (functionality and effectiveness), economic (capital/operational cost targets, LCA, value), and security (stability and information management) and should be measured quantitatively wherever possible (**Figure 23**). Example outcome performance evaluation is given in the Appendices of BS 8536_2:2016.

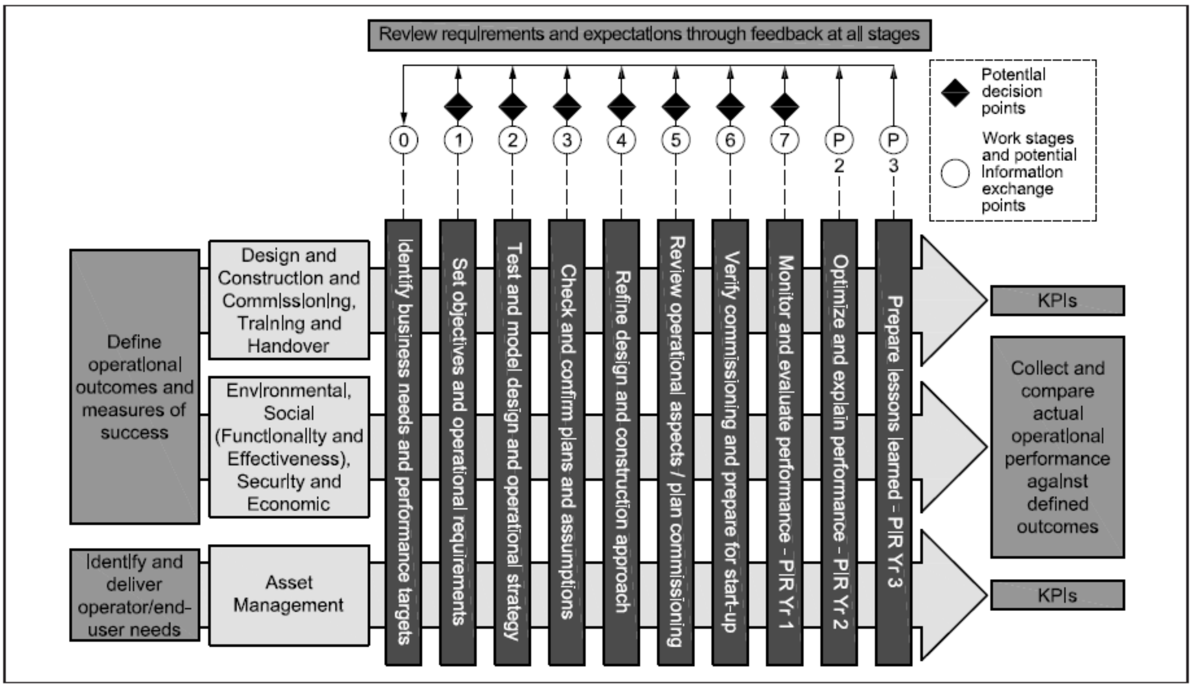


Figure 192 *Overall approach highlighting the importance of performance reviews and feedback (BS 8536_2:2016)*

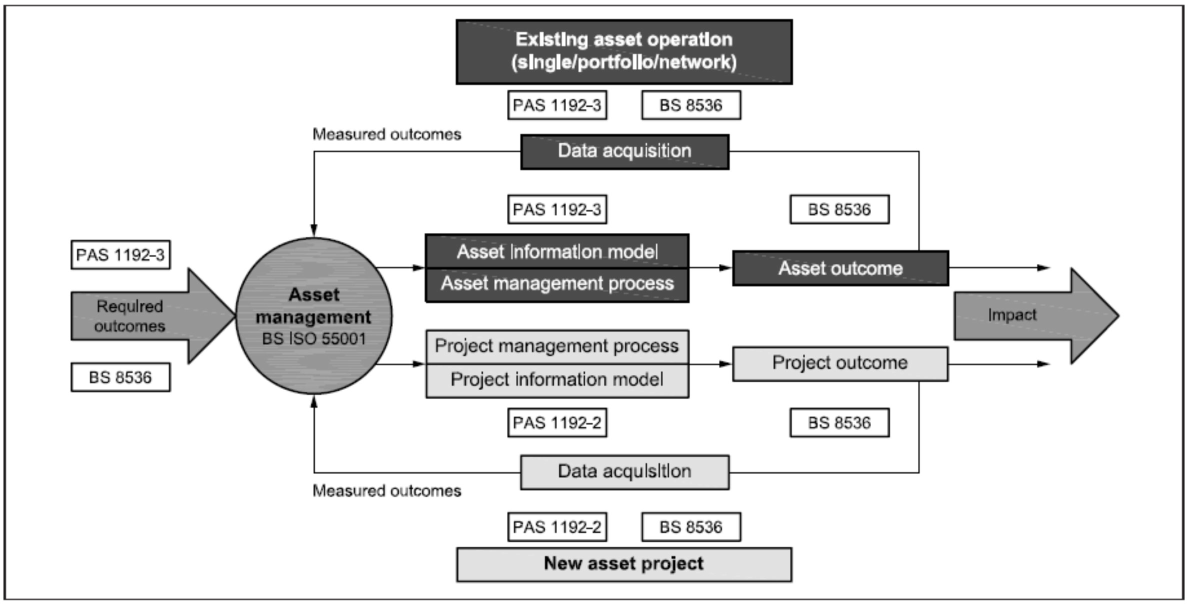


Figure 203 *Asset-project systems and feedback*

Exercise: use the BIM toolkit (https://toolkit.thenbs.com/) to analyse one of the ECOMED case studies and evaluate compliance with BIM standards for a selected workstage.

9. LEARNING AND TEACHING ACTIVITIES

The delivery of this module is web-based. It is essential that the student works through the reading materials and exercises provided on the virtual learning platform (VLP). Formal lectures are enhanced with tutorial/seminar sessions which allow for discussion. The delivery of this module is also via flexible learning (i.e. self-study). All the material are provided on VLP and presented in the form of course units and reading and self-study materials. It is the responsibility of the student to study in his/her own time. The student should also take the responsibility to seek clarification and/or guidance from the theme-specific Module Tutor or Module Leader.

The module is underpinned by assessment activities based on two courseworks. Students are encouraged to apply knowledge and insight gained from the tutorial/seminar sessions in their courseworks.

You will be expected to attend and to take notes at the tutorial/seminar sessions. For some (but not all) of the sessions you will be given an access to the lesson plan and/or miniature copies of the slides used during the presentation as support notes. Handouts will also be issued from time to time at the sessions. Spare copies of issued materials will be available at the discretion of the lecturer responsible for that section of the course. You will have regular opportunities for face to face contact with your tutor at these sessions.

10. ASSESSMENT AND FEEDBACK

This module is continuously assessed during the course of the semester. The assessment comprises two coursework reports. The pass mark for this module is 50% - you must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above.

Full details of the courseworks are contained in the Coursework Briefs which will be issued in due course.

Note: Failure to submit the coursework for the appropriate deadline without 'good cause' will be regarded as a non-submission, and hence will result in failure in this module. If you have a good reason for needing an extension to the deadline, you must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date.

To help you guide your development you will be provided with feedback on your performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort's overall performance will be provided. You will be given an opportunity to individually review your marked work to help you understand which aspects of your studies you are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. You are entitled to keep marked submissions for your review - however, you must return these when asked by the Module Leader or Module Tutor.

11. DIRECTED LEARNING AND PRIVATE STUDY

As you are expected to 'read' for your degree, you will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect you to be up to date with the current theme.

The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and you will be expected to demonstrate evidence of having sourced information from these in your coursework activities.

You should also make use of web-based materials and visit appropriate sites to develop a wider knowledge of the key issues and activities of not only your chosen discipline, but also in other related fields.

Please refer to the Module Descriptor for a detailed reading list. However, you may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section.

12. MODULE DIFFICULTIES AND EVALUATION

If you have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, you should speak with your employer or Academic tutor.

A module evaluation form will be made available to you on-line after the module is complete and you will be asked to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms are analysed (anonymously) and the findings considered by the appropriate professional organisation as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that you may have about the module in the first instance.

12.1 General Notes on Coursework Requirements

It is not easy to give hard and fast rules about criteria for marking either written reports, particularly those for which a specific answer is not appropriate. However, it is important that you first study carefully the coursework brief to make sure that you know what is expected. Please refer also to the General Marking Criteria in your Programme Handbook, which give you an idea what we are looking for in grading work at Masters level. You may then consider the following as universal marking criteria for written reports.

The following constitute positive criteria for marking and will be rewarded:

- Work that is planned and structured
- Work which embodies an argument and is rigorous, logical and sustained
- Work that is concise and precise
- Work that is clearly presented
- Work that is fully referenced
- Text which embodies a balance of explanation and analysis
- Text in which specific claims made in the narrative are supported by evidence
- Work which consistently engages with the question and is relevant to the topic

The following constitute negative criteria for marking and marks will be deducted for:

- Work that is deficient in planning and structure
- Work that is poorly argued
- Work that is poorly presented
- Work that is poorly referenced
- Text in which claims are made in the narrative that are unsupported and which lapse into opinion and anecdote
- Text which is deficient in explanation and analysis
- Text which is simply a reproduction of lecture notes or in which originality, innovation and imagination are conspicuous in their absence
- Text which does not relate to the terms of reference

And one other thought:

It is important that your courseworks are properly referenced as you will be submitting your courseworks via the plagiarism detection software facility on the VLP.

Plagiarism is defined as: "to use another person's idea or a part of their work and pretend that it is your own" (http://dictionary.cambridge.org/)

- This definition is straightforward - note it well and remember it. Plagiarism is a form of scientific misconduct and it may result in 'the suspension of the student from the university' as it is a serious offence. (see the university regulations regarding cheating and plagiarism, clause 8)
- Remember that each of the assignment activities is to be the student's own individual attempt - no student should collude with others or use someone else's work.

13. PERSONAL DEVELOPMENT PLANNING (PDP)

PDP is embedded within EFIB to assist you to develop as an independent and confident learner, not only during your time with us, but throughout your future career. It also allows more effective monitoring of your progress while undertaking your degree programme studies. The process has been described as

"A structured & supported process undertaken by individuals to reflect upon their own learning and performance, and/or achievement, and to plan for their personal education and career development."

As a member of a professional graduate community, you will be required to undertake Continuing Professional Development throughout your career. Learning therefore must be seen as a lifetime activity, and the introduction of PDP at the early stages of your career prepares you for these future requirements. PDP provides an opportunity for you to develop your capacity for learning by getting you to reflect on why and how you are learning, and to become more capable of reviewing, planning and taking responsibility for your studies. All of the foregoing will of course be supported by staff, in particular your Academic Tutor. The key objectives of the PDP process can be summarised as follows:

- To help you become a more effective, independent and confident self-directed learner
- To understand how you are learning and be able to relate that learning to a wider context
- To improve your general skills for study and career management
- To articulate your personal goals and evaluate your progress towards these
- To encourage you to develop a positive attitude to learning throughout your professional life.

14. OPEN ACCESS TO RESOURCES

Access to a wide range of services, information and software can be made through the EFIB homepage page: http://www.efib.eu. You will be automatically given access to the virtual learning platform (VLP ; e.g. Moodle) when you register with EFIB. VLP is the basic gateway to all other software and electronic resources on the EFIB webpage. VLP is an instructional software package which you are expected to use to read announcements, access resources and communicate with staff associated with the module.

You will be updated on progress with any upgrades and new palpitations of the software and resources. All software and related problems are dealt with by the EFIB Helpdesk.

15. REFERENCES

Mullins, Laurie J (2016) Management and organisational behaviour, Pearson.

APM (date) APM book of knowledge, Association of Project Management.

Lock, Dennis (2013) Project management, 10th ed, Gower

Charvat, J. (2003) Project Management Methodologies: Selecting, Implementing and Supporting Methodologies and Processes for Projects. John Wiley & Sons, NJ

Chapters 1&2 – A Guide to the Project Management Body of Knowledge (PMBOK® Guide 2004), 3rd Edition. Project Management Institute. ISBN: 1-930699-45-X

https://resources.workfront.com/project-management-blog/project-management-methodologies-a-beginners-guide?proxy=/blog/

https://thedigitalprojectmanager.com/project-management-methodologies-made-simple/

http://books.publishing.monash.edu/apps/bookworm/view/The+Project+as+a+Social+System%3A+Asia-Pacific+Perspectives+on+Project+Management/171/OEBPS/c11.htm

Schipper and Silvius (2013) Sustainability in Project Management

What advantages do you think it presents over traditional approaches to managing sustainability within construction projects?

Thomson C, El-Haram M (2014) "Potential and implications of sustainability action plans: Lessons from the Greater Middlehaven Regeneration Project", Built Environment Project and Asset Management, Vol. 4 Iss: 1, pp.108 - 122 10.1108/BEPAM-11-2012-0053 (Permanent URL)

16. USEFUL LINKS:

Open source textbooks:

FAO: http://www.fao.org/publications/e-book-collection/en/

UN: http://www.un.org/digital/#ebooks

EU: http://ec.europa.eu/environment/eia/index_en.htm

Standards and regulations:

http://www.standardsforhighways.co.uk/ha/standards/dmrb/index.htm

European Comission. Impact Assessment Guidelines: http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf

Databases:

UN: http://www.un.org/digital/#database

Real climate: http://www.realclimate.org/index.php/data-sources/

US Global Change : https://www.globalchange.gov/what-we-do/provide-data-tools

World Bank: https://data.worldbank.org/topic/climate-change

IPCC: http://www.ipcc-data.org/

EIA:

https://www.youtube.com/watch?v=30MCble5OAg

https://www.youtube.com/watch?v=St_PAkSBiYs

https://www.youtube.com/watch?v=0uReVJYe0qw

https://www.youtube.com/watch?v=dJa8LMGS8cs

https://www.youtube.com/watch?v=nrv1zBMAEL8

https://www.youtube.com/watch?v=JdHLa_th3CQ

https://www.youtube.com/watch?v=ugyFXVyxloQ

SEA:

https://www.youtube.com/watch?v=KTHKqx-C_C8

https://www.youtube.com/watch?v=xe3yJNKImHk

https://www.youtube.com/watch?v=2iRDr9oC_4E

EMS:

https://www.youtube.com/watch?v=9Yf9zKpiQ7g

https://www.youtube.com/watch?v=8qyqHtc4cOM

https://www.youtube.com/watch?v=b9wtggDHQXU

https://www.youtube.com/watch?v=J7Fak8QI6Ww

Sustainability:

https://www.youtube.com/watch?v=OcyPfnsnFOI

https://www.youtube.com/watch?v=vGBSLhoKI0s

https://www.youtube.com/watch?v=a1DOQSKmlnw

https://www.youtube.com/watch?v=8v4sZSDz484

https://www.youtube.com/watch?v=rmQby7adocM

https://www.youtube.com/watch?v=pgNLonYOc9s

Project management:

https://www.youtube.com/watch?v=ZKOL-rZ79gs

https://www.youtube.com/watch?v=CfFbUoCvelM

https://www.youtube.com/watch?v=BOU1YP5NZVA

https://www.youtube.com/watch?v=iYedJewuTVE

https://www.youtube.com/watch?v=UfW7zqV_C60&list=PLHIvsxgJ17w7YTcl4LjPusMtN16oL5Zyx

https://www.youtube.com/watch?v=VVIjo-u66qk

https://www.youtube.com/watch?v=DyLcB45rHNI

Environmental risk

https://www.youtube.com/watch?v=PZmNZi8bon8

https://www.youtube.com/watch?v=JxnBc_P4oFs

https://www.youtube.com/watch?v=kEinQtKEzwc

https://www.youtube.com/watch?v=NCPIgAcR2SI

https://www.youtube.com/watch?v=NMdRbjDtfTA

Risk:

http://extensionrme.org/pubs/introductiontoriskmanagement.pdf

http://www.cimaglobal.com/Documents/ImportedDocuments/cid_tg_intro_to_managing_rist.apr07.pdf

Risk assessments for activities:

http://www.geog.ucl.ac.uk/resources/safety/arrangements-for-management-of-hazards-and-activities

BIM:

http://construction.com/market_research/FreeReport/GreenBIM/

http://bim.wikispaces.com/

http://collab.northumbria.ac.uk/bim2/

http://www.wbdg.org/building-information-modeling-bim#nbims

http://www.buildingsmartalliance.org/

http://cife.stanford.edu/

http://bim.psu.edu/default.aspx

http://bim.arch.gatech.edu/reference.asp?mode=case&id=410

http://www.todaysfacilitymanager.com/articles/fm-issue-demystifying-bim.php

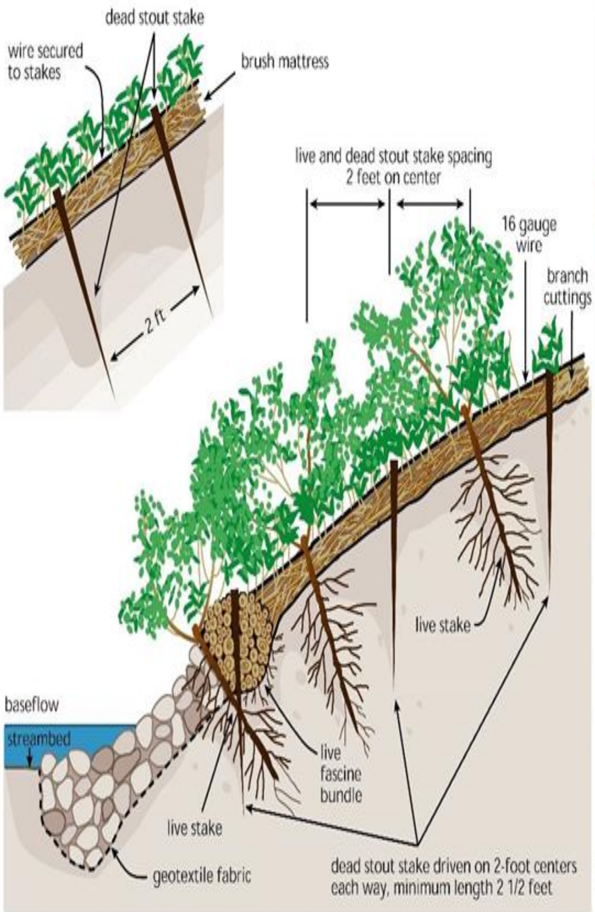
MODULE 6.

E-LEARNING, DATA MANAGEMENT AND TECHNICAL DRAWING

Module

6

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT



Brush Mattresses - http://prj.geosyntec.com/npsmanual/brushmattresses.aspx
https://www.gaiaresources.com.au/data-management-nrms-bugbear-resolved/
https://www.gbca.org.au/education-courses/online-elearning-courses/

Module 6 **E-Learning, Data Management and Technical Drawing**

SPECIALISATION PROCESS FOR THE ECOENGINEERING SECTOR IN THE MEDITERRANEAN ENVIRONMENT

E-LEARNING, DATA MANAGEMENT AND TECHNICAL DRAWING

Authors:

Hüseyin Emrullah ÇELİK, Ferhat GÖKBULAK

Betül UYGUR ERDOĞAN, Mehmet S. ÖZÇELİK

Istanbul University Faculty of Forestry

Dragan DIMITRIEVSKI, Darko ILIEVSKI

Geing Macedonia

September, 2018

TABLE OF CONTENT

FIGURES

TABLES

1. MODULE DESCRIPTOR

Status: core

Credit Points (ECTS): 3

Pre-requisite knowledge: NA

Module structure:

Activity	Total Hours
Lectures	20
Tutorials	10
Seminars	2
Practicals	10
Independent learning	30
Assessment	3
Total	3 ECTS = 75 hours (1ECTS=25hrs)

TEACHING / LEARNING STRATEGIES

Teaching will follow novel methods derived through the ECOMED project: Lectures for imparting fundamentals of module and tutorials and practical for application of the fundamentals. These will be supplemented with virtual learning content, case study analyses, site visits and work placements. Other learning and teaching strategies will be developed and implemented, appropriate to student needs, to enable all students to participate fully in the module.

As expected, students will spend about as much time in directed reading and private study as in enhancement sessions. This is non-negotiable and, therefore, lecturing staff will expect students to be up to date with the current theme. The indicative reading for this module comprises mainly open-source documents accessible to all in electronic format. Local libraries hold a large stock of basic reference texts which are available on short and extended loan. Academic libraries subscribe to a number of professional journals/magazines published by the leading professional bodies, and students will be expected to demonstrate evidence of having sourced information from these in students' coursework activities. Students should also make use of web-based materials and visit appropriate sites demonstrated by module leader to develop a wider knowledge of the key issues and activities of not only students chosen discipline, but also in other related fields. Please refer to the Module Descriptor for a detailed reading list. However, students may also wish to have a look at a number of Internet sources of information, which will be given in the References / Learning Resources section. If students have a particular problem with the academic content or the completion of any aspect of the module, please speak to the module leader in the first instance. If the problem persists, students should speak with students' employer or Academic tutor. A module evaluation form will be made available to students on-line after the module is complete and students will be required to address the set questions carefully and make any comments about the module in order to help us develop and improve the module content and delivery. These forms will be analyzed (anonymously) and the findings considered by the appropriate professional organization as part of the Quality Assurance processes. However, please feel free to contact the module leader with comments that students may have about the module in the first instance.

E-LEARNING

Summary of the module content

Technology is radically changing in every aspect of our professional and personal lives. Furthermore, it is changing formal and informal learning from preschool level through graduate school level and professional continuing education. In this context, e-learning provides several benefits including easy access to a broad range of information without limitation on time, location and quantity in campus-based, real life and online environments with low cost and more training in less time. In addition, e-learning provides advantages of updating and integrating current developments in teaching and education strategies and technologies timely manner into course materials depending on students' needs and profile. The purpose of this course is to introduce the theoretical and philosophical foundations of Instructional Technology (IT) to the students, and assist the students in developing a comprehensive definition of the soil and water bioengineering (SWB) field and a broad conception of the reciprocal impact of SWB technology on education and society.

Syllabus

- Introduction to course, the nature of distance learning.
- Key Approaches and sample programs
- Online Mentoring and issues of assessment
- Teleconferencing technology.
- Researchable Issues on Distance Learning
- Presentation and interpretation of research findings.
- Corporate Collaboration and Future Developments
- Assessment of Distance Learning in context of SWB.
- Project presentation

E-**Learning** outcomes

- Define instructional technology and discuss the discipline in light of its multiple dimensions.
- Discuss the primary theories and paradigms that support instructional technology.
- Articulate the major components of instructional development
- Compare and contrast instructional design models.
- Participate in the scholarly conversation on emerging pedagogies.
- Investigate research methodologies used to study instructional technology and digital learning.
- Discuss the broader effects technologies have upon the educational enterprise and society as a whole.

2. INTRODUCTION TO COURSE, THE NATURE OF DISTANCE LEARNING

E-learning is the learning utilizing electronic technologies to access educational curriculum outside of a traditional classroom at any time. In most cases, it refers to a course, program or degree delivered completely online.

https://www.youtube.com/watch?v=viHILXVY_eU (short animation about e-learning).

There are many terms used to describe learning that is delivered online, via the internet, ranging from distance education to computerized electronic learning, online learning, internet learning and many others. We define eLearning as courses that are specifically delivered via the internet without considering any distance to somewhere other than the classroom where the professor is teaching. It is not a course delivered via a DVD or CD-ROM, video tape or over a television channel. It is interactive in that you can also communicate and discuss with your teachers, professors or other students in your class. Sometimes it is delivered live, where you can "electronically" raise your hand and interact in real time and sometimes it is a lecture that has been prerecorded. There is always a teacher or professor interacting /communicating with you and grading your participation, your assignments and your tests.

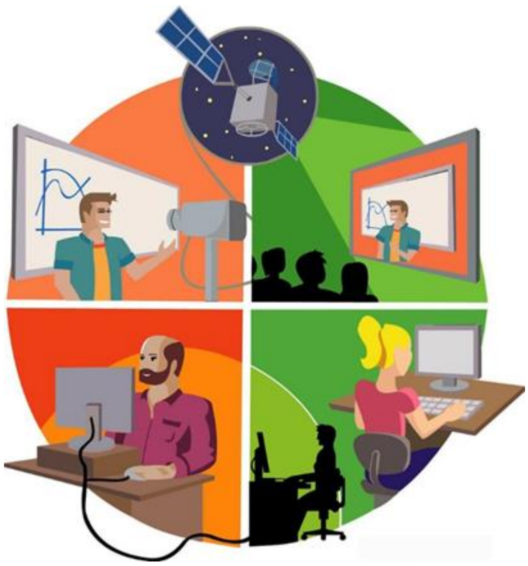


Fig. 2.1 The scheme of the distance learning.

The idea of eLearning has been around since the 1920's when the first testing machine was created. This was advanced even further when the University of Illinois created PLATO (Programmed Logic for Automatic Teaching Operations) (Trivantis, 2016) a terminal where students could access course work. A few years later, Stanford introduced computer aided instruction to elementary students in the gifted program for the Palo Alto Unified School District of California. With the increase of personal computers and the World Wide Web through the 70s and 90s, the adoption of online teaching practices has grown. The adoption of eLearning in the corporate sector soared during the 90s and continued into the 2000s and has since become a common practice.

https://www.youtube.com/watch?v=darOvcpbU8M (6 trends in e-learning design and development).

Technology has advanced so much that the geographical gap is bridged with the use of tools that make you feel as if you are inside the classroom. E-learning offers the ability to share material in all kinds of formats such as videos, slideshows, word documents and PDFs. Conducting webinars (live online classes) and communicating with professors via chat and message forums is also an option available to users.

https://www.youtube.com/watch?v=zv5bpfxJ2xE (what is an LMS?)

There is a plethora of different e-learning systems (otherwise known as **Learning Management Systems**, or **LMSs** for short) and methods, which allow courses to be delivered. With the right tool, various processes can be automated such as the marking of tests or the creation of engaging content. E-learning provides the learners with the ability to fit learning around their lifestyles, effectively allowing even the busiest person to further a career and gain new qualifications.

https://www.youtube.com/watch?v=L4XFGG1BgL8 (the advantages and disadvantages of e-learning).

Advantages: Your schedule, your pace, your place. If you can maintain the necessary self-discipline, the benefits of e-learning are almost too numerous to count. You can cover the material when you have time, go over it as often as you want, all without traveling to the classroom. There are no parking problems or expenses, transportation fees, athletic fees, housing and food service fees, plus you can take the class from any location with internet access. There have been many studies showing that eLearning students retain the material to a significantly greater degree than face-to-face instructor led classes. The content delivery is consistent and can be easily repeated if needed to gain a better understanding.

Many corporations and businesses have transitioned to e-learning because it saves time and is more accessible than traditional training. Because learners can access material through their personal or work computers, the need to travel is eliminated, and in-class materials are replaced with shareable files. ELearning also saves time, as instructors are no longer required to manually grade tests and quizzes, which reduces the need for and costs of third party trainers. Since eLearning can happen anytime and anywhere, there are no restrictions in terms of time, space and place. This makes e-learning ideal for global businesses or those with non-traditional work schedules. When done correctly, eLearning can provide just-in-time training, which means content is ready for learners when they need it. Content can also be tailored to meet the specific needs of your company.

E-learning is beneficial to education, corporations and to all types of learners. It is affordable, saves time, and produces measurable results. E-learning is more cost effective than traditional learning because less time and money is spent traveling. Moreover, e-learning can be considered environmental friendly because limited paper work can save energy and reduce the waste material that can be detrimental for environment. Since e-learning can be done in any geographic location and there are no travel expenses, this type of learning is much less costly than doing learning at a traditional institute.

Students like e-learning because it accommodates different types of learning styles. Students have the advantage of learning at their own pace. Students can also learn through a variety of activities that apply to many different learning styles learners have. Learners can fit e-learning into their busy schedule. If they hold a job, they can still be working with e-learning. If the learner needs to do the learning at night, then this option is available. Learners can sit in their home in their pyjamas and do the learning if they desire.

E-learning encourages students to peruse through information by using hyperlinks and sites on the worldwide web. Students are able to find information relevant to their personal situations and interest. E-learning allows students to select learning materials that meet their level of knowledge, interest and what they need to know to perform more effectively in an activity. E-learning is more focused on the learner and it is more interesting for the learner because it is information that they want to learn. E-learning is flexible and can be customized to meet the individual needs of the learners.

E-learning helps students develop knowledge of the Internet. This knowledge will help learners throughout their careers. E-learning encourages students to take personal responsibility for their own learning. When learners succeed, it builds self-knowledge and self-confidence in them.

Educators and corporations really benefit from e-learning. Learners enjoy having the opportunity to learn at their own pace, on their own time, and have it less costly.

Disadvantages: If it is not designed effectively and appropriately, e-learning can create a feeling of isolation since it’s based on an action that can be completed with little to no human interaction. This means questions might not be answered in a timely manner, and coaching occurs after the fact. Becoming an eLearning student also presents challenges, as the learner will need to learn how to log in to the LMS, navigate to the desired course, and complete the learning activity. Learners who lack motivation may also find it hard to pay attention or schedule time for eLearning. A skilled e-learning developer, however, can create engaging, easy-to-use courses that mitigate these factors.

One disadvantage of e-learning is that learners need to have access to a computer as well as the Internet. They also need to have computer skills with programs such as word processing, internet browsers, and e-mail account. Without these skills and software, it is not possible for the students to succeed in e-learning. E-learners need to be very comfortable using a computer. Slow internet connections or older computers may cause difficulties in accessing to course materials. This may cause the learners to get frustrated and give up. Another disadvantage of e-learning is managing computer files and online learning software. For learners with beginner-level computer skills it can sometimes seem complex to keep their computer files organized. Without good computer organizational skills, learners may lose or misplace reports causing them to be late in submitting assignments. Some of the students also may have trouble installing software that is required for the class.

E-learning also requires just as much time for attending class and completing assignments as any traditional classroom course. This means that students have to be highly motivated and responsible because all the work they do is on their own. Learners with low motivation or bad study habits may fall behind. Another disadvantage of e-learning is that without the routine structures of a traditional class, students may get lost or confused about course activities and deadlines causing the student to fail or do poorly.

2.1 Key approaches and sample programs

E-learning makes use of many technologies - some of which have been developed specifically for it, while others conveniently complemented the learning process, for example computer games. Communication technologies are also widely used in e-learning. Starting with the use of email and instant messaging, message forums and social networks, we see a plethora of tools that any internet user would use in any case.

There are also some technologies that work in a complementary manner to other software and enable new features, for example software that adds a whiteboard on your video conferencing tool to allow you or your peers to make changes on other people's work for review, or screen-sharing which allows someone to make a presentation while still making comments and giving input using the microphone.

E-learning makes good use of database and CMS (Content Management System) technologies. These two work hand in hand to store your course content, test results and student records. The data is stored in the database and the CMS provides a user interface for you to add, update and delete data. A good LMS will often provide reporting tools to generate and store progress reports.

Technologies to improve the quality of content are manifold. Software such as Flash and PowerPoint will help you make your presentations slick and interesting, with high quality, graphically rich content. There are word processing packages and HTML editors available these days that make formatting your text or web pages a breeze, removing a lot of the complexity. There are also many online services available that you can use to create interactive elements for your courses such as quizzes and games.

https://www.youtube.com/watch?v=WIex58-bn60 (top 5 e-learning LMS's).

There are many LMSs available depending on your needs and budget. There are even free systems such as open source software that by definition are 'open' i.e. the source code is freely available for you to use and to adapt to your own needs. Many users of open source software will make improvements or use add-ons for their own needs, and then put it back out into the community for others to use. Open source LMSs can grow rapidly if they get enough interest and input. While you may not get any official support for an open source LMS, there will usually be a strong community base online with forums or email lists where you can ask for and offer help.

https://www.youtube.com/watch?v=WbvveHWkQNk (ILIAS: open source e-learning program).

Of course, there are also commercial LMSs. If you are paying for an LMS then you will get a more robust product, you are also likely to get good documentation and you will probably have a good level of support as well. A commercial product may be more stable and bug-free than a free version, but of course there are always exceptions to that rule so it's a good idea to read reviews of various LMSs before you make your choice. Check out the features to ensure that everything you need is included.

You will also need to consider whether to use a deployed solution or a hosted system. A deployed solution system will generally be set up on computers within your premises and behind your firewall. A deployed solution (or Internal System) may incur extra costs, as the setting up of the system is likely to be done in-house rather than remotely. An installed system may also require more maintenance and support than you are able to provide unless you have a dedicated IT team ready to support it. It is vital your system stays up and running so before, you choose this option make sure you have people with the relevant skills available who will be willing to fix problems as soon as they occur.

With a hosted or SaaS (Software as a Service) LMS a lot of the work is taken off your hands, the system runs on someone else's server so you don't have to worry about server load or maintenance. The system will be set up by your provider and they should also take care of backups, or at least offer you a simple interface to schedule your own backups. A hosted service is normally up and running as soon as it's ordered since the service provider will be used to the procedure. In some cases, it can even done automatically by the system upon electronic request. They will also be able to implement any updates and fixes remotely for you.

A deployed solution will have a greater initial cost as you will have the software and installation to pay for, but it may be more cost effective in the long run. With a hosted system, you will have less to pay initially, no software purchase costs, no installation fees and limited technical problems but over the years, you may end up paying out more than, if you'd opted for an installed LMS.

2.2 Online Mentoring and issues of assessment

2.2.1 Online Mentoring

Online or e-mentoring uses the principles of a traditional mentoring relationship but changes the means of communication. The National Mentoring Centre defines this emerging practice as "mentoring projects that use technology to facilitate and support mentor relationships" (Howard, 2005). Instead of the mentor and mentee meeting once a week or once a month for social and /or professional development, e-mentors have the ability to meet more frequently and more conveniently. Typically, online mentoring is done through asynchronous communications, e-mail or a discussion forum, thereby freeing the mentor and mentee from the constraints of time, geography, high costs, or other limiting factors. Unfortunately, in a traditional face-to-face mentoring relationship, mentors and mentees may be matched based on geographic proximity despite other significant incompatibilities. E-mentoring facilitates a relationship with potentially greater compatibility, and, it is hoped, efficacy.

https://www.youtube.com/watch?v=oxg7o4EJxXI (I am an online mentor).

There are many types of online mentoring with various goals and objectives (see National Mentoring Partnership, http:www.mentoring.org/). These will certainly contribute to the ways in which a mentoring program is conducted, but some similar characteristics can be described.

While mentors are indeed disparate in their roles and responsibilities depending on the type of mentoring program, two main areas comprise the roles and contribute to the responsibilities of all online mentors: First, a mentor can provide support, encouragement, friendship, a person with whom to share joys, frustrations, and feelings; and second, a mentor offers professional development advice and information and serves as an intellectual resource. These two areas often intertwine and overlap. For example, the online mentoring of middle and high school science students by professional scientists involves professional advice on student projects in additional to emotional support on the challenges of completing scientific work.

In an online university or college classroom setting, mentors can assume active roles different from other online mentors. The online mentor in undergraduate or graduate online learning can be a supplementary figure to the course instructor, but he or she should not be construed in the formal sense as a "teaching assistant" but, instead, as a "learning assistant." The online mentor negotiates among the instructor, the online classroom and its technologies, and the students' various questions, needs, frustrations, concerns, and successes. The complexities of online learning contribute to a multi-faceted role for the online mentor. As e-mentoring develops, more elaborate roles and responsibilities are emerging.

https://www.youtube.com/watch?v=yBoSI8EydvA (VineUp: online mentoring software).

What roles and responsibilities does a mentee want of an online mentor? Researches reveal that online graduate students desire a mentor who can straddle the support-friendship/professional advice continuum. Specifically, mentees in a graduate-level program of library and information science expressed a need for a mentor:

• who will ease intimidation of the technology and technical issues in online learning;

• who will help immerse new students into an online program;

• who will give them guidance on the technology itself, but also, on coursework, professional development options, and navigating the institutional maze;

• who will help ease feelings of isolation; and

• who will help to discuss common pitfalls and frustrations, while sharing joys and tips on "how I made it through."

A mentor, it was felt, should understand how an online student experiences a typical day, from his/her responsibilities to school, work, and family obligations.

http://what-when-how.com/distance-learning/online-mentoring-distance-learning/

https://pdfs.semanticscholar.org/6f57/f13a17d1508f49bab935d6446599c96cd401.pdf

https://www.ellenensher.com/wp-content/uploads/downloads/Onlinementoring.pdf

2.2.2 Issues of Assessment

It is important to measure how people learn and not just what they have learnt. It is necessary to implement relevant technologies for assessments to make learning applicable to modern students, who are more digital and competence-based. Feedback should be used to improve learning.

https://www.youtube.com/watch?v=d0nfDOPaw_8 (Assessing student online learning).

According to the Quality Assurance Agency for Higher Education, assessment is one of the most relevant parts of the instructional process, and not just a matter of marking. Technology has promoted changes in how curricula might be designed and delivered online, but the challenges of e-assessments require new approaches. Some studies developed by JISC (Joint Information Systems Committee) in the UK pointed out that there are interesting innovations in assessment methods being performed in limited circles, but these have not yet been transferred to a larger scale.

https://www.youtube.com/watch?v=a5JMn2VrZEw (Grading and assessments in e-learning).

To enhance e-assessments and implement them successfully, we need to understand how ICT can be used to improve assessment experiences, provide evidence of higher-level learning, and explore its institutional and pedagogic dimensions while addressing sustainability and cultural issues (Guàrdia, Cris & Alsina, 2016).

To meet this challenge we recommend considering the following steps when designing e-assessments:

1. Instructional Design.

Integrating the e-assessment into the entire learning process as part of the course design. It is important to measure how people learn and not just what they have learnt. It is an ongoing process that should be assessed continuously, and Instructional Design can help teachers to plan how and when to do it. At the same time, Instructional Design can help teachers choose the right assessment methods, strategies, and technologies to enhance learning.

2. Variety of Methods.

Use different assessment methods and activities to measure different processes and outcomes, coming from different learning styles, such as: Multiple-choice questions-MCQ, ePortfolio assessment, concept maps, clickers, or personal response systems - PRCS, online role-plays, scenario-based activities, judged mathematical expression, online discussions, etc.

3. Technologies Enhance Assessments.

Use ICT to follow up the learning process: Build tools to monitor and support, to assess a large number of students; design scales and rubrics to be used as self-assessment; peer-review and teacher evaluation. Select technologies that support alternative assessment strategies and allow evidence of higher-level learning to be collected.

4. Evidence-Based Learning.

Use evidence-based learning strategies as an assessment approach. Using ePortfolios, scenario-based activities, role-paying, and simulations can provide evidence of learning. The European Network of ePortfolio Experts and Practitioners (EPNET) on the Europortfolio Portal present examples and guidance to implement ePortfolio as an assessment strategy.

5. Feedback and Feedforward.

Learners need substantial, regular, feedback (OECD, 2010) and e-assessment strategies offer a systematic format for providing this. The meaningful feedback can be personalized and provided by different actors (self, peers, teachers, professional actors, etc.). Feedback should be used to improve learning, and not given as a final activity, informing the students about a final mark; by promoting dialogical feedback and feedforward, assessment will make more sense than ever: It will encourage learners to modify, complement, and improve their learning. In fact, self-regulated learning should be applied if we want sustainable assessment, especially for a large number of students.

Final Thoughts

Effective teachers recognize the importance of engaging their students in learning; this is why it is necessary to implement relevant technologies for assessments to make learning applicable to modern students, who are becoming more digital and competence-based to meet the demand for future jobs. In this regard, teacher training is crucial to meet this challenge.

There is an urgent need to convince educational stakeholders of the effectiveness and appropriateness of using technologies for assessment purposes. Learning and teaching strategies based on ICT assessment, supported by Instructional Design, should choose e-assessment methods that promote alternative solutions and encourage experimentation through peer-assessment and self-regulated learning using different media and communication formats.

https://elearningindustry.com/challenges-of-e-assessments-5-steps

http://jolt.merlot.org/vol8no3/kearns_0912.pdf

http://eprints.lincoln.ac.uk/1610/1/OuluAssessmentChapterforRepository.pdf https://www.stjohns.edu/sites/default/files/documents/ir/f63bd49dcf56481e9dbd6975cce6c792.pdf

2.3 Teleconferencing Technology

Education across the world has a changed character, where reaching out to substantial knowledge isn't impossible. Video conferencing has made classrooms walls invisible, allowing students to have the entire world as their learning resource. Moreover, this technology has also helped in easy retention of knowledge in learners as visuals are always better remembered than words. Visual communication has double-fold benefits, both for the teacher and the taught as it opens up the door towards global learning. Here are some impending reasons to invest in video conferencing for education.

https://www.youtube.com/watch?v=aoGbrm_wRk0 (Introduction to teleconferencing).

https://www.youtube.com/watch?v=a5JMn2VrZEw (the technology behind 3D teleconferencing).

1. Stipulates Global Collaboration

Reading begets knowledge while visualizing help in understanding. Virtual field trips, face-to-face collaboration with the Subject Matter Experts, virtual classrooms, all these can be made possible through the effective use of a standardized video conferencing solutions built for the learning sector. This encourages cross-cultural bonding among students and assists them to mutate into more tolerant global citizens.

2. Endorse Distant Learning

Rural students often have lesser learning options due to the lack of infrastructures and resources. A video conferencing solution can help them get access to some great learning materials. They can get enrolled in a course of their choice, communicate with tutors, participate in group discussions, refer to the prerecorded resources from the digital library and remarkably improve their learning experience.

https://www.youtube.com/watch?v=8evWymAC1sI (benefits of video conferencing).

3. Enhanced Curriculum

High definition videos have now replaced chart and presentations, teachers are sharing their screens with the students for better and more life-like experience. An improved pattern of interactive learning suddenly opens up a wider spectrum of a subject that engages the students even more.

4. Encourages Self-Paced Learning

Students may not alone refer to teenagers; some of them may be professionals or even stay-at-home parents, who struggle hard to fit education into their busy schedules. Video conferencing for education promotes self-paced learning for all such knowledge aspirants. Education can now be scheduled. They may learn when they wish to, time is longer a constraint. Pre-recorded videos, archives are great student aids that add to their self-paced learning spree.

5. Best Administrative Tool

Video conferencing for education is not just restricted to imparting knowledge alone; it acts as a great admin tool for educational institutes as well. Circulating administrative updates, holding an interactive parent-teacher meeting, training sessions for teaching and non-teaching staffs without the requisition of the physical presence of the attendees, are some added advantages of the video conferencing solutions for the education industry.

https://ejournals.epublishing.ekt.gr/index.php/openjournal/article/viewFile/9806/9931.pdf https://elearningindustry.com/video-conferencing-for-education-5-reasons-invest

https://ieeexplore.ieee.org/document/4402868/

https://tr.uow.edu.au/uow/file/c194f4b2-3322-4b96-8297-4ef295c23e22/1/Teaching%20with%20Web%20and%20Videoconferencing%20Tech.pdf

2.4 Researchable Issues on Distance Learning

1- Philosophy and theory of distance education.
2- Distance students, their milieu, conditions, and study motivations.
3- Subject matter presentation.
4- Communication and interaction between students and their supporting organization (tutors, counsellors, administrators, other students).
5- Administration and organization.
6- Economics.
7- Systems (comparative distance education, typologies, evaluation, etc.).
8- History of distance education.
9- Quality ıssues on distance learning.

https://www.youtube.com/watch?v=zv5bpfxJ2xE (Webinar: future of e-learning).

https://www.sciencedirect.com/science/article/pii/S1877042817300435https://files.eric.ed.gov/fulltext/EJ847754.pdf

http://ldt.stanford.edu/~leemba/ldt/resources/issues_in_distance_learning.htm

https://www.sciencedirect.com/science/article/pii/S1877042817300435

2.5 Presentation of research findings

For some, presenting research can be a daunting task and one of the more stressful aspects of being a psychological scientist. Although research can take months or years to move from idea generation and design to data collection, analysis, and writing up the results, most oral presentations at conferences take only about 10-20 minutes. How does one go about cramming all of one's hard work into such a brief time allotment? Deciding what information to include in an oral presentation and how to organize that information can often be more stressful than actually giving the presentation.

https://www.youtube.com/watch?v=LzIJFD-ddol (how to prepare an oral research presentation).

Anyone riddled with presentation anxiety should remember that the difficult part is already over once it comes time to present. No one knows your research better than you and those who come to listen to your presentation are likely there because they are interested in your research and not because they are required to be there. Taking this perspective can make presenting your research much less stressful because the focus of the task is no longer to engage an uninterested audience — it is to keep an already interested audience engaged. The goal of this article is to provide general advice for constructing a presentation using the various multimedia tools that are currently available (e.g., PowerPoint, Keynote, Prezi).

Planning: What should be included?

Determining the main messages, you want to communicate in your presentation (i.e., take-home messages for the audience) is often a good first step in organizing the details of your research. As you create your presentation, sometimes it is difficult to determine whether a particular piece of information is important or necessary. Consider the value added by each piece of content as you determine whether to include or exclude information. Often, the background and theory for your research must be presented concisely in order for you to have time to present your study and findings. Ten minutes is not much time; share what needs to be shared and emphasize the main points so that your audience has a clear understanding of your take-home messages. When you start planning, writing out content on individual post-it notes can be a great way to visually organize your thoughts and, ultimately, your presentation.

Building slides: The do's and don'ts

After content has been decided the real fun begins: designing slides. There are no hard-and-fast rules for how to build a slide, but here are a few suggestions to keep in mind. Remember that you want to tell a story, not lecture people. The oral presentation as a whole should be a work of art and the slides should be second and supplementary to the story that you are trying to convey. When laying out content and designing slides, remember that less is more. Having more slides with less content on each will help keep your audience focused more on what you are saying and prevent them from staring blankly at your slides.

Consider the billboard. Marketers try to only use three seconds worth of content, the same amount of time a driver has to view a billboard. Your audience may not be driving cars, but you want them to stay engaged with your story and this makes the three-seconds rule a good one to apply when building a slide. If it takes more than three seconds to read the slide it may be advantageous to start a new slide. Having less content on each slide may leave more white space, but this is acceptable and even desirable.

White space will help the slide appear cleaner and more aesthetically appealing. It is important to note that white space may not always be white. Each presentation should have its own colour palette that consists of approximately three complementary colours. Try not to use many more than three colours and be aware of the emotion that may be attached to certain colours. For example, blue is the colour of the sky and the ocean and is typically a soothing and relaxing colour; red on the other hand, is a bold, passionate colour that may evoke more aggressive feelings.

In addition to colour, animation is another customizable option of presentations, but it may not be a worthwhile effort. Animation can be distracting and make it difficult for the audience to stay with the story being told. When in doubt about animation, remember to ask what value is being added. There may be times when you really want to add emphasis to a specific word or phrase. If this is the case, and you deem it necessary, animation may be an acceptable choice. For example, the "grow" feature may be useful for adding emphasis to a word or phrase.

It is important to have highly readable slides with good contrast between the words and background. Choose a font that is easy to read and be aware that each font has a different personality and sends a different message. The personality of some fonts may even be considered inappropriate for certain settings. For example, the font Comic Sans is a “lighter” font and would most likely not be a wise choice for a presentation at a conference.

Other important considerations include typesetting and the spacing of letters, words and lines. These all affect readability, but can also be used as a way to add emphasis. Sometimes you may feel a need to use bullet points. Do not. Typesetting can replace bullet points and add extra distinction to each line of content without cluttering the slide with bullets. For example, consider bolding and increasing the font size of parent lines and indenting child lines.

If you find that your slides mainly contain words, remember that a picture, chart or diagram can convey a thousand words. People often depend on vision as their primary sense; this gives your audience a potential preference for visual information beyond words on the screen.

Presenting data: Think about what kind of graph is the best

When sharing information, specifically about data, bar graphs should usually be the first choice with scatter plots a close second. Keep the chart or graph simple. The same suggestion about having more slides with less content on each applies to charts and graphs. If the graph or chart will look cleaner using two graphs instead of one, utilize a second graph. Accuracy of a graph is important. For example, it is easy to convey the wrong message simply by altering the range of the y-axis. A restricted y-axis can make the differences between groups look much larger than they actually are to those audience members who do not look closely. It is always important to be ethical and to ensure that information, especially about data, is not being misrepresented. Strive to make charts and graphs easily interpretable, and try not to clutter them with additional numbers if it can be avoided.

Building presentations does not need to be a challenge. Presenting should be an opportunity to share with others something very important to you — your research. These suggestions can be used as a starting point to guide the development of future research presentations and to help relieve some of the stress surrounding them.

http://www.apa.org/science/about/psa/2014/02/presenting.aspx

https://knowhownonprofit.org/how-to/how-to-present-research-findings

https://www.duarte.com/effective-presentations-effective-elearning/

2.6 Corporate collaboration and future developments

Corporate education is a necessity – organizations these days are changing strategies from day to day, and therefore must be flexible regarding adapting to learning curves. Employee training may happen more frequently, so being prepared for any new information or process is key to a smooth transition and a successful business.

1. Presentations and Graphics: Canva

Presentations are a part of corporate eLearning. A tool like Canva provides colourful and attractive presentation templates for various topics. Templates range from normal presentation templates to infographics, and each of them are visually appealing and fully customizable. This will help make corporate eLearning more enjoyable and interactive. Graphics can also be created in the tool, which can be added to your presentations to make them more interesting.

https://www.youtube.com/watch?v=3-IB4Q-k1OI (create beautiful graphics for free: Canva)

2. Video Calls: Skype

Have you ever thought of using Skype as an eLearning tool? Skype can be a great tool for keeping in touch with other remote educators within your company, or even for doing online training sessions. Using Skype, calls can be set up to teach learners new information or partner with other members within the organization in order to ensure messages are being received and understood. Skype is also a great instant communication tool for educators and learners. If an educator needs to communicate something to someone quickly, questions can be asked and answered in a matter of minutes. Longer interactions can be handled via a simple video call.

3. Video Creator: mysimpleshow

mysimpleshow is an Internet-based DIY video creation tool. This a great eLearning tool that enables anyone involved in training and development or with establishing eLearning courses to create their own explainer videos about any topic. Whether a change process or an introduction to new board members need to be communicated, making a video using the provided storyline templates can help explain anything! Use them to create a video library, to enhance a PowerPoint presentation, or to have learners create their own videos to establish their understanding of a subject. All of these materials can then be uploaded onto social learning sites like Wikispaces.

https://www.youtube.com/watch?v=ujkklaALEmY (creating a mysimpleshow).

4. Collaboration: Wikispaces

Wikispaces is yet another great eLearning tool. Using Wikispaces, Instructional Designers and learners can collaborate and work together on a living document. It is similar to Wikipedia, but it's more than just Wikipedia: the corporate administrator can create a suitable homepage, add links and easily upload images. Share lessons, media, and other materials online with organizational learners, or let them collaborate to build their own educational wiki. Wikispaces allows the site administrator to show videos from sites like YouTube, to run polls or even embed maps and slideshows. It also shows what is being read by whom, and who has completed a given assignment.

https://www.youtube.com/watch?v=50MenxCNYAI (Introduction to wikispaces)

https://www.youtube.com/watch?v=RJjT--hbbhc (How to easily use wikispaces)

5. Assessment: Quizlet

Assessment tools like Quizlet allow those in charge of corporate eLearning and education to gauge how well learners understand the information given to them. Tools like this are also an excellent way to get a better idea of how well lessons and training projects are received. Quizlet makes it easy for corporate educators to create study tools for learners and trainees, especially flashcards that can make memorizing important information a breeze. With this tool, you create a quiz using the content creation page to add terms and definitions. Quizlet will then turn the quiz into flash cards and short games. On the homepage, links to quizzes can be copied, and then pasted onto social learning sites.

https://www.youtube.com/watch?v=7oJk0IBynoU (what is quizlet?).

All of the above are eLearning tools that everyone involved in corporate eLearning needs to know about. These tools can help you to stay connected, stay organized, and increase the ease of building multimedia lessons with eLearning tools that will optimize continuous organizational learning.

Futuristic e-learning will probably involve technologies and platforms that derive from current trends. In this section, we will outline some of the recently popular and emerging trends, which could easily develop into exciting, advanced, and helpful learning models.

MOOCs (massive open online courses) are just what they sound like. These open, online courses allow millions of people to take the same course at once from just about anywhere in the world. Someone may be in Australia chatting with his or her classmate in Canada in real-time. Originally, MOOCs emphasized the open access features such as the open licensing of content, structure, and learning goals. However, newer MOOCs involve closed licensing for course materials, while maintaining free access to students. It is suggested that MOOCs may eventually not be free. However, a $7,000 computer science degree via a series of MOOCs from Georgia Tech sure is a lot more affordable than the actual tuition for four years (Georgia Tech unveils first all-MOOC computer science degree). With this model, learning is possible for just about anyone with an internet connection. Though MOOC providers are still figuring out ways to monetize this platform, free online education will probably just get better and better, become more accessible, and permeate throughout more avenues.

Mlearning (mobile learning)

Soon, online courses will become readily accessible on mobile devices. Not only do mobile devices allow you to learn from anywhere, newer devices are equipped with digital compasses, dual cameras, incredible audio, etc. Imagine the learners of the future who will be able to watch a lesson on-the-go while utilizing apps and features of their mobile devices to actually take measurements, do science experiments, or communicate with other learners. For instance, why do a geometry word problem on paper when you can actually go into the field and take measurements and make calculations, such as finding the length of the hypotenuse between the ground and the Statue of Liberty, which they can then input into their mobile device and use as part of the lesson? In 2014, there is a sharp distinction between formal and informal learning. However, e-learning, and especially mLearning, makes "informal learning" so accessible that much more "informal learning" could be incorporated into the curriculum. Students will eventually have nearly unlimited access to topics that interest them. Perhaps students will eventually have much more choice about what topics they explore, as long as they are developing necessary skills and meeting a basic set of requirements. mLearning also introduces the possibility of incorporating social media into the learning atmosphere. Why does "social" have to mean sharing cat photos and selfies? Social media could become the primary forum for idea sharing, tutoring, etc. Facebook, Twitter, and other social media sites share the common attributes of "instantaneous idea sharing." If those ideas were directed towards academic or training content, we might rethink using Facebook (or other social platforms) in the classroom.

Virtual technologies

In the 1990's and early 2000's, IMAX and 3D movies gave viewers a somewhat realistic experience. However, futuristic virtual reality technologies could actually put learners in the role of discoverer, astronaut, historical figure, businessman, etc. Technologies like Google Glass and other wearable tech devices might become so readily available that they can permeate throughout learning institutions. Sometimes called "immersive multimedia," the possibilities of virtual reality are endless (literally), because if you can imagine it, you could virtually design it, interact with it, and incorporate it into the learning experience. CAD software and multimodal devices are advancing rapidly, and so a futuristic learning experience could incorporate recreated sensory experiences including virtual taste, smell, sound, touch, and visuals.

Gamification

eLearning courses of the future will likely resemble an interactive video game rather than a traditional lecture. Candy Crush and World of Warcraft have taught us a lot about the cognitive psychology behind engagement. Learners like games. They like challenges, interactive elements, and opportunities to develop strategies. They also like mastering concepts (levelling up), immediate feedback, and characters with distinct personalities. Great courses of the future will likely include many of these elements which will make the learning experience so exciting, interactive, and fun that learners can't wait to participate and reap the benefits by mastering the content.

https://www.youtube.com/watch?v=n6Hwpp1jWok (e-learning gamification).

https://elearningindustry.com/top-differences-between-smb-focused-and-enterprise-lms

https://elearningindustry.com/elearning-future-what-will-elearning-look-like-2075

https://www.w3.org/community/learnonline/2016/08/04/elearning-trends/

https://skyprep.com/2018/01/29/4-ways-ai-will-shape-the-future-of-e-learning/

https://yourstory.com/2016/07/e-learning-future-landscape/

https://elearningindustry.com/elearning-tools-corporate-education

2.7 Assessment of distance learning in context of SWB

It is hard to build an e-learning tool since most of the soil-water bio-engineering studies are "site specific". Yet, there are some options to make useful e-learning courses for participants. For instance, some plant species and their "soil protecting" features can be shown online in order to make participants think about the local plants, which are useful for the same aim in their area. For example, root/shoot ratio is an important indicator for the plants that are usable in the areas, which are suffering from erosion.

On the other hand, the theory of the slope stabilization works can be shown via online courses and after those successful examples can be given to place the subject in the participants' minds.

Another option for e-learning in soil-water bioengineering works is to create some equation models and teach how to use these modules in the field. In this concept, all participants can use the model for their own work.

In the field works, e-learning can be a useful option for field analyses, i.e., soil texture analysis. These analyses are mostly based on general methods, so everyone's analyses will depend on the same method. In soil texture analyses example, a mentor can teach the basic principles and theory of the analyses and then show how to take field samples, how to air dry, how to sieve and lastly, how to analyse them in terms of texture, which shows where the location of that type of soil sample on the texture triangle.

Beside, e-learning can be used for teaching base information about soil and water researches even for kids. Animations and other useful technologies will be beneficial to create e-learning lessons. By e-learning technologies, even elementary school kids can be educated about environment and thus awareness can be raised among the society at young age.

https://www.youtube.com/watch?v=yslm7lmsK6c (layers of soil for kids).

2.8 Project Presentation

Each eLearning deliverable, regardless of the learning objective, in order to be effective has to be as interactive, immersive, and engaging as possible. Fortunately, there are now different varieties of presentation and slideshow creation tools that can help you to produce amazing and effective eLearning presentations and slideshows for your learners.

Map out your strategy in advance.

Before you dive into the creation process, it is always wise to map out your entire eLearning presentation or slideshow. Develop a plan for each page and decide which elements you are going to include. You may want to consider developing a mind map or storyboard to help you with this process. Determine the flow and pace of the eLearning presentation or slideshow, so that you can design the eLearning experience around this structure. Keep in mind that organization is key when creating eLearning presentations, as it will allow you to stay on-topic and only include elements those are necessary.

Always focus on the learning goals.

Students should always be aware of the learning objectives, so that they can custom tailor every aspect of the eLearning presentation to help learners get one-step closer to achieving their primary goal. For example, prior to choosing the ideal graphics to incorporate, decide whether or not that particular element is going to serve your learning objectives

Text should be concise, clear, and carefully crafted

The text, students include in their presentation or slideshow, should be brief and clear. Having lengthy paragraphs and run-on sentences will only distract or bore the learners. Students can consider adding bullet points if there is a great deal of text, or they can omit certain pieces of information that may be irrelevant. Also, if they are narrating the presentation, they can try not to include text for topics or ideas that they have already verbally presented, unless of course it's a key point that needs to be stressed.

Use high quality, relevant images

E-learners must choose high quality images and photos for their eLearning presentation in order to make it more engaging and immersive. However, they should remember that the images they use should be relevant to the topic-at-hand. In other words, they do not just use graphics for the sake of using graphics. Also, e-leraners should be picky about the images they incorporate, and they should not use too many on any one particular page. Last, but certainly not least, e-learners should always ensure that they own the rights to the photo or that they opt for royalty free images.

Keep colours, branding, and overall design consistent throughout

In terms of aesthetic appeal, few things are worse than an eLearning presentation that looks like its parts were just pieced together. In other words, the slides of your eLearning slideshow should not look as though they have been designed by different individuals. Cohesive eLearning design is a vital aspect of your eLearning slideshow or presentation as it helps learners from becoming confused. So, make sure that the colours, fonts, branding, and overall design of the project flows well and is consistent throughout the presentation or slideshow. Also, the design should effectively reflect your brand's image and message.

Include audio or video to create a more immersive experience

Audio or video integration is ideal, especially if you are trying to make your eLearning presentation more dynamic and interactive. Narration, background music, and video explanations are all examples of multimedia tools that you can (and should) use. Some say that videos hold the future of eLearning. Embed links to references and resources.

Including links to articles, reference sites, and other web resources can give you the opportunity to expand the learning experience of your learners beyond the eLearning presentation. Rather than making the learners scour the web for these resources, you can direct them to specific sites that they may find helpful.

Integrate real life examples

Real life examples, such as those that your learners will encounter on the job, allow them to relate to the content. They also help them to see the value of the eLearning experience, given that they are made aware of exactly how to utilize the knowledge or skills acquired in the real world. This gives them added motivation to pay attention and absorb the information you are offering through the presentation.

Limit the amount of time spent on each slide

Do not spend more than 20 to 30 seconds on each page or slide. You want the eLearning presentation or slideshow to move along at a steady pace, rather than remain stagnant on a specific screen. This way, learners keep staying focus and engaged rather than get bored. Also, try to focus on one core topic or idea for each screen, if possible, as this can help to avoid cognitive overload.

Do not forget about recaps and self-assessments.

Even though an eLearning presentation may not be a full course, it is still important to include recaps or self-assessments to ensure that the learners are acquiring and retaining the information. For example, you can add a recap screen after every ten slides in order to summarize the concepts, or have them complete a self-assessment quiz at the end of the slideshow. This will also help them to commit the information to their long-term memory, rather than forgetting about it as soon as they click away from the presentation.

https://elearningindustry.com/top-10-tips-create-effective-elearning-presentations-and-slideshows

https://elearningindustry.com/use-perfect-learning-objectives-to-boost-the-quality-of-your-e-learning

3. DATA MANAGEMENT

3.1 Summary of the module content

The Data Management module encompasses the whole process of data within the context of the ways in which data is stored and shared by the implementer including collecting, extracting, transforming, analysing and evaluating.

Purpose of the data management is to acquire, validate, store, protect, and process required data to ensure the accessibility, reliability, and timeliness of the data for the users. Types of data can be as numerical, categorical and ordinal.

Data management in Soil Water Bioengineering (SWB) minimizes the risks and costs of regulatory non-compliance, legal complications, and security breaches. It also provides access to accurate and relevant data when and where it is needed, without ambiguity or conflict, thereby avoiding miscommunication.

3.2 Learning outcomes

On successful completion of this module students should be able to:

- Capable of making experimental design based on objective of studies and types of data.
- Understand the fundamentals of how data is acquired, transferred, and stored for Soil Water Bioengineering (SWB) applications.
- Have the knowledge of using some software programs for data analyses.
- Know the fundamentals of Structured Query Language (SQL) and how it can be used to store and retrieve data from a relational database.
- Be able to apply the principles used in class to build a web-based database application from the ground up.
- Create appropriate documentation in order to prepare data for effective long-term use and reuse by themselves or others.
- Collection, transformation, analyzation, evaluation, interpretation and management of basic statistic and dynamic parameters of soil and water bioengineering.

3.3 Teaching / learning strategy

The teaching and learning strategy will involve a diverse range of data as the material. The delivery of the modules will encourage an investigative approach and students will be expected to consider how principles and concepts impact upon managing the experimental design in the study site and improving the quality of data.

Relevant individual tutorials, discussion groups, group tutorials, practical exercises and live data will inform students. The programme will include both site specific and general data exercises which will provide an opportunity to see the differences of processes between big and simple data.

3.4 Syllabus

- Understanding core database objects: creating database objects
- Data types: numerical (discrete and continuous), categorical, and ordinal
- Overview relational database management systems: database, conceptual schema, relational database design, normalization
- Determination of appropriate experimental design for specific data collection
- Understand the foundations of structured query language: querying, table relationships and joins
- Data management in SWB context
- Overview business intelligence and analytics
- Descriptive analytics: data visualization and exploration
- Data query, data model and reports

3.5 Transferable skills development

Learning skills will be enhanced by use of some software programs to create database and analyse information for managing data of any case study.

Decision-making skills will be enhanced by requiring the use of appropriate software, data type, experimental design and descriptive analytics when determining and evaluating information of case studies.

Time managing skills will be developed by learning the documentation and organization of data, files and folders in a quick edit mode.

3.6 Assessment methods

Component	Duration (hrs)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Coursework 1	10	20	50	Overview relational database management systems: database, conceptual schema, relational database design, normalization of soil and water bioengineering.
Class test	2	10	50	The correct selection, design and data types, structured query language for the soil and water bioengineering techniques based on the development of the data management skills and analyses.
Practical	15	30	50	Ability to apply the principles used in class to build a web-based database application

				from the ground up by using some software programs for data analyses.
Exam	3	50	50	Ability to make experimental design based on objective of studies and types of data in the context of transformation, analyzation, evaluation, interpretation and management of basic static and dynamic parameters of soil and water bioengineering by using software programs.
Total	25 hours			

Assessment Strategy

In line with the innovative nature of this course, the supporting assessment strategy uses a blend of assessment methods. Evidence of the achievement of the learning outcomes will be in the form of:

- Written and practical assignments
- Participation in discussions and data management exercises
- The production of a portfolio of case studies
- Examination

Both formative and summative assessment methods will be used throughout this programme. Formative assessment creates a point for both students and tutors from which to appraise development, consolidate learning and to plan ahead.

Summative assessment allows recognition for progression to further study, informs those involved of the level of achievement, and validates the learning process.

Students will be expected to apply theoretical understanding in a variety of different scenarios and employ a range of approaches to expression and articulation in assignments.

At the end of this module, students will have developed the knowledge and skills presented below that needed for enhanced employability opportunities in the area of data management especially Soil and Water Bioengineering:

- Improving data quality and consistency and facilitating reuse in the data lifecycle
- Evaluating data management plans and processes against the framework to understand and develop best practices that ensure an institution or repository's data is accessible, discoverable, understood, and reusable
- Ensuring that processes are sustainable, scalable, and consistent
- Elevating and aligning good data

- Speeding the advancement of science through better accessibility and reusability of data
- Improving repeatability in the research processes and outputs

3.7 Understanding core database objects: creating database objects

3.7.1 What is data and how can create database?

Wisdom, knowledge, information and data are all closely related through being on the same continuum – from wisdom, to knowledge, then to information and, finally, to data. There are many definitions of data available in dictionaries and textbooks but, in essence, most of these definitions basically say that data is 'facts, events, transactions and similar that have been recorded'.

An often-heard definition of information is that it is 'data placed in context'. This implies that some information is the result of the translation of some data using some processing activity, and some communication protocol, into an agreed format that is identifiable to the user. In other words, if data has some meaning attributed to it, it becomes information. Figure 3.1 provides an overview of the relationship between data and information in the context of a computerised information system. The user of the system extracts the required information from their overall knowledge and inputs the information into the system. As it enters the system, it is converted into data so that it can be stored and processed. When another system user requires that information, the data is interpreted – that is, it has meaning applied to it – so that can be of use to the user.

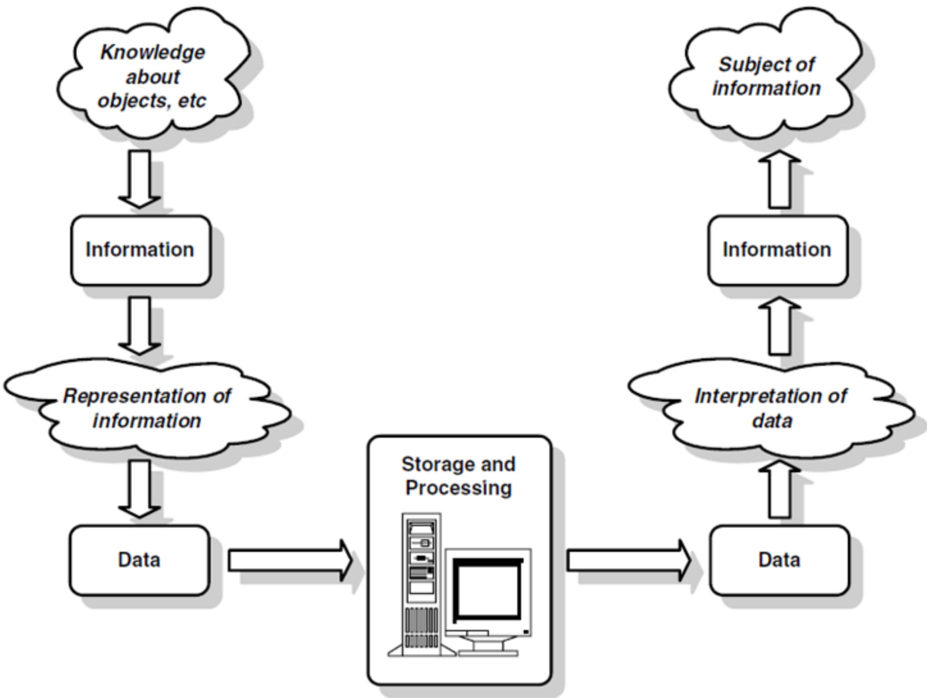


Fig. 3.1 The relationship between data and information

When the data becomes a database, the meaning and types of database should be known to be able to apply the appropriate design, software for analysing.

A database (db) is an organized collection of data, typically stored in electronic format. It allows you to input, organize, and retrieve data quickly. Traditional databases are organized by fields, records, and files.

To better understand what a database is, consider the telephone book as a simple example. If you had the telephone book stored on disk, the book would be the file. Within the telephone book, you would have a list of records—each of which contains a name, address, and telephone number. These single pieces of information (name, address, phone number) would each constitute a separate field.

Because a database can store thousands of records, it would be a chore if you had to open a table and go through each record one at a time until you found the record you needed. Of course, the process would be even more difficult if you had to retrieve multiple records. Thankfully, you do not have to go through database records in this way. Rather, to retrieve data within a database, you run a database query, which is an inquiry into the database that returns information back from the database. In other words, a query is used to ask for information from a database. If a database contains thousands of records with many fields per record, it may take even a fast computer a significant amount of time to search through a table and retrieve the requested data. This is where a database index comes in handy. An index is a data structure that improves the speed of data retrieval operations on a database table. The disadvantage of indexes is that they need to be created and updated, which requires processing resources and takes up disk space.

There are four types of databases with which you should be familiar in order to make the appropriate choice when developing your own database tables:

- Flat-type databases
- Hierarchical databases
- Object-Oriented database
- Relational databases

Each database type has its own important design features.

Flat-type databases are considered "flat" because they are two-dimensional tables consisting of rows and columns. Each column can be referred to as a field (such as a person's last name or a product's ID number), and each row can be referred to as a record (such as a person's or product's information). Table 3.1 is an example of a simple flat-type database in which a supply company has matched each customer with what he or she consistently orders for easy retrieval and reordering purposes:

Table 3.1 An example of flat-type database

Id	Customer	Order
1	Allen	Notebook
2	Smith	Paper
3	Dennis	Pens
4	Alex	Ink cartridges
5	Sloan	Printer

Hierarchical databases were the earliest models, resembling an upside-down tree. Files are related in a parent-child manner, with each parent capable of relating to more than one child, but each child only being related to one parent. Most of you will be familiar with this kind of structure—it is the way most file systems work. There is usually a root, or top-level, directory that contains various other directories and files. Each subdirectory can then contain more files and directories, and so on. Each file or directory can only exist in one directory itself—it only has one parent. As you can see in the Figure 3.2 below A1 is the root directory, and its children are B1 and B2. B1 is a parent to C1, C2, and C3, which in turn has children of its own.

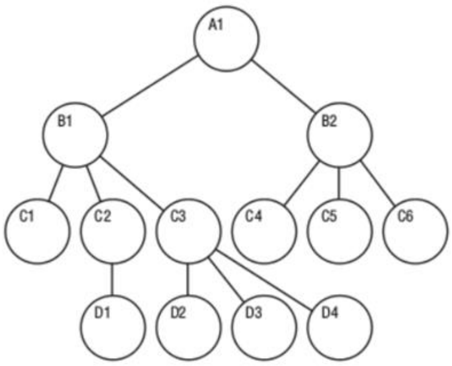


Fig. 3.2 An example of hierarchical database

Object-Oriented database store objects rather than data such as integers, strings or real numbers. Objects are used in object oriented languages such as Smalltalk, C++, Java, and others. Objects basically consist of the following:

- Attributes - Attributes are data which defines the characteristics of an object. This data may be simple such as integers, strings, and real numbers or it may be a reference to a complex object.
- Methods - Methods define the behaviour of an object and are what was formally called procedures or functions.

Therefore, objects contain both executable code and data (Figure 3.3). There are other characteristics of objects such as whether methods or data can be accessed from outside the object. We do not consider this here, to keep the definition simple and to apply it to what an object database is.

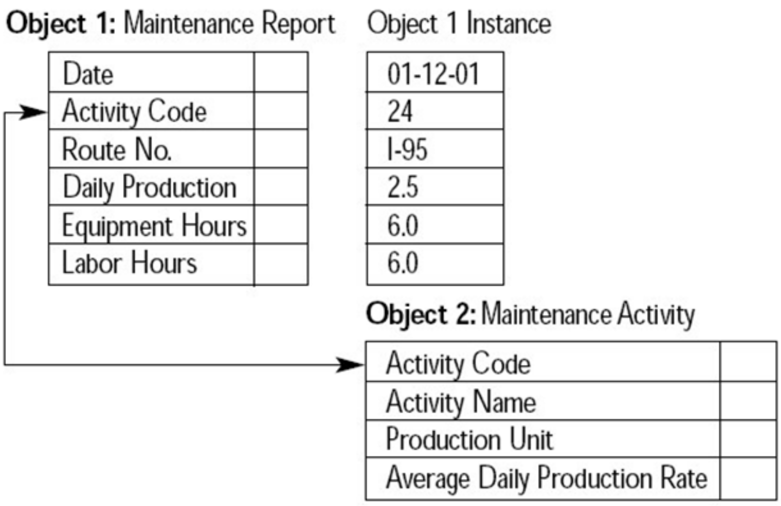


Fig. 3.3 An example of Object-Oriented database

Relational database is the last yet most important database type. A relational database is similar to a hierarchical database in that data is stored in tables and any new information is automatically added into the table without the need to reorganize the table itself. Unlike in hierarchical databases, however, a table in a relational database can have multiple parents.

Relational databases have no problems with many-to-one or many-to-many relationships. Their records are built as multiple "tables," rather than tree structures, and each record on a table has a unique identifier. A company could then have a table with the names of all the parents, a table with the names of all the children, and each record on the parent table could have a relationship with one (or more, or none) of the unique records on the child table-that relationship being "is the parent of." The ability to give records such relationships is what give relational databases their name.

An example of a relational database is shown in Figure 3.4. The first parent table shows the salespeople within a company, and the second parent table lists what product models are sold by the company. Meanwhile, the child table lists customers who have purchased models from the company; this child table is linked to the first parent table by the SalesNum and to the second parent table by the Model.

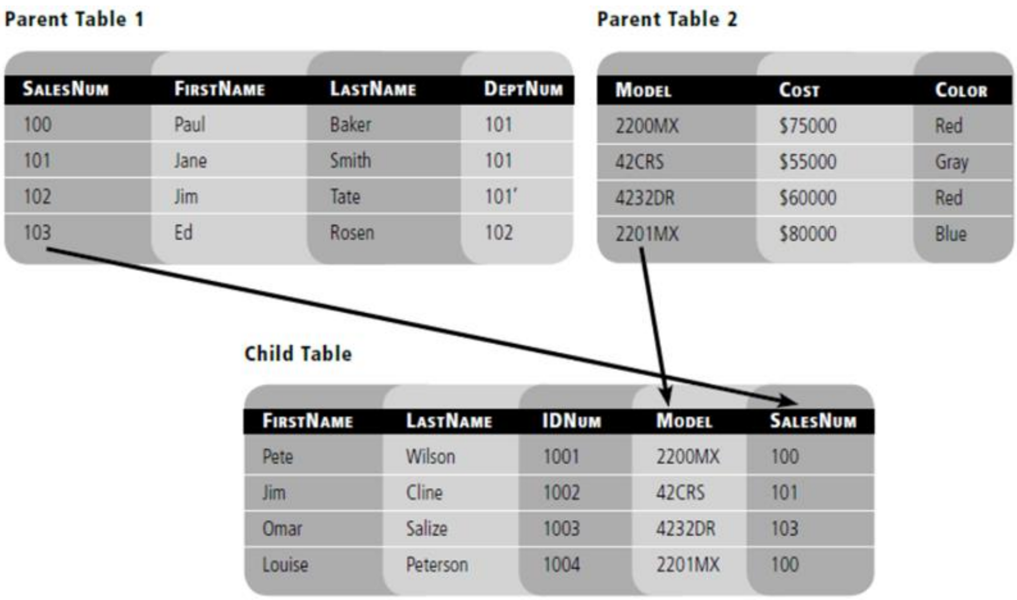


Fig. 3.4 Relational database showing two parents table and one child table

Additionally, a **database object** is any aspect of a database that you can use to manipulate or hold data. In other words, that covers a wide variety of objects - anything from a saved search to a table could be a database object. In short, almost anything except the data kept in each individual record can be considered a database object. While it may not initially be the easiest concept to fully understand, after this lesson you will not only be able to explain database objects and identify many of them, but also appreciate just why they are so important to keep organized.

Two small but important distinctions in database objects are needed:

- An object type is the base concept or idea of an object; for example, the concept of a table or index.
- An object instance is an example of an object type. For example, a table called CUSTOMER_MASTER is an instance of the object type TABLE.

Most of the major database engines offer the same set of major database object types:

- Tables
- Indexes
- Sequences
- Views
- Synonyms

Although there are subtle variations in the behaviour and the syntax used for the creation of these major database object types, they are almost identical in their concept and what they mean. A table in Oracle behaves almost exactly as a table in SQL Server. This makes work much easier for the database administrator. It is analogous to moving from one car to another made by a different manufacturer; the switches for turning the headlights on may be in different locations, but the overall layout is broadly similar.

When creating an object instance, it is a good idea to follow an easy-to-understand naming convention. This is especially important for database designers whose products are intended to be used by several people. It is also helpful to make work as simple as possible for in-house database administrators by reducing the number of queries made to the creator later. A simple guideline is to add suffixes. Here are two examples:

- Suffix all the master tables using _MASTER:
  - CUSTOMER_MASTER
  - ACCOUNTS_MASTER
  - LOANS_MASTER
- Suffix all transactional tables using the suffix _TRANS:
  - DAILY_TRANS
  - LOANS_TRANS
  - INTERBANK_TRANS

More information can be found in several web sites and some of them are given below.

https://www.techveze.com/understanding-flat-type-databases/

https://mariadb.com/kb/en/library/understanding-the-hierarchical-database-model/

https://www.techwalla.com/articles/relational-database-vs-hierarchical-database

https://study.com/academy/lesson/what-are-database-objects-definition-examples.html

https://www.techopedia.com/definition/24081/database-object

https://www.google.com/search?q=object+oriented+database+example&client=firefox-b&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiOjZ2cv_vbAhUIr6QKHVBVDTsQsAQIMw&biw=1536&bih=727#imgrc=_

3.8 Data types: numerical (discrete and continuous), categorical, and ordinal

Data Types are an important concept of statistics, which needs to be understood, to correctly apply statistical measurements to your data and therefore to correctly conclude certain assumptions about it. The different data types you need to know, to do proper exploratory data analysis (EDA) on your dataset, which is one of the most underestimated parts of a machine learning project are presented below (Fig. 3.5):

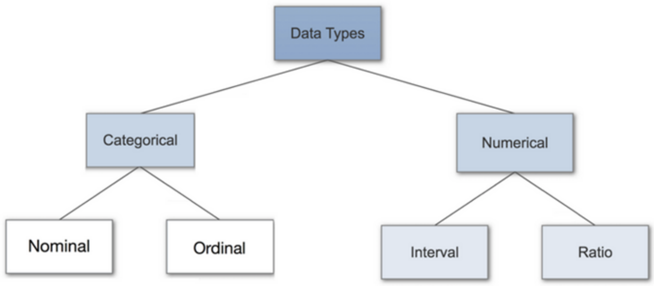


Fig. 3.5 The flowchart of data types

Numeric data have values that describe a measurable quantity as a number, like 'how many' or 'how much. Therefore, numeric variables are quantitative variables. Numeric variables may be further described as either continuous or discrete:

- A **continuous data** is a numeric variable. Observations can take any value between a certain set of real numbers. The value given to an observation for a continuous variable can include values as small as the instrument of measurement allows. Examples of continuous variables include height, time, age, and temperature.

- A **discrete data** is a numeric variable. Observations can take a value based on a count from a set of distinct whole values. A discrete variable cannot take the value of a fraction between one value and the next closest value. Examples of discrete variables include the number of registered cars, number of business locations, and number of children in a family, all of which measured as whole units (i.e. 1, 2, 3 cars).

  Discrete data may be described as either **interval** or **ratio:**

  Interval Data represent ordered units that have the same difference. Therefore, we speak of interval data when we have a variable that contains numeric values that are ordered and where we know the exact differences between the values.

Ratio Data are ordered units with intermediate values. Ratio values are the same as interval values, with the difference that they do have an absolute zero. Good examples are height, weight, length etc.

The data collected for a numeric variable are quantitative data.

Categorical data have values that describe a 'quality' or 'characteristic' of a data unit, like 'what type' or 'which category'. Categorical variables fall into mutually exclusive (in one category or in another) and exhaustive (include all possible options) categories. Therefore, categorical variables are qualitative variables and tend to be represented by a non-numeric value.

Categorical data represents characteristics. Therefore, it can represent things like a person's gender, language etc. Categorical data can also take on numerical values (Example: 1 for female and 0 for male). Note that those numbers do not have mathematical meaning.

Categorical data may be further described as **ordinal** or **nominal**:

- An **ordinal variable** is a categorical variable. Observations can take a value that can be logically ordered or ranked. The categories associated with ordinal variables can be ranked higher or lower than another, but do not necessarily establish a numeric difference between each category. Examples of ordinal categorical variables include academic grades (i.e. A, B, C), clothing size (i.e. small, medium, large, extra-large) and attitudes (i.e. strongly agree, agree, disagree, strongly disagree).

- A **nominal variable** is a categorical variable. Observations can take a value that is not able to be organised in a logical sequence. Examples of nominal categorical variables include sex, business type, eye color, religion and brand.

  The data collected for a categorical variable are qualitative data.

3.8.1 Here is the important point of researches; What are research data?

Research data are the factual pieces of information used to produce and validate research results. Data can be classified into five categories:

• **Observational:** data which are tied to time and place and are irreplaceable (e.g. field observations, weather station readings, satellite data)

• **Experimental:** data generated in a controlled or partially controlled environment which can be reproduced although it may be expensive to do so (e.g. field plots or greenhouse experiments, chemical analyses)

• **Simulation:** data generated from models (e.g. climate or population modelling)

• **Derived:** data which are not collected directly but generated from (an) other data file(s) (e.g. a population biomass which has been calculated from population density and average body size data)

• **Metadata:** data about data

Links:

https://towardsdatascience.com/data-types-in-statistics-347e152e8bee

http://www.abs.gov.au/websitedbs/a3121120.nsf/home/statistical+language+-+what+are+variables

3.9 Overview relational database management systems: database, conceptual schema, relational database design, normalization

A database is accessed through a DBMS or **database management system**. This is a specialized software that handles the storage, updating, and retrieval of data that is housed within a database. A DBMS allows you to **query** a database, which is the process that involves writing a snippet of simple code that displays or alters data in a database, matching the requirements given by the user. This is a quick way of accessing only the data you need without having to look through tables that potentially contain millions of entities.

A database management system receives instruction from a database administrator (DBA) and accordingly instructs the system to make the necessary changes. These commands can be to load, retrieve or modify existing data from the system.

A DBMS always provides data independence. Any change in storage mechanism and formats are performed without modifying the entire application. There are four main types of database organization:

- **Relational Database:** Data is organized as logically independent tables. Relationships among tables are shown through shared data. The data in one table may reference similar data in other tables, which maintains the integrity of the links among them. This feature is referred to as referential integrity – an important concept in a relational database system. Operations such as "select" and "join" can be performed on these tables. This is the most widely used system of database organization.
- **Flat Database:** Data is organized in a single kind of record with a fixed number of fields. This database type encounters more errors due to the repetitive nature of data.
- **Object-Oriented Database:** Data is organized with similarity to object-oriented programming concepts. An object consists of data and methods, while classes group objects having similar data and methods.
- **Hierarchical Database:** Data is organized with hierarchical relationships. It becomes a complex network if the one-to-many relationship is violated.

Most well-known DBMS applications fall into the RDBMS category. Examples include Oracle Database, MySQL, Microsoft SQL Server, and IBM DB2. Some of these programs support non-relational databases, but they are primarily used for relational database management.

Examples of non-relational databases include Apache HBase, IBM Domino, and Oracle NoSQL Database. These type of databases are managed by other DMBS programs that support NoSQL, which do not fall into the RDBMS category.

Another important component of DBMS is the **database schema** which represents the logical configuration of all or part of a relational database. It can exist both as a visual representation and as a set of formulas known as integrity constraints that govern a database. These formulas are expressed in a data definition language, such as SQL. As part of a data dictionary, a database schema indicates how the entities that make up the database relate to one another, including tables, views, stored procedures, and more (Figure 3.6). In addition, **Conceptual Schema** represents the entire information content of the database (Figure 3.7). Consists of multiple types of conceptual record. This level preserves the data independence of the database. Conceptual Schema defines each of the various types of conceptual record, in a conceptual Data Definition Language.

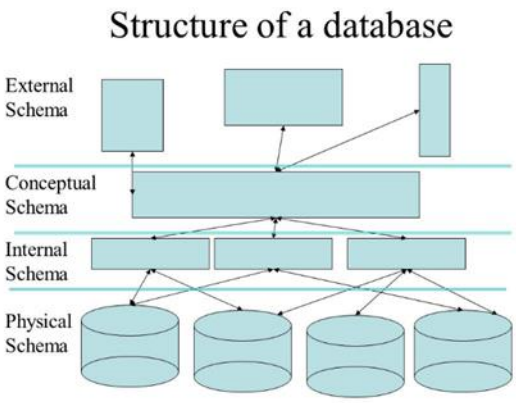


Fig. 3.6 An example for the structure of database

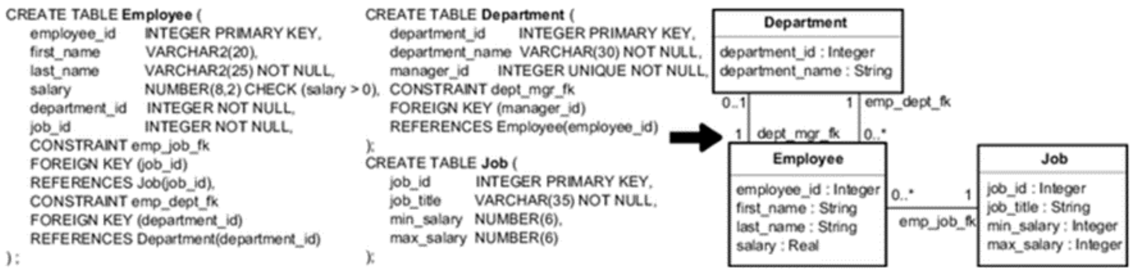


Fig. 3.7 Database schema to conceptual schema

Relational Database Design Process

Database design is more art than science, as you have to make many decisions. Databases are usually customized to suit a particular application. No two customized applications are alike, and hence, no two database are alike. Guidelines (usually in terms of what not to do instead of what to do) are provided in making these design decision, but the choices ultimately rest on you - the designer.

Step 1: Define the Purpose of the Database (Requirement Analysis)

Gather the requirements and define the objective of your database. Drafting out the sample input forms, queries and reports, often helps.

Step 2: Gather Data, Organize in tables and Specify the Primary Keys

Once you have decided on the purpose of the database, gather the data that are needed to be stored in the database. Divide the data into subject-based tables.

Choose one column (or a few columns) as the so-called *primary key*, which uniquely identify the each of the rows.

Primary Key

In the relational model, a table cannot contain duplicate rows, because that would create ambiguities in retrieval. To ensure uniqueness, each table should have a column (or a set of columns), called *primary key* that uniquely identifies every records of the table.

For example, a unique number customerID can be used as the primary key for the Customers table; productCode for Products table; isbn for Books table.

A primary key is called a *simple key* if it is a single column; it is called a *composite key* if it is made up of several columns.

Most RDBMSs build an index on the primary key to facilitate fast search and retrieval. The primary key is also used to reference other tables.

You have to decide which column(s) is to be used for primary key. The decision may not be straight forward but the primary key shall have these properties:

- The values of primary key shall be unique (i.e., no duplicate value). For example, customerName may not be appropriate to be used as the primary key for the Customers table, as there could be two customers with the same name.
- The primary key shall always have a value. In other words, it shall not contain NULL.

Consider the followings in choose the primary key:

- The primary key shall be simple and familiar, e.g., employeeID for employees table and isbn for books table.
- The value of the primary key should not change. Primary key is used to reference other tables. If you change its value, you have to change all its references; otherwise, the references will be lost. For example, phoneNumber may not be appropriate to be used as primary key for table Customers, because it might change.
- Primary key often uses integer (or number) type. But it could also be other types, such as texts. However, it is best to use numeric column as primary key for efficiency.
- Primary key could take an arbitrary number. Most RDBMSs support so-called *auto-increment* (or AutoNumber type) for integer primary key, where (current maximum value + 1) is assigned to the new record. This arbitrary number is *fact-less*, as it contains no factual information. Unlike factual information such as phone number, fact-less number is ideal for primary key, as it does not change.
- Primary key is usually a single column (e.g., customerID or productCode). But it could also make up of several columns. You should use as few columns as possible.

Step 3: Create Relationships among Tables

A database consisting of independent and unrelated tables serves little purpose (you may consider to use a spreadsheet instead). The power of relational database lies in the relationship that can be defined between tables. The most crucial aspect in designing a relational database is to identify the relationships among tables. The types of relationship include:

1. one-to-many
2. many-to-many

3. one-to-one

One-to-Many

In a "class roster" database, a teacher may teach zero or more classes, while a class is taught by one (and only one) teacher. In a "company" database, a manager manages zero or more employees, while an employee is managed by one (and only one) manager. In a "product sales" database, a customer may place many orders; while an order is placed by one particular customer. This kind of relationship is known as *one-to-many*.

One-to-many relationship cannot be represented in a single table. For example, in a "class roster" database, we may begin with a table called Teachers, which stores information about teachers (such as name, office, phone and email). To store the classes taught by each teacher, we could create columns class1, class2, class3, but faces a problem immediately on how many columns to create. On the other hand, if we begin with a table called Classes, which stores information about a class (courseCode, dayOfWeek, timeStart and timeEnd); we could create additional columns to store information about the (one) teacher (such as name, office, phone and email). However, since a teacher may teach many classes, its data would be duplicated in many rows in table Classes.

To support a one-to-many relationship, we need to design two tables: a table Classes to store information about the classes with classID as the primary key; and a table Teachers to store information about teachers with teacherIDas the primary key (Figure 3.8). We can then create the one-to-many relationship by storing the primary key of the table Teacher (i.e., teacherID) (the "one"-end or the *parent table*) in the table classes (the "many"-end or the *child table*), as illustrated below:

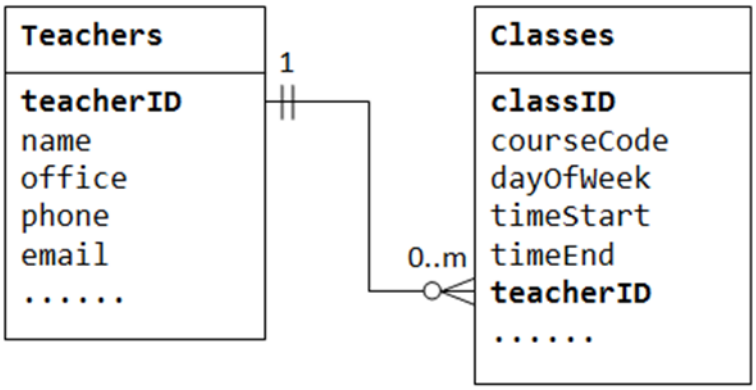


Fig. 3.8 An example for a one-to-many relationship

The column teacherID in the child table Classes is known as the *foreign key*. A foreign key of a child table is a primary key of a parent table, used to reference the parent table.

Take note that for every value in the parent table, there could be zero, one, or more rows in the child table. For every value in the child table, there is one and only one row in the parent table.

Many-to-Many

In a "product sales" database, a customer's order may contain one or more products; and a product can appear in many orders. In a "bookstore" database, a book is written by one or more authors; while an author may write zero or more books. This kind of relationship is known as *many-to-many*.

Let's illustrate with a "product sales" database. We begin with two tables: Products and Orders. The table products contains information about the products (such as name, description and quantityInStock) with productID as its primary key. The table orders contains customer's orders (customerID, dateOrdered, dateRequired and status). Again, we cannot store the items ordered inside the Orders table, as we do not know how many columns to reserve for the items. We also cannot store the order information in the Products table.

To support many-to-many relationship, we need to create a third table (known as a *junction table*), say OrderDetails (or OrderLines), where each row represents an item of a particular order (Figure 3.9). For the OrderDetails table, the primary key consists of two columns: orderID and productID that uniquely identify each row. The columns orderID and productID in OrderDetails table are used to reference Orders and Products tables, hence, they are also the foreign keys in the OrderDetails table.

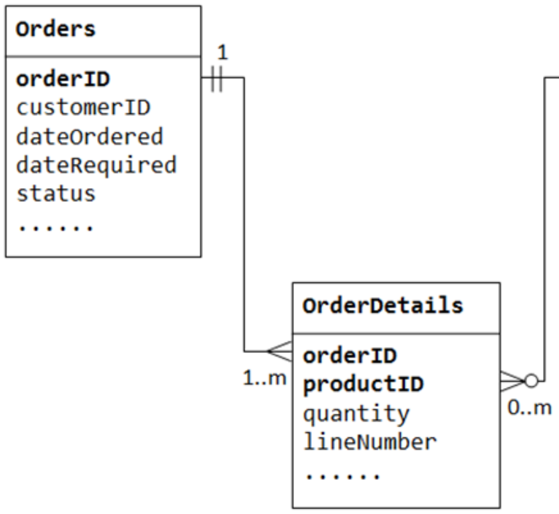


Fig. 3.9 An example for a many-to-many relationship

The many-to-many relationship is, in fact, implemented as two one-to-many relationships, with the introduction of the junction table.

1. An order has many items in OrderDetails. An OrderDetails item belongs to one particular order.
2. A product may appear in many OrderDetails. Each OrderDetails item specified one product.

One-to-One

In a "product sales" database, a product may have optional supplementary information such as image, moreDescription and comment. Keeping them inside the Products table results in many empty spaces (in those records without these optional data). Furthermore, these large data may degrade the performance of the database.

Instead, we can create another table (say ProductDetails, ProductLines or ProductExtras) to store the optional data. A record will only be created for those products with optional data. The two tables, Products and ProductDetails, exhibit a *one-to-one relationship* (Figure 3.10). That is, for every row in the parent table, there is at most one row (possibly zero) in the child table. The same column productID should be used as the primary key for both tables.

Some databases limit the number of columns that can be created inside a table. You could use a one-to-one relationship to split the data into two tables. One-to-one relationship is also useful for storing certain sensitive data in a secure table, while the non-sensitive ones in the main table.

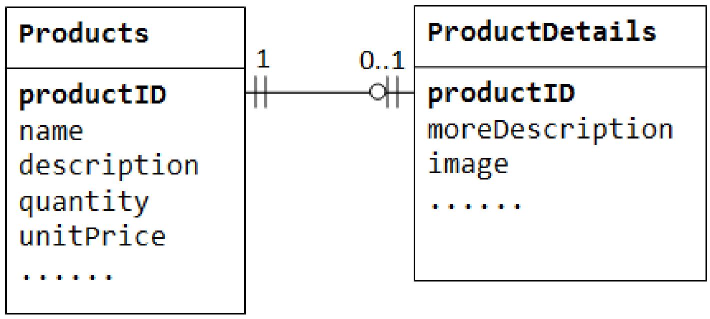


Fig. 3.10 An example of a one-to-one relationship

Column Data Types

You need to choose an appropriate data type for each column. Commonly data types include: integers, floating-point numbers, string (or text), date/time, binary, collection (such as enumeration and set).

Step 4: Refine & Normalize the Design

For example,

- adding more columns,
- create a new table for optional data using one-to-one relationship,
- split a large table into two smaller tables,
- others.

Normalization

Apply the so-called *normalization rules* to check whether your database is structurally correct and optimal.

First Normal Form (1NF): A table is 1NF if every cell contains a single value, not a list of values. This property is known as *atomic*. 1NF also prohibits repeating group of columns such as item1, item2,.., itemN. Instead, you should create another table using one-to-many relationship.

Second Normal Form (2NF): A table is 2NF, if it is 1NF and every non-key column is fully dependent on the primary key. Furthermore, if the primary key is made up of several columns, every non-key column shall depend on the entire set and not part of it.

For example, the primary key of the OrderDetails table comprising orderID and productID. If unitPrice is dependent only on productID, it shall not be kept in the OrderDetails table (but in the Products table). On the other hand, if the unitPrice is dependent on the product as well as the particular order, then it shall be kept in the OrderDetails table.

Third Normal Form (3NF): A table is 3NF, if it is 2NF and the non-key columns are independent of each other's. In other words, the non-key columns are dependent on primary key, only on the primary key and nothing else. For example, suppose that we have a Products table with columns productID (primary key), name and unitPrice. The column discountRate shall not belong to Products table if it is also dependent on the unitPrice, which is not part of the primary key.

Higher Normal Form: 3NF has its inadequacies, which leads to higher Normal form, such as Boyce/Codd Normal form, Fourth Normal Form (4NF) and Fifth Normal Form (5NF), which is beyond the scope of this tutorial.

At times, you may decide to break some of the normalization rules, for performance reason (e.g., create a column called totalPrice in Orders table which can be derived from the orderDetails records); or because the end-user requested for it. Make sure that you fully aware of it, develop programming logic to handle it, and properly document the decision.

Integrity Rules

You should also apply the integrity rules to check the integrity of your design:

Entity Integrity Rule: The primary key cannot contain NULL. Otherwise, it cannot uniquely identify the row. For composite key made up of several columns, none of the column can contain NULL. Most of the RDBMS check and enforce this rule.

Referential Integrity Rule: Each foreign key value must be matched to a primary key value in the table referenced (or parent table).

- You can insert a row with a foreign key in the child table only if the value exists in the parent table.
- If the value of the key changes in the parent table (e.g., the row updated or deleted), all rows with this foreign key in the child table(s) must be handled accordingly. You could either (a) disallow the changes; (b) cascade the change (or delete the records) in the child tables accordingly; (c) set the key value in the child tables to NULL.

Most RDBMS can be setup to perform the check and ensure the referential integrity, in the specified manner.

Business logic Integrity: Beside the above two general integrity rules, there could be integrity (validation) pertaining to the business logic, e.g., zip code shall be 5-digit within a certain range, delivery date and time shall fall in the business hours; quantity ordered shall be equal or less than quantity in stock, etc. These could be carried out in validation rule (for the specific column) or programming logic.

Column Indexing

You could create *index* on selected column(s) to facilitate data searching and retrieval. An index is a structured file that speeds up data access for SELECT, but may slow down INSERT, UPDATE, and DELETE. Without an index structure, to process a SELECT query with a matching criterion (e.g., SELECT * FROM Customers WHERE name='Tan Ah Teck'), the database engine needs to compare every records in the table. A specialized index (e.g., in BTREE structure) could reach the record without comparing every records. However, the index needs to be rebuilt whenever a record is changed, which results in overhead associated with using indexes.

Index can be defined on a single column, a set of columns (called concatenated index), or part of a column (e.g., first 10 characters of a VARCHAR(100)) (called partial index) . You could built more than one index in a table. For example, if you often search for a customer using either customerName or phoneNumber, you could speed up the search by building an index on column customerName, as well as phoneNumber. Most RDBMS builds index on the primary key automatically.

Links:

https://study.com/academy/lesson/database-terminology.html

https://techterms.com/definition/rdbms

https://www.techopedia.com/definition/24361/database-management-systems-dbms

https://slideplayer.com/slide/5333132/

http://www3.ntu.edu.sg/home/ehchua/programming/sql/relational_database_design.html

Database design basics (Microsoft Access 2007)", available at

http://office.microsoft.com/en-us/access/HA012242471033.aspx.

Paul Litwin, "Fundamentals of Relational Database Design", available at

http://www.deeptraining.com/litwin/dbdesign/FundamentalsOfRelationalDatabaseDesign.aspx.

Codd E. F., "A Relational Model of Data for Large Shared Data Banks", Communications of the ACM, vol. 13, issue 6, pp. 377–387, June 1970.

https://www.researchgate.net/publication/259590709_Extracting_UMLOCL_Integrity_Constraints_and_Derived_Types_from_Relational_Databases/Fig.s?lo=1

http://www.informit.com/articles/article.aspx?p=761837&seqNum=2

3.10 Determination of appropriate experimental design for specific data collection

A key challenge facing researchers today is the need to work with different data sources. It is not uncommon now for projects to integrate any combination of data types into a single analysis, even drawing on data from disciplines outside ecology and evolution. As research becomes increasingly collaborative and interdisciplinary, this issue will grow in prevalence.

3.10.1 Creating data

In the data lifecycle (Figure 3.11) creating datasets occurs as a researcher collects data in the field or lab, and digitizes them to end up with a raw dataset. Quality control during data collection is important because often there is only one opportunity to collect data from a given situation. Researchers should be critical of methods before collection begins – high-quality methods will result in high-quality data. Likewise, when collection is under way, detailed documentation of the collection process should be kept as evidence of quality.

Fig. 3.11 The data lifecycle

Research design is a comprehensive plan for data collection in an empirical research project. It is a "blueprint" for empirical research aimed at answering specific research questions or testing specific hypotheses, and must specify at least three processes: (1) the data collection process, (2) the instrument development process, and (3) the sampling process.

1) Collecting Data

We will focus on four methods for collecting data: Observational studies, experiments, simulations, and surveys.

• In an **observational study,** a researcher measures and observes the variables of interest without changing existing conditions.

• In an **experiment**, a researcher assigns a **treatment** and observes the **response**. Sometimes, a **control group** (a group receiving no treatment or a placebo) may be used to compare the effectiveness of a treatment.

• A **simulation** uses a mathematical, physical, or computer model to replicate the conditions of a process or situation. This is frequently used when the actual situation is too expensive, dangerous, or impractical to replicate in real life.

• A **survey** is used to investigate characteristics of a population. It is frequently used when the subjects are people, and questions are asked of them. When designing a survey, you must be very careful of wording (and sometimes ordering) the questions so that the results are not biased.

Key things to consider during data collection:

• logistical issues in the field

• calibration of instruments

• taking multiple measurements/observations/samples

• creating a template for use during data collection to ensure that all information is collected consistently, especially if there are multiple collectors

• describing any conditions during data collection that might affect the quality of the data

• creating an accompanying questionnaire for multiple collectors, asking them any questions which may affect the quality of the data

• widening the possible applications of data, and therefore increasing their impact, by adding variables and parameters to data, e.g. wider landscape variables, which will encourage reuse and potentially open up new avenues for research.

2) Experimental Design

Definitions and Terminology

• A **confounding variable** occurs when an experimenter cannot tell the difference between the effects of different factors on a variable.

• The **placebo effect** occurs when a subject (or "experimental unit") reacts favourably to a placebo when no medicated treatment has been given.

• **Blinding** is a technique used to make the subjects "blind" to which treatment (or placebo) they are being given.

• A **double-blind** experiment is one in which neither the experimenter nor the subjects know which treatment is being given.

• **Randomization** is a process of randomly assigning subjects to treatment groups. There are several different techniques for randomization:

– A **completely randomized design** assigns subjects to different treatment groups through random assignment.

– A **randomized block design** is sometimes used to make sure that subjects with certain characteristics are assigned to each treatment. For example, when testing a certain medication, you might first want to split subjects in groups according to either gender or age (or both), then randomly assign each of these groups to the different treatments.

• A **matched pairs design** pairs up subjects according to similarities. One subject in the pair receives one treatment, while the other receives a different treatment.

• **Sample size** is the number of participants in the experiment. The larger the sample, the more representative of the population the results will be, but the costs of the experiment will also be higher.

• **Replication** is the ability to reproduce the experiment (and results) under similar conditions.

3) Sampling Techniques

Ideally, that is, use every member of a population as a subject since the descriptive statistics would be sufficient. However, this is often too costly and difficult. Instead, we sample part of the population. With sampling, we need to make sure that the sample is representative of the population and large enough to be meaningful.

Definitions and Terminology

• A **sampling error** is the difference between the results of the sample and those of the population. Even with the best sampling techniques, this is possible.

• A **biased sample** is one that is not representative of the entire population. We want to avoid bias.

• A **random sample** is one in which every member of the population has an equal chance of being chosen.

• A **simple random** sample (SRS) is a sample in which every possible sample of the same size has the same chance of being collected. Normally, we will start by using a simple random sample.

• A **stratified sample** is used when it is important to have members from multiple segments of the population. First, the population is split into segments (called "strata"), then a predetermined number of subjects is chosen from each of the strata.

• **Cluster sampling** can be used when the population naturally falls into subgroups with similar characteristics. First, determine the clusters, then select all the members of one or more of the clusters.

• **Systematic sampling** first involves assigning a number to each member of the population and ordering them in some way. Sample members are selected by choosing the first member randomly, then selecting subsequent members at regular intervals after the starting number (for example, every 7th person). This method is fairly simple to use, but should be avoided if there are regularly occurring patterns in the data.

• A **convenience sample** consists only of available members of the population, but this often leads to biased studies.

• A **volunteer sample** is a kind of convenience sample in which only volunteers participate.

Links:

http://www.math.utah.edu/~anna/Sum12/LessonPlans/Section13.pdf

3.10.2 Digitizing data

Data may be collected directly in a digital form using devices that feed results straight into a computer or they may be collected as hand-written notes. Either way, there will be some level of processing involved to end up with a digital raw dataset.

Key things to consider during data digitization include:

• designing a database structure to organize data and data files

• using a consistent format for each data file – e.g. one row represents a complete record and the columns represent all the parameters that make up that record (this is known as spreadsheet format)

• atomizing data – make sure that only one piece of data is in each entry

• using plain text characters (e.g. ASCII, Unicode) to ensure data are readable by a maximum number of software programmes

• using code – coding assigns a numerical value to variables and allows for statistical analysis of data. Keep coding simple

• describing the contents of your data files in a 'readme.txt' file, or other metadata standard, including a definition of each parameter, the units used and codes for missing values

• keeping raw data raw

3.10.3 Processing data

Data should be processed into a format that is suited to subsequent analyses and ensures long-term usability. Data are at risk of being lost if the hardware and software originally used to create and process them are rendered obsolete. Therefore, data should be well organized, structured, named and versioned in standard formats that can be interpreted in the future.

Digital information can be altered very easily, so it is important to be transparent in all aspects of processing that have taken place. Careful documentation and using a script will help demonstrate the authenticity of the data.

File formats: Data should be written in non-proprietary formats, also known as open standard formats, as far as possible. These files can be used and implemented by anyone, as opposed to proprietary formats which can only be used by those with the correct software installed. The most common format used for spreadsheet data are comma-separated values files (.csv). Other non-proprietary formats include: plain text files (.txt) for text; and GIF, JPEG and PNG for images.

Filenames and folders: To keep track of data and know how to find them, digital files and folders should be structured and well organized – this is particularly important when working in collaboration. Use a folder hierarchy that fits the structure of the project (e.g. grouping according to who collected data is only relevant to the collectors, not to those using the data for other things – grouping by data or site may be more relevant) and ensure that it is used consistently. Drawing a folder map which details where specific data are saved may be particularly useful if others will be accessing folders, or if there is simply a lot to navigate.

Filenames should be unique, descriptive, succinct, naturally ordered and consistent. Ideally they should describe the project, file contents, location, date, researcher's initials and version. Computers will add basic properties to a file, such as dates and file type, but relying on these is not best data management practice. Do not use spaces in filenames – these can cause problems with scripting and metadata.

Quality assurance: Checking that data have been edited, cleaned, verified and validated to create a reliable masterfile which will become the basis for further analyses. Use a scripting language, such as R, to process your data for quality checking so that all steps are documented.

Assurance checks may include:

• identifying estimated values, missing values or double entries

• performing statistical analyses to check for questionable or impossible values and outliers (which may just be typos from data entry)

• checking the format of the data for consistency across the dataset

• checking the data against similar data to identify potential problems

Version control: Once the masterfile has been finalized, keeping track of ensuing versions of this file can be challenging, especially if working with collaborators in different locations. A version control strategy will help locate required versions, and clarify how versions differ from one another.

Version control best practice includes:

• deciding how many and which versions to keep

• using a systematic file naming convention, using filenames that include the version number and status of the file, e.g. v1_draft, v2_internal, v3_final

• record what changes took place to create the version in a separate file, e.g. a version table

• mapping versions if they are stored in different locations

• synchronizing versions across different locations

• ensuring any cross-referenced information between files is also subject to version control

3.10.4 Documenting data

Producing good documentation and metadata ensures that data can be understood and used in the long term. Documentation describes the data, explains any manipulations and provides contextual information – no room should be left for others to misinterpret the data. All documentation requirements should be identified at the planning stages so you are prepared for it during all stages of the data lifecycle, particularly during data creation and processing. This will avoid having to perform a rescue mission in situations where you have forgotten what has happened or when a collaborator has left without leaving any key documentation behind.

Data documentation includes information at project and data levels and should cover the following:

<u>Project level</u>

• the project aim, objectives and hypotheses

• personnel involved throughout the project, including who to contact with

questions

• details of sponsors

• data collection methods, including details of instrumentation

and environmental conditions during collection, copies of collection

instructions if applicable

• standards used

• data structure and organisation of files

• software used to prepare and read the data

• procedures used for data processing, including quality control and versioning

and the dates these were carried out

• known problems that may limit data use

• instructions on how to cite the data

• intellectual property rights and other licensing considerations

<u>Data level</u>

• names, labels and descriptions for variables

• detailed explanation of codes used

• definitions of acronyms or specialist terminology

• reasons for missing values

• derived data created from the raw file, including the code or algorithm used to create them

If a software package such as R is used for processing data, much of the data level documentation will be created and embedded during analysis.

Metadata help others discover data through searching and browsing online and enable machine-to-machine interoperability of data, which is necessary for data reuse. Metadata are created by using either a data centre's deposit form, a metadata editor, or a metadata creator tool, which can be searched for online. Metadata follow a standard structure and come in three forms:

• descriptive – fields such as title, author, abstract and keywords

• administrative – rights and permissions and data on formatting

• structural – explanations of e.g. tables within the data

3.10.5 Preserving data

To protect data from loss and to make sure data are securely stored, good data management should include a strategy for backing up and storing data effectively. It is recommended to keep three versions of your data: the original, external/local and external/remote.

Institutional policies: These will be in place to regulate methods of data preservation and should be adhered to. Determining a backup and storage procedure will depend on the availability of resources at the institution.

Backup: When designing a backup strategy, thought should be given to the possible means by which data loss could occur. These include:

• hardware failure

• software faults

• virus infection or hacking

• power failure

• human error

• hardware theft or misplacement

• hardware damage (e.g. fire, flood)

• backups – good backups being overwritten with backups from corrupt data

The likelihood of each of these will be different, and it may be environment specific (e.g. data being collected in the field may be subject to different risks than data being used across a multi-institutional research team). An ideal backup strategy should provide protection against all the risks, but it can be sensible to consider which are the most likely to occur in any particular context and be aware of these when designing your backup strategy.

Things to consider when drawing up a backup strategy include:

• which files require backup

• who is responsible for backups

• the frequency of backup needed, this will be affected by how regularly files are updated

• whether full or incremental backups are needed – consider running a mix of frequent incremental backups (capturing recent data changes) along with periodic full backups (capturing a 'snapshot' of the state of all files)

• backup procedures for each location where data are held, e.g. tablets, home-based computers or remote drives

• how to organize and label backup files

Data storage: Data storage, whether of the original or backed up data, needs to be robust. This is true whether the data are stored on paper or electronically, but electronic storage raises particular issues. Best practice for electronic storage of data is to do the following:

• use high-quality storage systems (e.g. media, devices)

• use non-proprietary formats for long-term software readability

• migrate data files every two to five years to new storage – storage media such as CDs, DVDs and hard drives can degrade over time or become outdated (e.g. floppy disks)

• check stored data regularly to make sure nothing has been lost

• use different forms of storage for the same data, this also acts as a method of backup, e.g. using remote storage, external hard drives and a network drive

• label and organize stored files logically to make them easy to locate and access

• think about encryption: sensitive data may be regarded as protected while on a password-protected computer, but when backed up onto a portable hard drive they may become accessible to anyone – backups may need to be encrypted or secured too

Data can be stored and backed up on:

• **Network drives** which are managed by IT staff and are regularly backed up. They ensure secure storage and prohibit unauthorized access to files.

• **Personal devices** such as laptops and tablets are convenient for short-term, temporary storage but should not be used for storing master files. They are at high risk of being lost, stolen or damaged.

• **External devices** such as hard drives, USB sticks, CDs and DVDs are often convenient because of their cost and portability. However, they do not guarantee long-term preservation and can also be lost, stolen or damaged. High-quality external devices from reputable manufacturers should be used.

• **Remote or online services** such as Dropbox, Mozy and A-Drive use cloud technology to allow users to synchronize files across different computers. They provide some storage space for free but any extra space or functions will have to be bought.

• **Paper!** If data files are not too big, do not overlook the idea of printing out a paper copy of important ones as a complement to electronic storage. It may not be convenient, but ink on paper has proven longevity and system independence (as long as you can remember where you put it)!

3.10.6 Sharing data

Research data can be shared in many ways and each method of sharing will have advantages and disadvantages. Ways to share data include:

- using a disciplinary data centre such as Dryad or GenBank
- depositing data in your research funder's data centre
- depositing data in university repositories
- making data available online via open notebooks or project websites
- using virtual research environments such as SharePoint and Sakai

The BES data archiving policy, which mandates that all data used to support the results in papers published in its journals be archived in a suitable repository that provides 'comparable access and guarantee of preservation'4, encourages authors to pick a repository best suited to their type of data and is most useful to the community most likely to access their data.

Data repositories: Archiving your data in a repository is a reliable method of sharing data. Data submitted to repositories will have to conform to submission guidelines, which may restrict which data you share via the repository. However, the advantages of sharing data through these centres include:

- assurance for others that the data meet quality standards
- guaranteed long-term preservation
- data are secure and access can be controlled
- data are regularly backed up
- chances of others discovering the data are improved
- citation methods are specified
- secondary usage of the data is monitored

Longitudinal datasets that span many years are important in ecology and evolution. Journals mandating that authors archive their data only guarantees the preservation of the data used in a particular paper, but researchers should be aware of the value of archiving and sharing large datasets to drive discovery. Sharing large datasets has not been common practice in fields such as ecology. However, as trust in ethical guidelines and the community's expectations with regards to accessing and correctly citing others' data grow, progress can be made towards a more open access data future.

3.10.7 Reusing data

All aspects of data management lead up to data discovery and reuse by others. Intellectual property rights, licenses and permissions, which concern reuse of data, should be explained in the data documentation and/or metadata. At this stage of the lifecycle it is important to state your expectations for the reuse of your data, e.g. terms of acknowledgement, citation and co-authorship. Likewise, it becomes the responsibility of others to reuse data effectively, credit the collectors of the original data, cite the original data and manage any subsequent research to the same effect.

When requesting to use someone else's data it is important to clearly state the purpose of the request, including the idea you will be addressing and your expectations for co-authorship or acknowledgement.

Co-authorship is a complex issue and should be discussed with any collaborators at the outset of a project.

Increasing openness to data and ensuring long-term preservation of data fosters collaboration and transparency, furthering research that aims to answer the big questions in ecology and evolution. By implementing good data management practices, researchers can ensure that high-quality data are preserved for the research community and will play a role in advancing science for future generations.

Article: "A Guide to Data Management in Ecology and Evolution".

https://www.britishecologicalsociety.org/wp-content/uploads/Publ_Data-Management-Booklet.pdf

3.11 Understand the foundations of structured query language: querying, table relationships and joins

Databases are often found on database servers so that they can be accessed by multiple users and provide a high level of performance. One popular database server is Microsoft SQL Server. Structured Query Language (SQL) is the language of databases. It can be used to access and manipulate information. Commands form the basis of the language, and through these commands you can perform various operations meant to view, organize, and transform the information stored within. SQL was initially developed by IBM in the early 1970's, and released by Oracle in 1979. It has gone on to garner global acceptance and was subsequently standardized by the American National Standards Institute (ANSI), and a few years after that, the International Organization of Standardization (ISO). Nowadays, many companies use it, and a select few offer it as a product. Among those are Oracle, IBM, SyBase, Postgres, and Microsoft.

Database servers like SQL Server do not actually house graphical programs, word-processing applications, or any other type of applications. Instead, these servers are entirely optimized to serve only the purposes of the database itself, usually using advanced hardware that can handle the high processing needs of the database. It is also important to note that these servers do not act as workstations; they generally are mounted on racks located in a central data centre and can be accessed only through an administrator's desktop system.

Microsoft SQL Server uses three types of files to store databases. Primary data files, which have an .mdf extension, are the first files created in a database and can contain user-defined objects, such as tables and views, as well as system tables that SQL Server requires for keeping track of the database. If the database becomes too large and you run out of room on your first hard disk, you can create secondary data files, which have an .ndf extension, on separate physical hard disks. The third type of file used in SQL Server is a transaction log file. Transaction log files use an .ldf extension and don't contain objects such as tables or views. Most users do not access a database directly. Instead, they use a database management system (DBMS) to access it indirectly. A DBMS is a collection of programs that enables you to enter, organize, and select data in a database. For example, a ticket agent may run a ticket system program on his or her desk computer that in turn accesses a ticketing database.

3.11.1 SQL Server Management Studio (SSMS)

The central future of SSMS is the object explorer which allows the user to browse, select and manage any of any of the objects within the server (Figure 3.12).

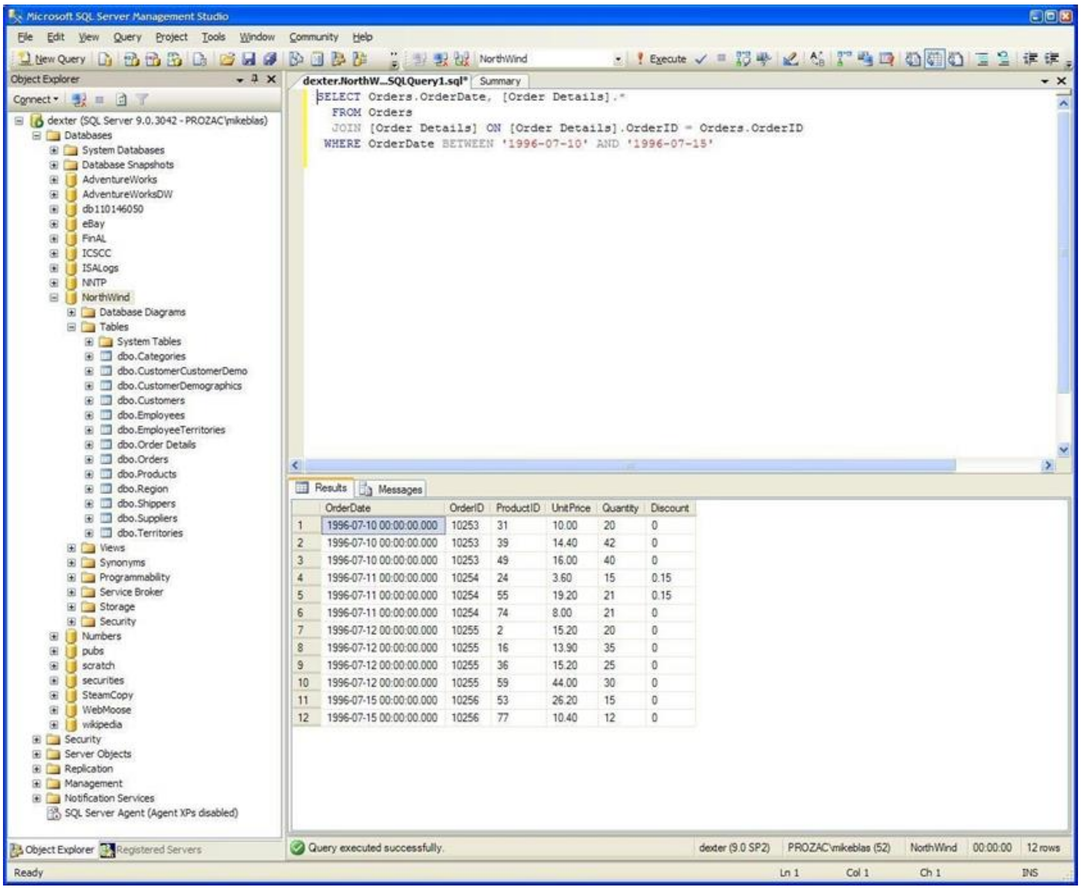


Fig. 3.12 An example of SQL Server Management Studio page

3.11.2 Data Manipulation Language

A data manipulation language (DML) is a family of computer languages including commands permitting users to manipulate data in a database. This manipulation involves inserting data into database tables, retrieving existing data, deleting data from existing tables and modifying existing data. DML is mostly incorporated in SQL databases.

DML resembles simple English language and enhances efficient user interaction with the system. The functional capability of DML is organized in manipulation commands like SELECT, UPDATE, INSERT INTO and DELETE FROM, as described below in Figure 3.13:

- **SELECT:** This command is used to retrieve rows from a table. The syntax is SELECT [column name(s)] from [table name] where [conditions]. SELECT is the most widely used DML command in SQL.

- **UPDATE:** This command modifies data of one or more records. An update command syntax is UPDATE [table name] SET [column name = value] where [condition].

- **INSERT:** This command adds one or more records to a database table. The insert command syntax is INSERT INTO [table name] [column(s)] VALUES [value(s)].
- **DELETE:** This command removes one or more records from a table according to specified conditions. Delete command syntax is DELETE FROM [table name] where [condition].

UPDATE statements

These statements are used to update (change) data.

Example:

UPDATE employees SET first_name = " Ali "

This will update all the rows in the employees table setting the "first_name" to " *Ali* "

Fig. 3.13 An example for Data Manipulation Language (DML)

3.11.3 Data Definition Language (DDL)

A data definition language (DDL) is a computer language used to create and modify the structure of database objects in a database. These database objects include views, schemas, tables, indexes, etc. This term is also known as data description language in some contexts, as it describes the fields and records in a database table. However, it is considered to be a subset of SQL (Structured Query Language). SQL often uses imperative verbs with normal English such as sentences to implement database modifications. Hence, DDL does not show up as a different language in an SQL database, but does define changes in the database schema.

Commonly used DDL in SQL querying are (Figure 3.14):

- **CREATE:** This command builds a new table and has a predefined syntax. The CREATE statement syntax is CREATE TABLE [table name] ([column definitions]) [table parameters]. CREATE TABLE Employee (Employee Id INTEGER PRIMARY KEY, First name CHAR (50) NULL, Last name CHAR (75) NOT NULL).

- **ALTER:** An alter command modifies an existing database table. This command can add up additional column, drop existing columns and even change the data type of columns involved in a database table. An alter command syntax is ALTER object type object name parameters. ALTER TABLE Employee ADD DOB Date.

- **DROP:** A drop command deletes a table, index or view. Drop statement syntax is DROP object type object name. DROP TABLE Employee.

```
` DDL

Begin SQL
    CREATE TABLE ACTOR_FANS
     (ID INT32,
     Name VARCHAR);

     INSERT INTO ACTOR_FANS
      (ID, Name)
      VALUES(1, 'Francis');

     ALTER TABLE ACTOR_FANS
      ADD Phone_Number VARCHAR;

     INSERT INTO ACTOR_FANS
      (ID, Name, Phone_Number)
      VALUES (2, 'Florence', '01446677888');
End SQL
```

Fig. 3.14 An example for Data Definition Language (DDL)

3.11.4 Table Relationships and Joins

The majority of databases worked with as a developer will have more than one table, and those tables will be connected together in various ways to form table relationships. So that, exploring the reasons for having multiple tables in a database, looking at how to define relationships between different tables, and outline the different types of table relationships that can exist were explained below:

The entity relationships described above can be classified into three relationship types:

- One to One
- One to Many
- Many to Many

To describe the relationships, we need to model between the entities:

1. A User can have **ONE** address. An address has only **ONE** user.
2. A review can only be about **ONE** Book. A Book can have **MANY** reviews.
3. A User can have **MANY** books that he/she may have checked out or returned. A Book can be/ have been checked out by **MANY** users.

A **one-to-one** relationship between two entities exists when a particular entity instance exists in one table, and it can have only one associated entity instance in another table.

Example: A user can have only one address, and an address belongs to only one user.

In the database world, this sort of relationship is implemented like this: the id that is the PRIMARY KEY of the users table is used as both the FOREIGN KEY *and* PRIMARY KEY of the addresses table (Figure 3.15).

```
/*
one to one: User has one address
*/

CREATE TABLE addresses (
  user_id int, -- Both a primary and foreign key
  street varchar(30) NOT NULL,
  city varchar(30) NOT NULL,
  state varchar(30) NOT NULL,
  PRIMARY KEY (user_id),
  FOREIGN KEY (user_id) REFERENCES users (id) ON DELETE CAS
);
```

Fig. 3.15 An example of SQL statement

Executing the above SQL statement will create an addresses table, and create a relationship between it and the users table. Notice the PRIMARY KEY and FOREIGN KEY clauses at the end of the CREATE statement. These two clauses create the constraints that makes the user_id the Primary Key of the addresses table and also the Foreign Key for the users table (Figure 3.16).

```
INSERT INTO addresses (user_id, street, city, state) VALUES
  (1, '1 Market Street', 'San Francisco', 'CA'),
  (2, '2 Elm Street', 'San Francisco', 'CA'),
  (3, '3 Main Street', 'Boston', 'MA');
```

Fig. 3.16 An example of SQL statement for connecting tables

The user_id column uses values that exist in the id column of the users table in order to connect the tables through the foreign key constraint we just created (Figure 3.17).

users

id (PK)	full_name	enabled	last_login
1	John Smith	f	2017-10-25 10:26:10.015152
2	Alice Walker	t	2017-10-25 10:26:50.295461
3	Harry Potter	t	2017-10-25 10:26:50.295461
5	Jane Smith	t	2017-10-25 10:36:43.324015

addresses

user_id (PK) (FK)	street	city	state
1	1 Market Street	San Francisco	CA
2	2 Elm Street	San Francisco	CA
3	3 Main Street	Boston	MA

Fig. 3.17 An example of SQL statement for the foreign key constraint

One-to-Many

A one-to-many relationship exists between two entities if an entity instance in one of the tables can be associated with multiple records (entity instances) in the other table.

Example: A book has many reviews. A review belongs to only one book (Figure 3.18).

```
CREATE TABLE books (
  id serial,
  title varchar(100) NOT NULL,
  author varchar(100) NOT NULL,
  published_date timestamp NOT NULL,
  isbn char(12),
  PRIMARY KEY (id),
  UNIQUE (isbn)
);

/*
 one to many: Book has many reviews
*/

CREATE TABLE reviews (
  id serial,
  book_id integer NOT NULL,
  reviewer_name varchar(255),
  content varchar(255),
  rating integer,
  published_date timestamp DEFAULT CURRENT_TIMESTAMP,
  PRIMARY KEY (id),
  FOREIGN KEY (book_id) REFERENCES books(id) ON DELETE CASC
);
```

Fig. 3.18 Creating tables for one-to-many relationship

These table creation statements for our books and reviews tables are fairly similar to our previous example. There's a key difference worth pointing out in the statement for our reviews table however:

- Unlike our addresses table, the PRIMARY KEY and FOREIGN KEY reference different columns, id and book_id respectively. This means that the FOREIGN KEY column, book_id is not bound by the UNIQUE constraint of our PRIMARY KEY and so the same value from the id column of the books table can appear in this column more than once. In other words, a book can have many reviews.

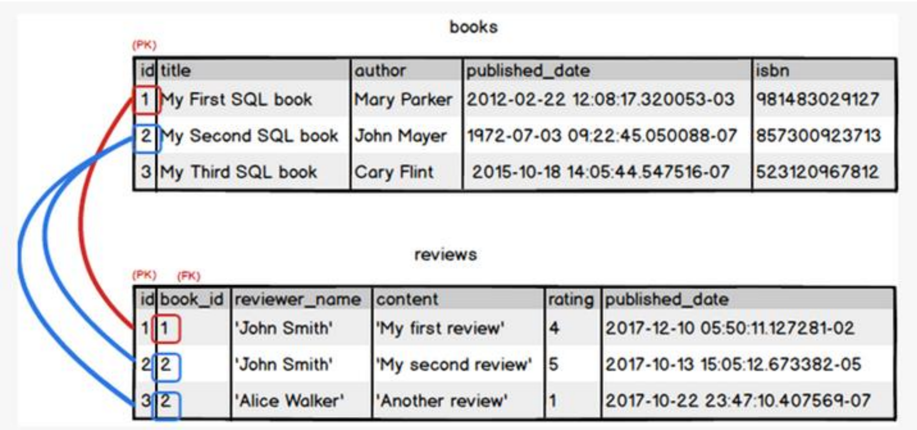
The order in which we add the data is important here. Since a column in reviews references data in books we must first ensure that the data exists in the books table for us to reference (Figure 3.19).

```
INSERT INTO books (id, title, author, published_date, isbn)
  (1, 'My First SQL Book', 'Mary Parker', '2012-02-22 12:08
  (2, 'My Second SQL Book', 'John Mayer', '1972-07-03 09:22
  (3, 'My First SQL Book', 'Cary Flint', '2015-10-18 14:05


INSERT INTO reviews (id, book_id, reviewer_name, content, r
  (1, 1, 'John Smith', 'My first review', 4, '2017-12-10 05
  (2, 2, 'John Smith', 'My second review', 5, '2017-10-13 1
  (3, 2, 'Alice Walker', 'Another review', 1, '2017-10-22 2
```

Fig. 3.19 Adding some more data to tables

Just as with the users/addresses relationship, the FOREIGN KEY references creates relationships between the reviews table and the books table (Figure 3.20). Unlike that users/ addresses relationship however, both books and users can have multiple review. For example, the id value of 2 for My Second SQL Book appears twice in the book_id column of the reviews table. In a real database our reviews table would probably also have a Foreign Key reference to the id column in users table rather than have user type data directly in a reviewer_name column.


books (PK)

id	title	author	published_date	isbn
1	My First SQL book	Mary Parker	2012-02-22 12:08:17.320053-03	981483029127
2	My Second SQL book	John Mayer	1972-07-03 09:22:45.050088-07	857300923713
3	My Third SQL book	Cary Flint	2015-10-18 14:05:44.547516-07	523120967812

reviews (PK) (FK)

id	book_id	reviewer_name	content	rating	published_date
1	1	'John Smith'	'My first review'	4	2017-12-10 05:50:11.127281-02
2	2	'John Smith'	'My second review'	5	2017-10-13 15:05:12.673382-05
3	2	'Alice Walker'	'Another review'	1	2017-10-22 23:47:10.407569-07

Fig. 3.20 An example of creating relationships between the reviews table and the books table

Many-to-Many

A many-to-many relationship exists between two entities if for one entity instance there may be multiple records in the other table, and vice versa.

Example: A user can check out many books. A book can be checked out by many users (over time).

In order to implement this sort of relationship we need to introduce a third, cross-reference table. This table holds the relationship between the two entities, by having **two** FOREIGN KEYs, each of which references the **PRIMARY KEY** of one of the tables for which we want to create this relationship (Figure

3.21). We already have our books and users tables, so we just need to create the cross-reference table: checkouts.

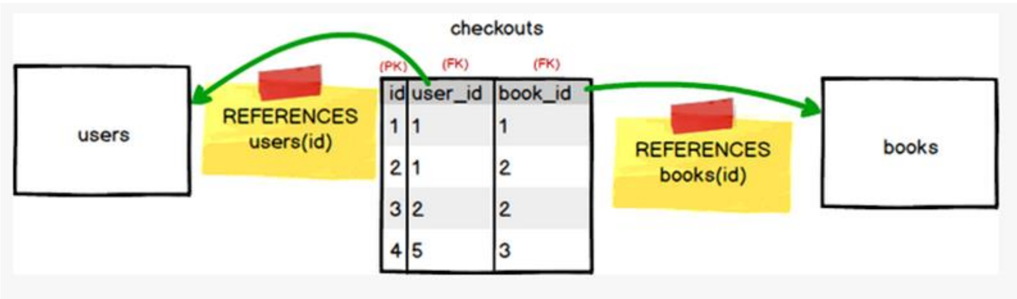


Fig. 3.21 An example of the cross-reference table

Here, the user_id column in checkouts references the id column in users, and the book_id column in checkouts references the id column in books. Each row of the checkouts table uses these two Foreign Keys to create an association between rows of users and books.

We can see on the first row of checkouts, the user with an id of 1 is associated with the book with an id of 1. On the second row, the same user is also associated with the book with an id of 2. On the third row a different user, with and id of 2, is associated with the same book from the previous row. On the fourth row, the user with an id of 5 is associated with the book with an id of 3. Create our checkouts table and add some data to it (Figure 3.22).

```
CREATE TABLE checkouts (
  id serial,
  user_id int NOT NULL,
  book_id int NOT NULL,
  checkout_date timestamp,
  return_date timestamp,
  PRIMARY KEY (id),
  FOREIGN KEY (user_id) REFERENCES users(id) ON DELETE CASC
  FOREIGN KEY (book_id) REFERENCES books(id) ON DELETE CASC
);
```

Fig. 3.22 Creating checkouts' table

Now that we have our checkouts created, we can add the data that will create the associations between the rows in users and books (Figure 3.23).

```
INSERT INTO checkouts (id, user_id, book_id, checkout_date
  (1, 1, 1, '2017-10-15 14:43:18.095143-07', NULL),
  (2, 1, 2, '2017-10-05 16:22:44.593188-07', '2017-10-13 1
  (3, 2, 2, '2017-10-15 11:11:24.994973-07', '2017-10-22 1
  (4, 5, 3, '2017-10-15 09:27:07.215217-07', NULL);
```

Fig. 3.23 Inserting the data to create the relation between users and books

When checking the beginning data, it looks like in terms of the relationships between the tables in Fig. 3.24.

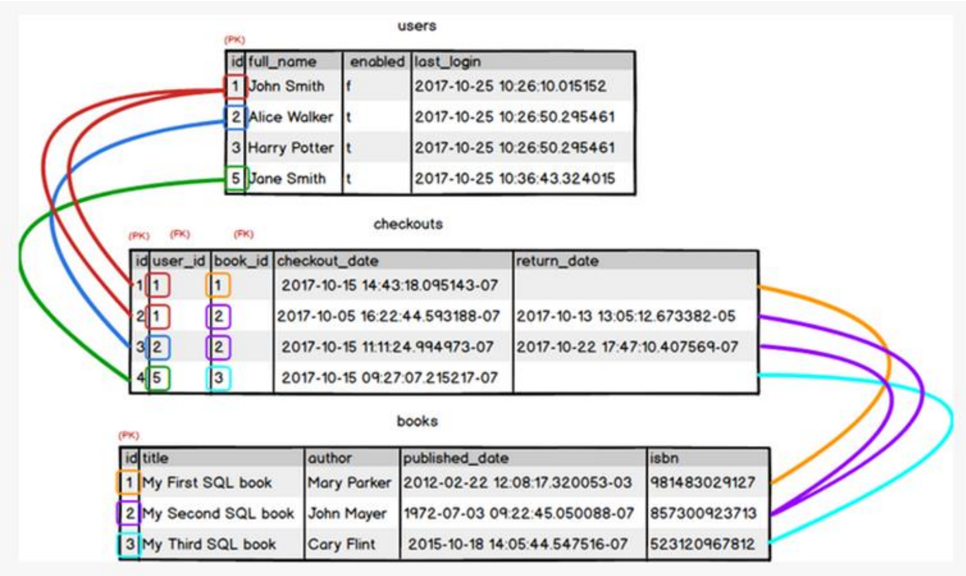


Fig. 3.24 View of the relationship

Here we can see that the id value of 1 from the users table for 'John Smith' appears twice in the user_id column of checkouts, but alongside different values for book_id (1 and 2); so this satisfies the 'a user can check out many books' part of the relationship. Similarly, we can see that id value of 2 from the books table for 'My Second SQL Book' appears twice in the books_id column of checkouts, alongside different values for user_id (1 and 2); so this satisfies the 'a book can be checked out by many users' part of the relationship.

Links:

https://www.techopedia.com/definition/1175/data-definition-language-ddl

https://www.techopedia.com/definition/1179/data-manipulation-language-dml

https://launchschool.com/books/sql/read/table_relationships

3.12 Data management in Soil and Water Bioengineering (SWB) context

3.12.1 Data Management

Data management is one of the important part of the experimental researches and administrative processes due to its role on final decision in addition to being a time and money consuming process. Data management concerns the dealing with data in the scientific context. Often, more importance is given to results, analysis and derived conclusion than to the data themselves. Research data are considered all information collected, observed or created for purposes of analysis and validation of original research results. Data can be quantitative or qualitative and comprises also photos, objects or audio files, resulting from as different sources as field experiments, model outputs or satellite data.

Data Management is a group of activities relating to the planning, development, implementation and administration of systems for the acquisition, storage, security, retrieval, dissemination, archiving and disposal of data. Such systems are commonly digital, but the term equally applies to paper-based systems where the term records management is commonly used. The term embraces all forms of data, whether these datasets are simple paper forms, the contents of relational databases, multi-media datasets such as images, or scientific data.

Data Management is a comprehensive collection of practices, concepts, procedures, processes, and a wide range of accompanying systems that allow for an organization to gain control of its data resources. Data Management as an overall practice is involved with the entire lifecycle of a given data asset from its original creation point to its final retirement, how it progresses and changes throughout its lifetime through the internal (and external) data streams of an enterprise.

3.12.2 Why do we need to manage our data?

Data management ideally begins at the planning and proposal phase of the research project. Purpose of the data management is to acquire, validate, store, protect, and process required data to ensure the accessibility, reliability, and timeliness of the data for the users. Types of data can be as numerical, categorical and ordinal.

Data management concerns how you plan for all stages of the data lifecycle and implement this plan throughout the research project. Done effectively it will ensure that the data lifecycle is kept in motion. It will also keep the research process efficient and ensure that your data meet all the expectations set by you, funders, research institutions and legislation (e.g. copyright, data protection).

Potential benefits of good data management include:

- ensuring data are accurate, complete, authentic and reliable
- increasing research efficiency
- saving time and money in the long run – 'undoing' mistakes is frustrating
- meeting funder requirements
- minimizing the risk of data loss
- preventing duplication by others
- facilitating data sharing

Link:

http://www.dataversity.net/what-is-data-management/

3.12.3 Data management in Soil and Water Bioengineering (SWB)

Data management in SWB minimizes the risks and costs of regulatory non-compliance, legal complications, and security breaches. It also provides access to accurate and relevant data when and where it is needed, without ambiguity or conflict, thereby avoiding miscommunication.

Data management in Soil and Water Bioengineering provides researchers to be able to:

- Improve data quality and consistency and facilitating reuse in the data lifecycle
- Evaluate data management plans and processes against the framework to understand and develop best practices that ensure an institution or repository's data is accessible, discoverable, understood, and reusable
- Ensure that processes are sustainable, scalable, and consistent
- Elevate and aligning good data
- Speed the advancement of science through better accessibility and reusability of data
- Improve repeatability in the research processes and outputs

Article: "A Guide to Data Management in Ecology and Evolution".

https://www.britishecologicalsociety.org/wp-content/uploads/Publ_Data-Management-Booklet.pdf

Data management in Soil and Water Bioengineering provides more benefits fort he researcher and the others:

- more time on research, less on data management
- easier to use, find and analyse – by the researcher and others
- documenting and establishing requirements means you can get credit for your data products

Journals and funders want you to share your data

- valuable products of the scientific enterprise
- agencies under pressure to demonstrate the benefits of research investment (publications and data products)
- new requirements for DMPs

It will benefit the scientific community

- enhanced ability of others to access, understand and use your data, advancing knowledge and discovery

Article: "How to manage ecological data for effective use and reuse".

https://www.dataone.org/sites/all/documents/ESA11_WS17_Intro_AEB.pdf

3.13 Overview business intelligence and analytics

The amount of data available to an organization is growing literally exponentially. Finding the right information, understanding its quality and producing good data in a timely and cost-effective manner are all critical issues.

Business Intelligence (BI) begins with Data; Data Management begins with BI

Business Intelligence helps derive meaningful insights from raw data. It's an umbrella term that includes the software, infrastructure, policies, and procedures that can lead to smarter, data-driven decision making.

Today, business intelligence is defined by Forrester as "a set of methodologies, processes, architectures, and technologies that transform raw data into meaningful and useful information used to enable more effective strategic, tactical, and operational insights and decision-making."

These are a few of the biggest trends and developments in business intelligence right now:

- **The blending of software and consulting services** – Vendors are beginning to offer "information as a service" and presenting intelligence to clients, as opposed to selling the software and infrastructure businesses need to access intelligence on their own.
- **Increasing Self-service** – Software is increasingly focused on increasing the functions that be performed without having to involve IT staff or data scientists.
- **Cloud-based business intelligence** – While cloud computing has taken hold in other areas, it's beginning to catch on in business intelligence, too. As this progresses, it will allow businesses to use intelligence without dedicating internal resources to manage infrastructure and perform software upgrades.
- **Mobile intelligence** – Mobile is becoming a key part of day-to-day business and it's no different in business intelligence. Mobile tools allow decision makers to access intelligence wherever they need it, not just when they're at their desks.
- **Big Data** – Businesses have access to more data than ever, and a lot of it comes from outside the organization in non-structured form. Business intelligence is increasingly being combined with Big Data analytics, so businesses can make decisions using all the information they have at their disposal, regardless of what form it takes.

Why do companies use business intelligence? The primary goal is stay ahead of the competition and make the right decision at the right time. Those decisions can be made around pretty much any aspect of running a business, such as:

- Figuring out how to increase the effectiveness of marketing campaigns
- Deciding whether and when to enter new markets
- Improving products and services to better meet customers' needs

One of the key aspects of business intelligence is that it's designed to put information in the hands of business users. Organizations are required to make decisions at an increasingly faster pace, so today's business intelligence tools help decision makers access the information they need without having to first go through the IT department or specifically designated data scientists.

Rather than request a report and then wait for it to be created, the user can log into the business intelligence application and view all the critical information presented in a way that doesn't take a specialist to understand.

Popular business intelligence solutions include; QlikView, SAP BusinessObjects, IBM Cognos and Microstrategy.

Like business intelligence, business analytics (BA) collects and analyses data, employs predictive analytics and generates richly visualized reports in custom dashboards. The aim of these features is to help identify and address an organization's weak points. This is where the similarities end. Business analytics software is used to explore and analyse historical and current data. It utilizes statistical analysis, data mining and quantitative analysis to identify past business trends.

It then uses that data for predictive modelling, which can predict and, in most cases, prepare for future business climates. One of the most powerful aspects of BA is ad-hoc reporting, which allows companies to perform ad-hoc analysis of their data in real-time and, therefore, make quicker business decisions. In effect, business analytics uses predictive analysis to solve problems before they've occurred.

Popular business analytics solutions include; SAP Business Analytics Suite, Pentaho BA, Birst BI and Tableau BIg Data Analytics. If you're looking to purchase BI or business analytics tools, a good place to start is with a list of expert requirements from Selecthub. Our BI requirements document templates contain the top criteria to consider when prioritizing requirements.

3.13.1 Choosing between Business Intelligence and Business Analytics

While superficially similar, the difference between business intelligence vs business analytics is clear: BI uses past and current data to optimize the present for current success. BA uses the past and analyses the present to prepare companies for the future.

Choosing the solution for your business depends on your aims. If you are satisfied with your business model as a whole and mainly wish to improve operations, increase efficiency and meet organizational goals, business intelligence may be an optimal solution. In particular, companies that rely on real-time reporting tend to lean toward BI. On the other hand, if you intend to change your business processes, or even your entire business model but don't yet have the necessary insights, business analytics might be the best option.

It may feel overwhelming to select the correct system. However, there are simple ways to determine the best option, and mostly they come down to what you prioritize in your decision-making process: current improvements or future planning.

Companies that require extensive data (e.g. the need for data warehousing) and intuitive reporting should seriously consider business intelligence. BI has the added advantages of targeting a business's weak areas and providing actionable insights to those problems. Business Intelligence tools are excellent solutions for managers who want to improve decision making and understand their organization's productivity, work processes and employees. And, with that understanding, improve their business from the ground up.

Link:

https://www.pac-online.com/bi-analytics-data-management

https://selecthub.com/business-intelligence/business-intelligence-vs-business-analytics/

https://www.betterbuys.com/bi/definitive-guide-bi/

3.14 Descriptive analytics: data visualization and exploration

Descriptive Analytics is the examination of data or content, usually manually performed, to answer the question "What happened?"

Data visualization is the presentation of data in a pictorial or graphical format. It enables decision makers to see analytics presented visually, so they can grasp difficult concepts or identify new patterns. With interactive visualization, you can take the concept a step further by using technology to drill down into charts and graphs for more detail, interactively changing what data you see and how it's processed (Figure 3.25).

Visualization tools present data using charts, graphs and other formats to aid understanding. Traditional formats include bar graphs, pie charts and scorecards, while advanced data visualization can create interactive and dynamic content, automatically choosing the best type of representation and personalizing content for the user.

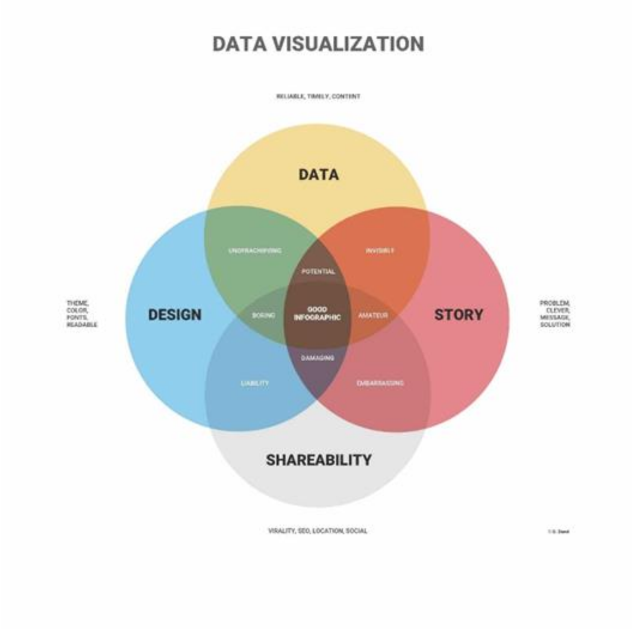


Fig. 3.25 The schema of data visualization

Why is data visualization important?

Because of the way the human brain processes information, using charts or graphs to visualize large amounts of complex data is easier than poring over spreadsheets or reports (Figure 3.26). Data visualization is a quick, easy way to convey concepts in a universal manner – and you can experiment with different scenarios by making slight adjustments.

Data visualization can also:

- Identify areas that need attention or improvement.
- Clarify which factors influence the study.
- Help you understand which factors to place where.

Dashboards is the primary graphical interface used when working with a business intelligence system. Typically, the first thing the user sees when logging on, the dashboard presents the most important reports and data visualizations for the user, customized based on the person's role.

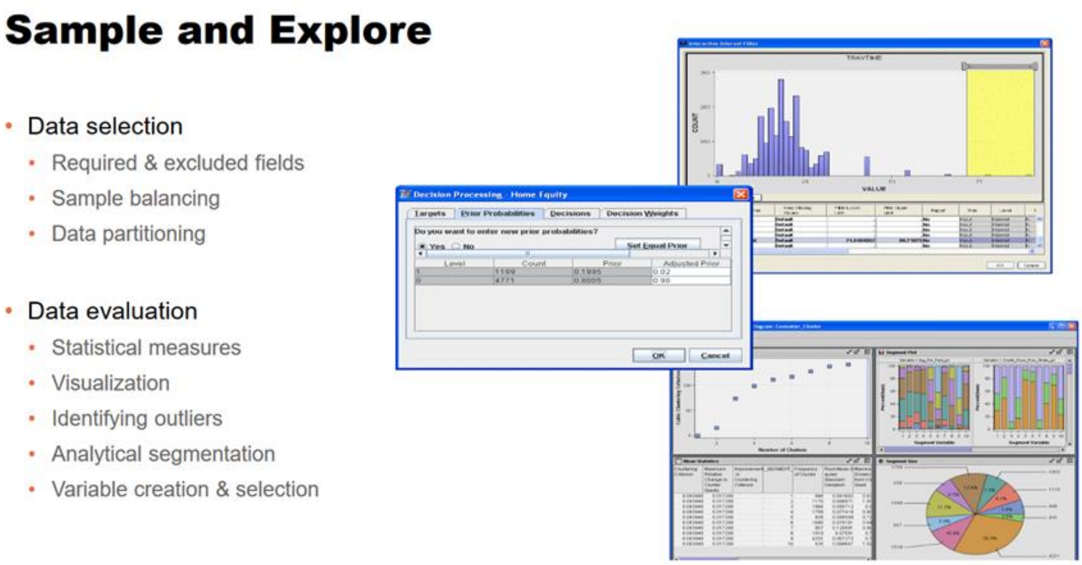


Fig. 3.26 An example for exploring and visualization of data in SAS

Link:

https://www.r-bloggers.com/descriptive-analytics-part-5-data-visualisation-continuous-variables/

https://www.sas.com/en_us/insights/big-data/data-visualization.html

https://www.sas.com/content/dam/SAS/en_gb/doc/other1/events/sasforum/slides/manchester-day2/I.%20Brown%20Data%20Exploration%20and%20Visualisation%20in%20SAS%20EM_IB.pdf

3.15 Data query, data model and reports

To create the query:

1. Launch Reports Builder (or, if already open, choose **File > New > Report**).

2. In the Welcome or New Report dialog box, select **Build a new report manually**, then click **OK**.

3. In the Data Model view that displays, click the SQL Query tool in the tool palette then click in an open area of the Data Model view to display the SQL Query Statement dialog box.

4. In the **SQL Query Statement** field, enter the following **SELECT** statement (Figure 3.27):

```
SELECT ALL CUSTOMERS_A1.CUST_FIRST_NAME,
  CUSTOMERS_A1.CUST_LAST_NAME, ORDERS.ORDER_ID, ORDERS.ORDER_TOTAL
FROM CUSTOMERS CUSTOMERS_A1, ORDERS
WHERE (ORDERS.CUSTOMER_ID = CUSTOMERS_A1.CUSTOMER_ID)
ORDER BY CUSTOMERS_A1.CUST_LAST_NAME
```

Fig. 3.27 Creating the data query

Click **OK** to display the data model for your new query in the Data Model view. In the **G_CUST_FIRST_NAME** group, click **CUST_FIRST_NAME** and drag it above the group to create another group. Click **CUST_LAST_NAME**, then drag it into the new group. Double-click the new group (**G_1**) to display the Property Inspector, and set the following properties:

Under **General Information**, set the Name property to G_Name.

Your data model should now look like this in Figure 3.28:

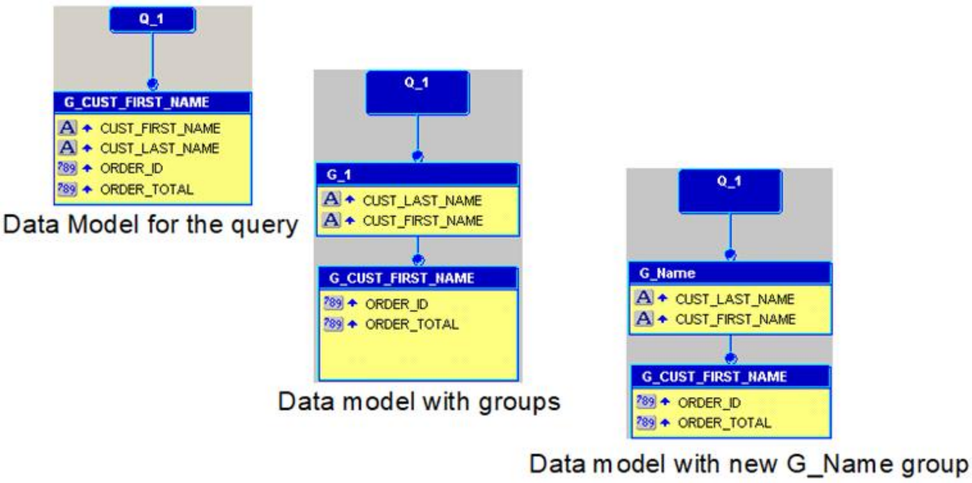


Fig. 3.28 Data model example of the query

Save your report.

The reports type depend on the program that used for the data management (Figure 3.29).

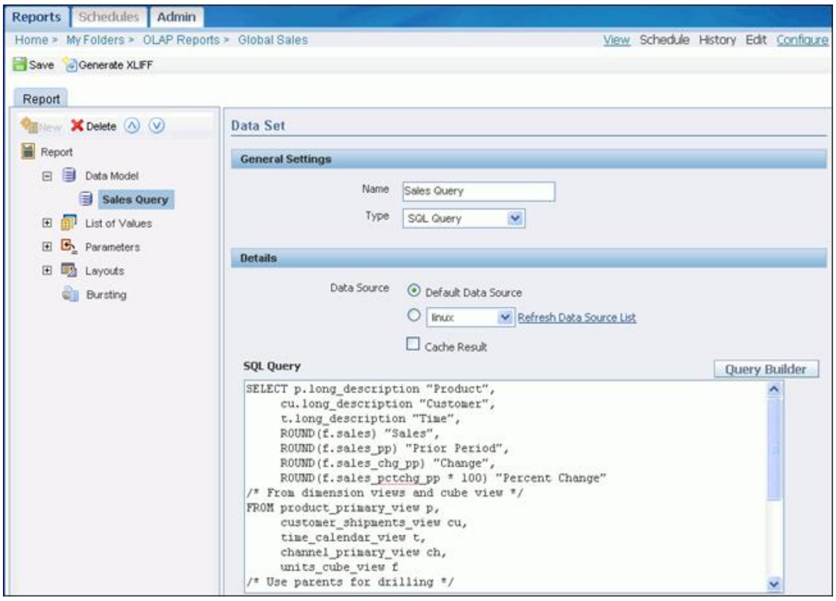


Fig. 3.29 An example for reporting in OLAP program

On the other hand, there are a wide variety of reporting options such as Charts, Pivot tables, Summary views and Tabular views (Figure 3.30).

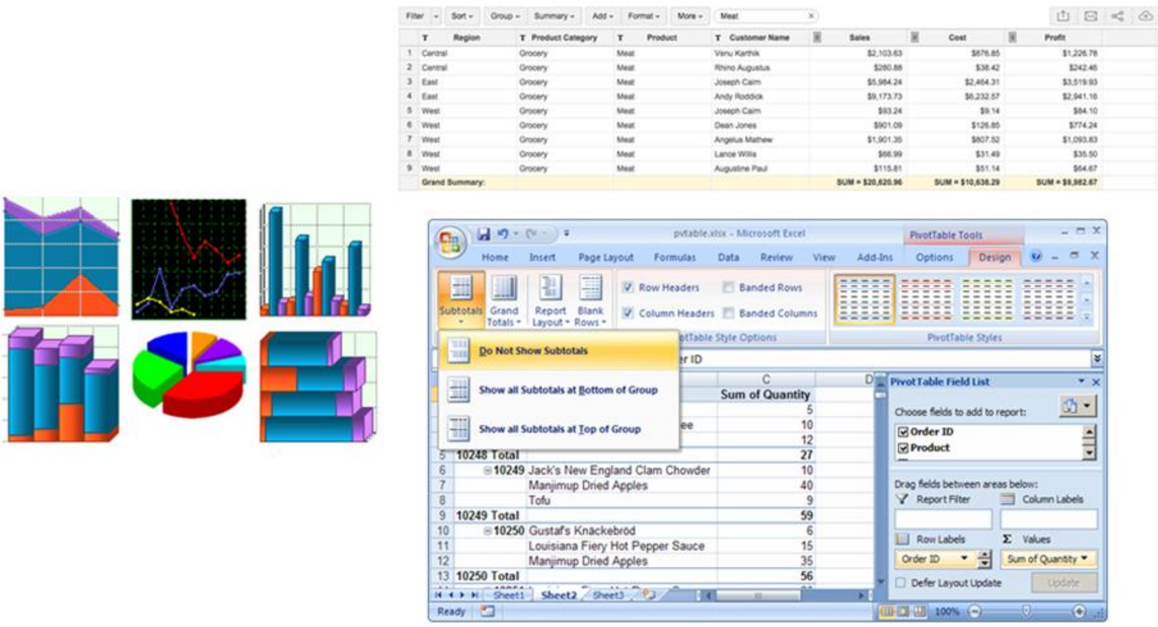


Fig. 3.30 Examples for Charts, Pivot tables, Summary views and Tabular views

Link:

https://docs.oracle.com/cd/E29542_01/bi.1111/b32122/orbr_wrapped002.htm#RSBDR1363

https://www.google.com/search?client=firefoxb&biw=1536&bih=727&tbm=isch&sa=1&ei=SupAW7PJHoGYsAGAIK4Ag&q=Data+query%2C+data+model+and+reports&oq=Data+query%2C+data+mo

del+an+reports&gs_l=img.3...30433.50103.0.50669.14.11.0.1.1.0.381.1644.0j9j0j1.10.0....0...1c.1j2.64.img..3.8.007...0j0i67k1j0i30k1j0i10k1.0.MBwVvND6gWI#imgrc=62jz9_4K8OwXeM:

https://www.google.com/search?client=firefoxb&tbm=isch&q=Pivot+tables&chips=q:pivot+tables,online_chips:excel+pivot&sa=X&ved=0ahUKEwiSg7O8tY3cAhVI2CwKHdb8AvYQ4lYIKSgC&biw=1536&bih=7&dpr=1.25

https://www.zoho.com/reports/help/tabular/working.html

3.16 Some Software Programs for Data Analyses

MaxStat by MaxStat Software

Complete statistics package with intuitive user interface and easily understandable results. Designed for researchers and students.

SPSS by IBM

Predictive Analytics can uncover unexpected patterns and associations and develop models to guide front-line interaction.

Minitab 17 by Minitab

Analyze your data and improve your products and services with the leading statistical software used for quality improvement worldwide.

DataMelt ("Dmelt") by jWork.ORG

Data analysis, math and data visualization program which combines the power of Python and Java (free)

Analytica by Lumina Decision Systems

Analytica is a powerful, stand-alone application for visual quantitative modelling with a full array of statistical analysis functions.

Statwing by Statwing

Statwing chooses statistical tests automatically, then reports results in plain English. Statwing is delightful and efficient analysis.

Stata by StataCorp

Stata statistical software is a complete, integrated statistical software package.

STEM by Princeton National Surveys

Excel macro package for running statistical tests on summary data. Output arranged to easily produce graphs in PowerPoint.

XLSTAT by Addinsoft

Variety of tools to enhance the analytical capabilities of Excel, making it the ideal for data analysis and statistics requirements.

SAS Buiseness Intelligence by SAS Institute

Business Intelligence software to prepare data, easily discover insights and share it in a self-service, governed manner.

AcaStat by AcaStat Software

Statistical software and instructional aids to help you quickly organize and analyse data.

AlterWind Log Analyzer by AlterWind

A log analyzer tool for determining the basic characteristics of the hits on your site.

Analyse-it by Analyse-it Software

Statistical analysis software for researchers in environmental & life sciences, engineering, manufacturing and education.

Analysis Studio by Appricon

Provides an end to end model generation process designed for fast development, analysis and deployment.

ChemStat by Starpoint Software

Full featured RCRA compliant statistical analysis of ground water data.

CoPlot by CoHort Software

A program for making publication-quality maps, technical drawings, and 2D and 3D scientific graphs; includes a statistical add-on.

Decision Analyst STATS by Decision Analyst

Windows-based statistical software for marketing research.

Decision Science by Stone Analytics

Embeddable analytic engines designed for integration into a wide variety of enterprise applications.

Develve by Develve Statistical Software

Statistical software for fast and easy analysis. Basic statistics, Design of Experiments, Gauge R&R and Sample size calculations.

EasyFit by MathWave Technologies

Data analysis and simulation software with data management, reporting functionality for probability distribution selection

ESBStats by ESB Consultancy

Statistical Analysis and Inference Software Package for Windows.

Forecast Pro by Business Forecast Systems

A standalone analytic tool for business forecasting that combines proven statistical methods with an intuitive interface.

JMP Statistical Software by JMP Statistical Software

JMP, data analysis software for scientists and engineers, links dynamic data visualization with powerful statistics, on the desktop.

KnowledgeSTUDIO by Angoss

Business intelligence and predictive analytics software suite with decision tress and data visualization.

MATLAB by The MathWorks

A programming environment for algorithm development, data analysis, visualization, and numerical computation.

MedCalc by MedCalc Software

A complete Windows-based statistical program for biomedical researchers.

Number Analytics by Number Analytics

Provides statistical analytics software for business users, pricing & promotion optimization, conjoint analysis, new product design.

PolyAnalyst by Megaputer Intelligenc

Offers a comprehensive selection of algorithms for automated analysis of text and structured data.

Predictive Suite by Predictive Dynamix

Computational intelligence software for data mining analysis and predictive modelling.

Scilab by Scilab Enterprises

Open source software for numerical computation providing a computing environment for engineering and scientific applications.

SigmaPlot by Systat Software

Systat Software presents award winning scientific data analysis software.

The R Project by R-Project.Org

Software environment for statistical computing and graphics (free).

Orange by Biolab.Si

Open source data visualization and data analysis for novice and expert (free)

Statistix by Analytical Software

Easy-to-use, comprehensive statistics and data manipulation

Weka by Waikato Machine Learning Group

Machine learning algorithms for data mining tasks software (free).

UNISTAT by UNISTAT

A statistical software package featuring a statistics add-in for Excel data analysis, charting and presentation-quality reporting.

Link:

http://jwork.org/main/node/25

3.17 Useful Links

BES, Data Archiving Policy

http://www.britishecologicalsociety.org/publications/journal-policies/#data

DataONE Best Practices Primer

https://www.dataone.org/sites/all/documents/DataONE_BP_Primer_020212.pdf

DCC, How to Develop a Data Management and Sharing Plan

http://www.dcc.ac.uk/resources/how-guides/develop-data-plan

EPSRC, Clarifications of EPSRC expectations on research data management

http://www.epsrc.ac.uk/files/aboutus/standards/clarificationsofexpectationsresearchdatamanagement/

MANTRA, Research Management Training http://datalib.edina.ac.uk/mantra/

Norman, H. 'Mandating data archiving: experiences from the frontline' Learned Publishing 27 S35-S38

http://www.ingentaconnect.com/content/alpsp/lp/2014/00000027/00000005/art00007

RCUK, Common Principles on Data Policy http://www.rcuk.ac.uk/research/datapolicy/

UK Data Archive, Managing and Sharing Data (2011)

http://www.data-archive.ac.uk/media/2894/managingsharing.pdf

http://guides.library.cornell.edu/c.php?g=150193&p=987948

https://www.quora.com/What-is-the-best-data-analysis-software

https://www.capterra.com/statistical-analysis-software/

https://www.predictiveanalyticstoday.com/top-free-statistical-software/

https://support.sap.com/en/my-support/software-downloads.html

Video: https://www.slideshare.net/unmgrc/software-programs-for-data-analysis

3.18 Exercises

3.18.1 Exercise 1: Creating database of experimental study which has a story presented below and using an appropriate software program for data analyses

The story of experimental study: The objective of this study was to determine how physical water quality parameters change due to decrease in forestry cover by management activities. In order to investigate impact of decrease in forest cover on physical water quality characteristics including pH, electrical conductivity, colour, turbidity, suspended sediment concentration, stream water and air temperatures, 18 % of standing timber volume was harvested and its effects on physical water quality parameters were examined by using a paired watershed methodology.

Two watersheds were selected as a control (W-I) and treatment (W-IV) and monitored for both streamflow and selected physical water quality characteristics between December 2005 and October 2011 for a calibration period of 6 years. During the calibration period, water grab samples were collected from the streams of both watersheds close to outlets just above the V-notch weirs on weekly basis and analysed for pH, electrical conductivity (EC), colour, turbidity and suspended sediment concentration (SSC) on the same day of collection. In October 2011, 18 % of the standing timber volume was removed from one watershed (W-IV, treatment) and the other one (W-I, control) was left untouched as a control watershed. After timber removal, stream water sampling in both watersheds were continued for 46 months until November 2015 for the treatment period.

Solution: 1 st step: Database of this experimental study can be created simply by using Excel as it is presented in Figure 3.31:

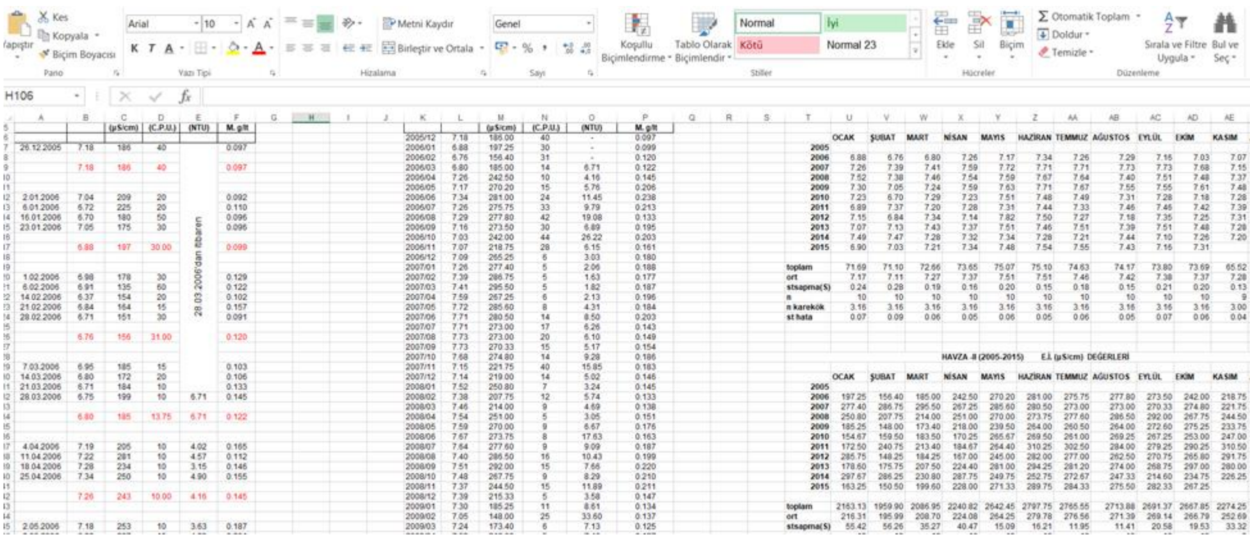


Fig. 3.31 Creating database by using Excel

2 nd step: Using an appropriate software program for data analyses:

The decision of software depends on the data analyses chosen for the database. So that the analyses should be decided firstly. Here it is clear that a calibration period should be evaluated. However, the database must be analysed for the normal distribution by using SPSS, Minitab programs (Figure 3.32). If the data don't have normal distribution, transformation is required (Figure 3.33). When the data have normal distribution, t-test can be used for determining the relationship between measured and estimated values by using Excel, SPSS or Minitab programs (Figure 3.34 and 35).

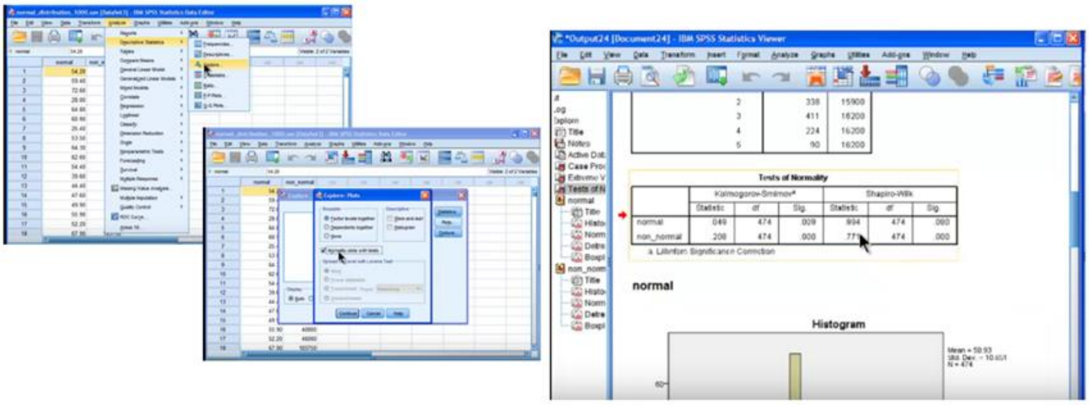


Fig. 3.32 The flowchart for Normality test by using SPSS program

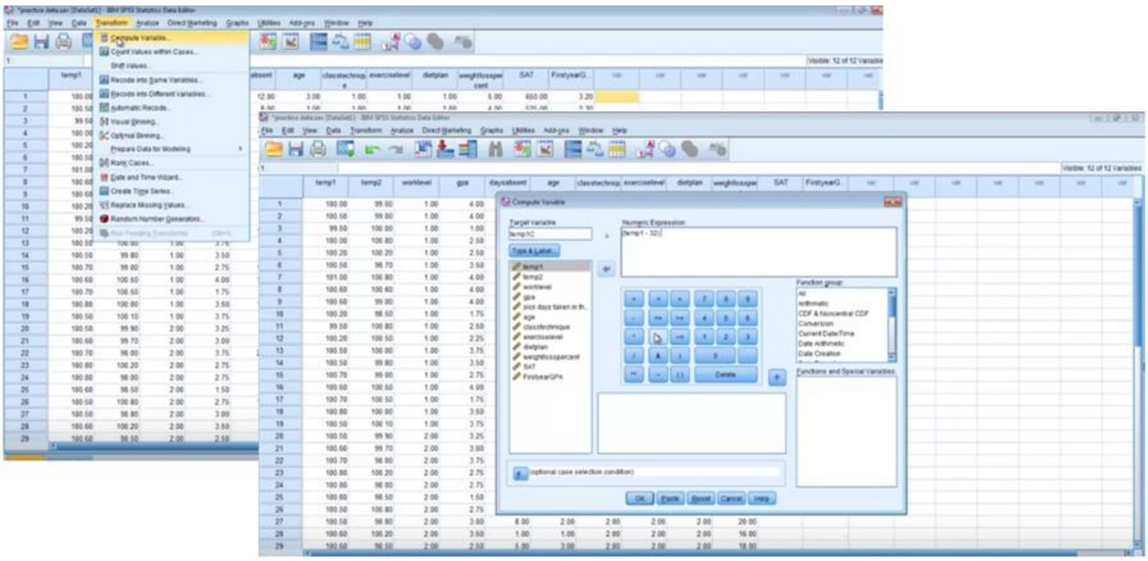


Fig. 3.33 The process of transformation of data by using SPSS program

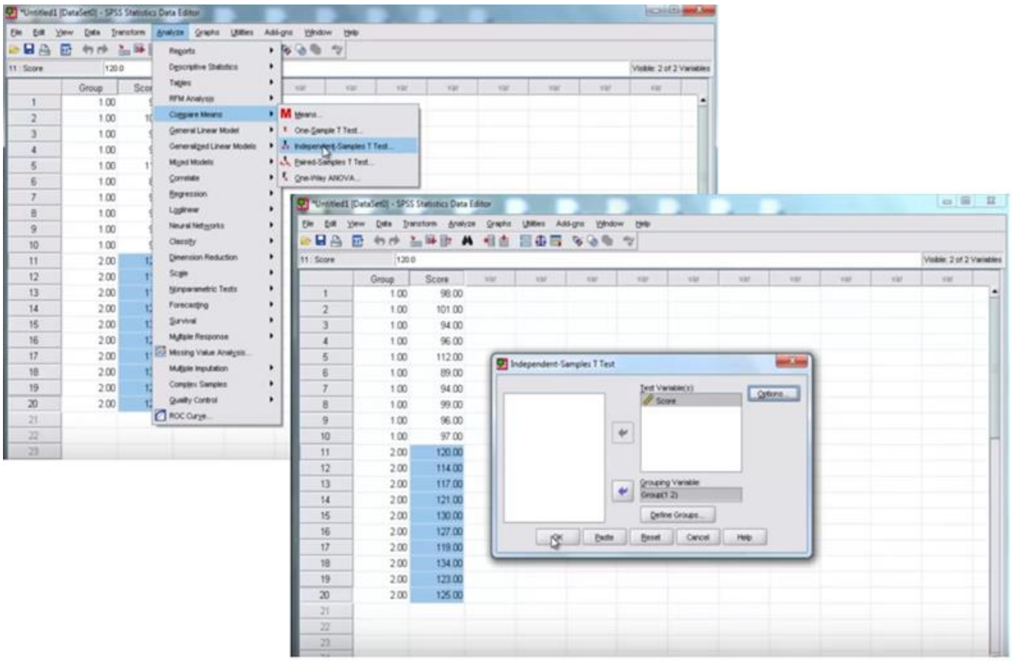


Fig. 3.34 The process of t-test by using SPSS program

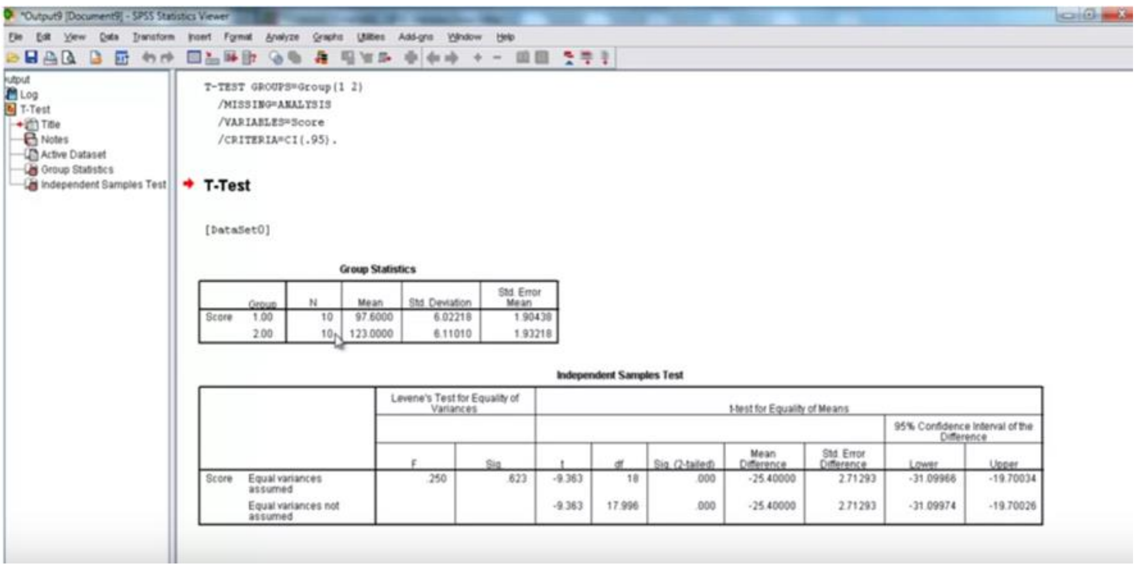


Fig. 3.35 The output of t-test

Link:

https://www.youtube.com/watch?v=sQkB-AIJgPI

https://www.youtube.com/watch?v=VUUfBWIzilU

https://www.youtube.com/watch?v=CTWgb4FO5_Y

3.18.2 Exercise 2: Data visualization of experimental study

The data shown in Table 3.2 are the values of water quality parameters related to the land use types of some sub-watersheds in an experimental study. How could you visualize these data in terms of determining the relationship between these data?

Table 3.2 The data related to an experimental study

Sub-watersheds	***Value of water quality parameters***				***Area of land use types as a percentage of sub-watershed area (%)***			
	pH	*EC*	*Turbidity*	*TSS*	*Rangeland*	*Agriculture*	*Urban*	*Forest*
SW-1	*7.14*	*539*	*12.24*	*0.475*	*0.14*	*0.21*	*0.02*	*0.61*
SW-2	*7.29*	*646*	*44.15*	*0.698*	*0.14*	*0.16*	*0.17*	*0.51*
SW-3	*7.38*	*798*	*66.04*	*0.943*	*0.3*	*0.26*	*0.26*	*0.15*
SW-4	*7.36*	*533*	*31.47*	*0.67*	*0.28*	*0.02*	*0.11*	*0.59*
SW-5	*7.19*	*460*	*5.64*	*0.362*	*0.02*	*0.12*	*0.00*	*0.86*
SW -6	*7.37*	*463*	*11.91*	*0.723*	*0.65*	*0.00*	*0.00*	*0.35*
SW -7	*7.42*	*480*	*13.63*	*0.811*	*0.79*	*0.00*	*0.00*	*0.21*
SW -8	*7.34*	*618*	*30.09*	*0.558*	*0.04*	*0.22*	*0.11*	*0.63*
SW -9	*7.59*	*786*	*46.05*	*0.914*	*0.48*	*0.35*	*0.15*	*0.02*
SW -10	*7.74*	*911*	*118.41*	*1.242*	*0.19*	*0.04*	*0.52*	*0.24*

Solution: The relationship between data can be basically shown in two ways as visualized below where it evaluates the correlation between these data in the first graph (Figure 3.36) and the alteration related to each other in the second graph (Figure 3.37):

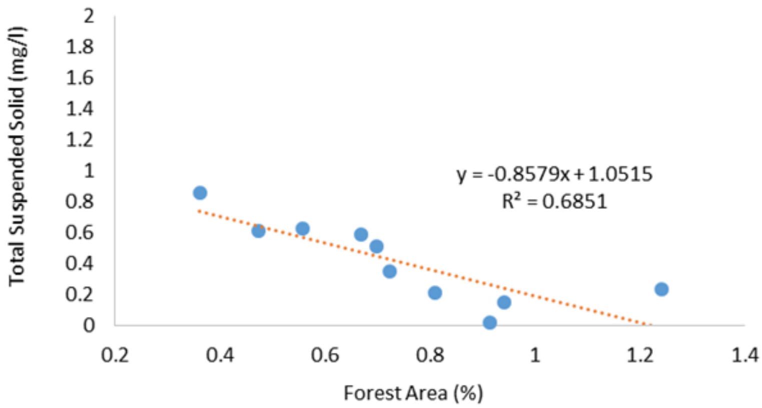


Fig. 3.36 The visualization of selected data stated in Table 3.2 in terms of relationship

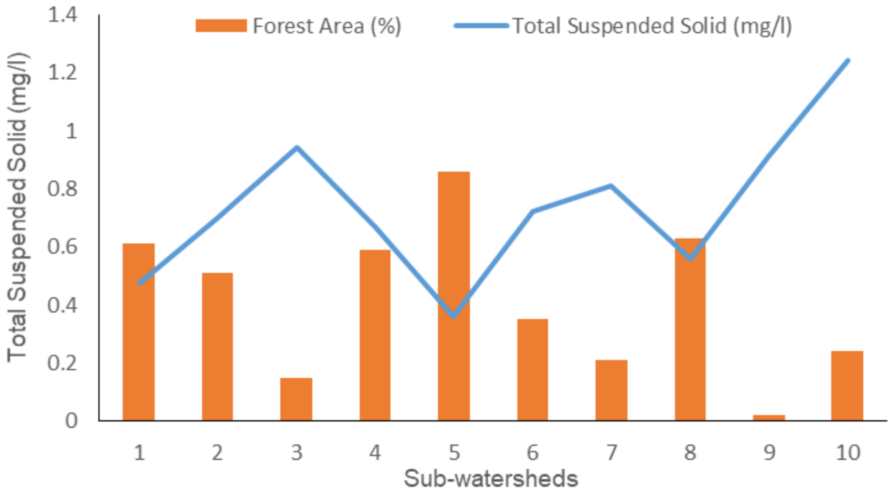


Fig. 3.37 The visualization of selected data stated in Table 3.2 in terms of alteration related to each other

3.19 Case Study Analyses

A case study analysis throughout the project, the Data Management Checklist should be taken into consideration in construction and monitoring stages:

Data Management Checklist*

• Are you using standardized and consistent procedures to collect, process, check, validate and verify data?

• Are your structured data self-explanatory in terms of variable names, codes and abbreviations?

• Which descriptions and contextual documentation can explain what your data mean, how they were collected and the methods used to create them?

• How will you label and organize data, records and files?

• Will you apply consistency in how data are catalogued, transcribed and organized, e.g. standard templates or input forms?

• Which data formats will you use? Do formats and software enable sharing and long-term validity of data, such as non-proprietary software and software based on open standards?

• When converting data across formats, do you check that no data or internal metadata have been lost or changed?

• Are your digital and non-digital data, and any copies, held in a safe and secure location?

• Do you need secure storage for personal or sensitive data?

• If data are collected with mobile devices, how will you transfer and store the data?

• If data are held in various places, how will you keep track of versions?

• Are your files backed up sufficiently and regularly and are backups stored safely?

• Do you know what the master version of your data file is?

• Do your data contain confidential or sensitive information? If so, have you discussed data sharing with the respondents from whom you collected the data?

• Are you gaining (written) consent from respondents to share data beyond your research?

• Do you need to anonymize data, e.g. to remove identifying information or personal data, during research

or in preparation for sharing?

• Have you established who owns the copyright of your data?

• Who has access to which data during and after research? Are various access regulations needed?

• Who is responsible for which part of data management?

• Do you need extra resources to manage data, such as people, time or hardware?

*Article: “UK Data Archive-Managing and Sharing Data”

http://www.data-archive.ac.uk/media/2894/managingsharing.pdf

4. TECHNICAL DRAWING

4.1 Summary of the module content

This course is a course for students interested in swb or any other technical field. This course will require students to use the knowledge gained in the first level of this course and apply that knowledge to more complex and in depth drawings as well as more advanced types of drawings. They will continue to use drawing boards, cad. They will use this software to create swb drawings as solutions to design problems.

4.2 Syllabus

- Lettering
- Working drawings
- Sectional views
- Advanced orthographic and pictorial drawings
- Auxiliary views
- Sections
- Isometric perspective
- Reading technical drawings
- Free hand sketching and CADD
- SWB drawings and sketching

4.3 Technical Drawing outcomes

- Create advanced technical drawings using freehand sketching, drafting equipment or CADD
- Work independently with attention to detail and neatness
- Read and understand advanced orthographic projections and pictorial drawings

4.4 Assessment Methods

This module is continuously assessed during the course of the semester. The assessment comprises list here as per the assessment table. The pass mark for this module is 50% - students must achieve an overall aggregate of 50%. The weightings of each assessment are as shown in the table above. Full details of the course works are contained in the Coursework Briefs which will be issued in due course. Note: Failure to submit the coursework for the appropriate deadline without 'good cause' will be regarded as a non-submission, and hence will result in failure in this module. If students have a valid reason for needing an extension to the deadline, students must discuss this with the module leader beforehand, or if this is not possible, within seven days of the published hand-in date. To help, guide and develop students will be provided with feedback on students' performance throughout the module. This feedback will generally be presented to the class as a whole in which general comments about common positive and negative aspects of the cohort's overall performance will be provided. Students will be given an opportunity to individually review students marked work to help students understand which aspects of student's studies students are performing well in and which aspects require further attention. These comments will be made with regard to both the communication skills (i.e. spelling, grammar and presentation) as well as the technical content of the module. Students are entitled to keep marked submissions for students review however; students must return these when asked by the Module Leader or Module Tutor.

Student performances will be graded based on following titles shown in the table method.

Table 4.1 The criteria for grading student performances

Component	Duration (hours)	Weighing in total module mark (%)	Threshold (min pass mark, %)	Description
Coursework	188	20	50	Current critical literature review report
Class test	20	10	50	Design calculation for one element
Practical	28	30	50	Numerical model / installed ecoengineering structure
Final exam	20	50	50	Unseen exam / project report
Total	256			

4.5 Introduction

Drawing has been the main tool to communicate the ideas for nearly twenty thousand years. It seemed to lose importance after the writing was found, but with different changes in the society like improvements of technical drawing, icons used in computers and mobile phones, manuals using draw language, etc. the drawing have settled down in our lives again.

Technical drawing is the language of engineers, architects, designers, and many other professionals. Therefore, they have to use same words, grammar etc. to easily and correctly communicate each other. When you draw lines, sections, profiles, details etc. everybody have to use them in the same way that the other side, for example employee, professional, boss, controller etc. could easily understand.

In this part of the module, after the main aspects of technical drawing has been addressed, the use of technical drawing on the soil bioengineering will be emphasized.

For the preparation of a neat and correct drawings, good drawing instruments have to be used. A list of drawing instruments and materials required includes: drawing board, engineer's/architects scale, protractor, drawing sheets, eraser, drawing pencils (HB, H and 2H), rulers, squares, drawing pens, compass, geometric designer template (Rathnam 2018; Görcelioğlu and Çelik 2000)

4.5.1 Drawing Sheet formats

In the process of preparation of a drawing, it is necessary to pay attention to the sheet dimensions. The sheet dimensions are standardized and generally A (A0 841*1189) standard and its trimmed sizes are used in the process of creating a project (Fig. 4.1).

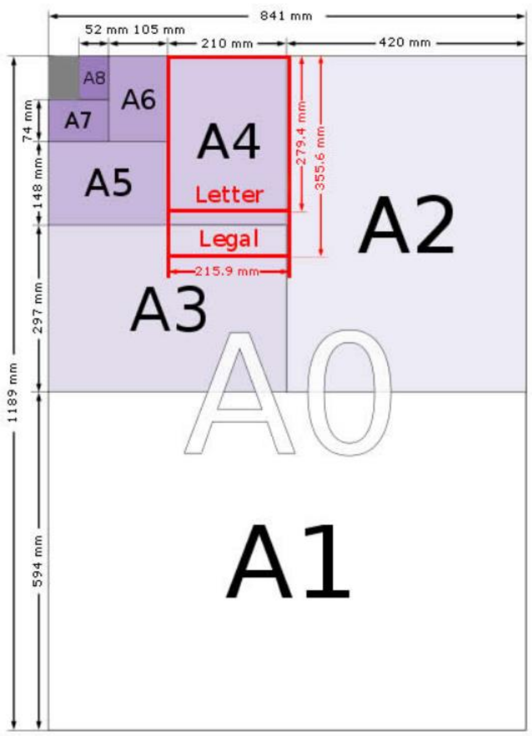


Fig. 4.1 A series standard sheet sizes

A0 = 1189 x 841 mm
A1 = 841 x 594 mm
A2 = 594 x 420 mm
A3 = 420 x 297 mm
A4 = 297 x 210 mm
A5 = 210 x 148 mm
A6 = 148 x 105 mm
A7 = 105 x 74 mm
A8 = 74 x 52 mm

The most commonly used format in the preparing of design documentation is the A4 format, while the technical drawings are often set in a special format so it should be adjusted i.e. by folding the drawing, the dimensions of the format with which the whole design is printed is acquired. To obtain an aesthetic and economic result, according to drawing and scale chosen, drawing should have a reasonable distance to the borders. On the other hand, to choosing a big sheet is not economic. More information is freely available online in the following web sites:

Introduction to technical drawing: https://www.youtube.com/watch?v=YE0oZZO7vbk

Intro to mechanical engineering: https://www.youtube.com/watch?v=1Hm5Zyjmjac

How to draw isometric object: https://www.youtube.com/watch?v=kYqn4QhUqe4

Auxiliary views and section: https://www.youtube.com/watch?v=nQnx0CURudM

Isometric projection: https://www.youtube.com/watch?v=c6DygJMwos8

Isometric sketch exercise: https://www.youtube.com/watch?v=sSuyM60s7eA

Engineering graphics:
https://www.youtube.com/watch?v=9weED8e3nes&list=PLePyjH9K_4N_rRbunGVfpGoFhQCPf2x5_&index=4

Auxiliary views:
https://www.youtube.com/watch?v=7yMNRs4qYHc&list=PLePyjH9K_4N_rRbunGVfpGoFhQCPf2x5_&index=18

4.5.2 Types of lines and their usage

There are different types of lines that are used for different purpose in the technical drawing (BS EN ISO 128-20:2001) (Fig. 4.2 and 4.3)

The basic types of lines used in the preparation of a drawing are:

A continuous line used for drawing the contours (dimensions) of an object or a structure, visible edges etc.

The dashed line that is most often used for something that is in the background of the drawing, hidden and not visible in the cross-section.

The dash-dot line with a dot in between is used to show some interruption or if we want to reduce the drawing and show that the same applies further, but we must mark how far it applies.

The variable line with different lengths of the segments is most often used if there is something not checked, dimensions that are not known or it could undergo a change.

There are other types of lines used during the technical drawing designated by the designer, but there must be a legend that explains the meaning of each line individually (Fig. 4.3).

No.	Representation	Description
01		continuous line
02		dashed line
03		dashed spaced line
04		long dashed dotted line
05		long dashed double-dotted line
06		long dashed triplicate-dotted line
07		dotted line
08		long dashed short dashed line
09		long dashed double-short dashed line
10		dashed dotted line
11		double-dashed dotted line
12		dashed double-dotted line
13		double-dashed double-dotted line
14		dashed triplicate-dotted line
15		double-dashed triplicate-dotted line

Fig. 4.2 Types of lines used in drawing (BS EN ISO 128-20:2001)

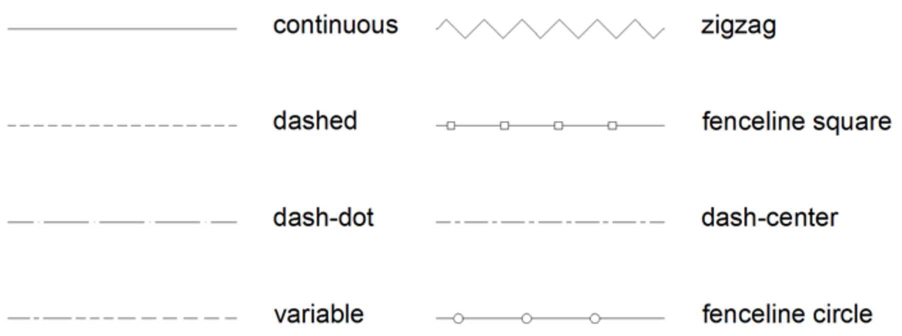


Fig. 4.3 Different types of lines used in drawing

4.5.3 Line widths

On a construction drawing three line widths, narrow, wide and extra-wide, are normally used (BS ISO 128-23:1999) (Table 4.2). The proportions between the line widths are 1:2:4.

A special line width is used for representation and lettering of graphical symbols. This line width is situated between the width of the narrow and the wide line.

Table 4.2 Line widths (BS ISO 128-23:1999)

Dimensions in millimetres

Line group	Narrow line	Wide line	Extra-wide line	Line widths for graphical symbols
0,25	0,13	0,25	0,5	0,18
0,35	0,18	0,35	0,7	0,25
0,5	0,25	0,5	1	0,35
0,7	0,35	0,7	1,4	0,5
1	0,5	1	2	0,7

The line widths shall be chosen according to the type, size and scale of the drawing and the requirements at microcopying and other methods of reproduction.

4.5.4 Hierarchy of lines

In addition to the type of the line that will be chosen, there must be hierarchy of lines that are used in the drawing, thus a distinction could be made between what is priority and what is not.

The thin lines are always auxiliary lines, such as dimension lines, the isotypes that provide terrain information, and some structures that are not important and which are not in the focus of the drawing. Then there are things that influence the design and by increasing their thickness, we show that those structures, border etc. are of importance, while the thickest line shows what the designer has envisaged designed.

As the thickness of the line increases, what is planned and designed by the engineer comes into foreground.

4.5.5 Hatches

When showing materials especially in the sections, different type of lines are used to determine the material. If you use AutoCAD, there is a library of materials (Fig. 4.4).

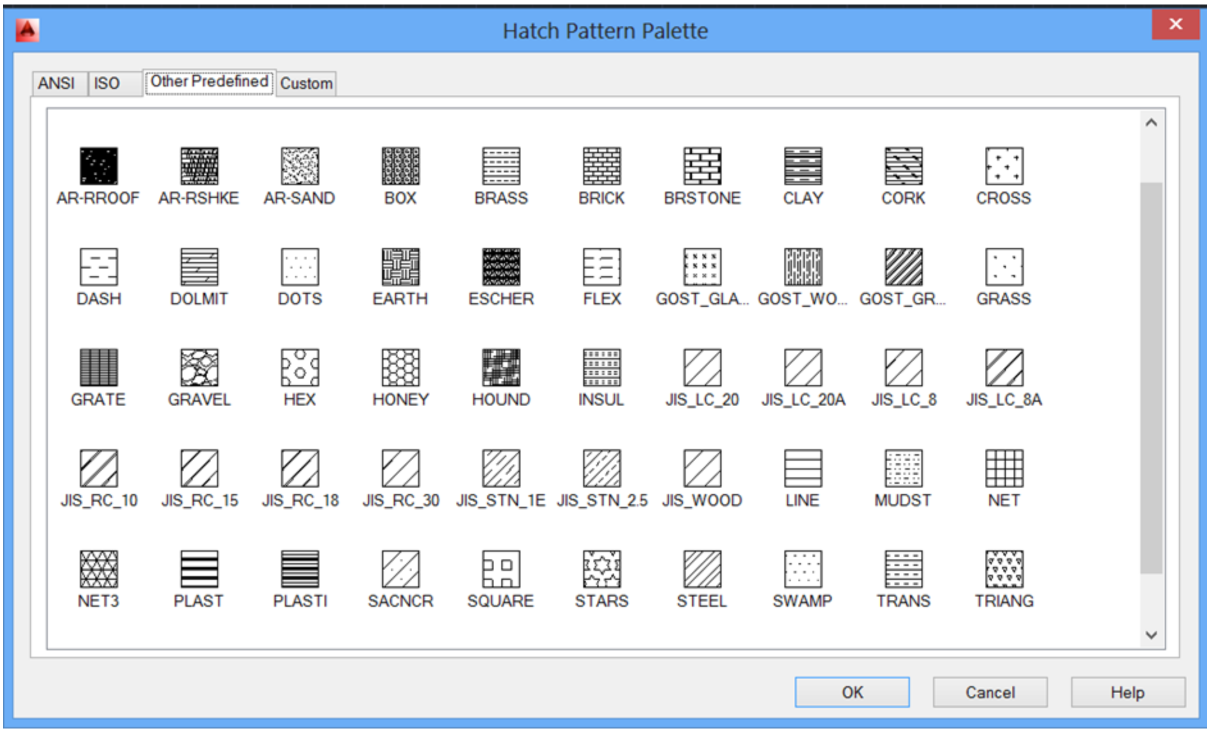


Fig. 4.4 Hatching and conventional showing of material types of AutoCad

4.5.6 Lettering

Letters and numbers are the inseparable parts of a drawing. To relate every drawing to reality is possible with letters and numbers. Dimensioning, definition of the subject, material, technical etc. many information could be given only by writing (Fig. 4.5).

Standard letters are vertical or 75° oblique to right. Letters should be readable, clean, balanced and uniform. Space between letters should be approximately equal. Word spaces should be equal the letter height.

4.5.7 Dimensioning

Drawing describes the shape of an object. For constructing of the object, size description is required. Dimensions are shown on the drawings. The same unit of measurement (i.e. millimetres) is adopted for all dimensioning but without showing the unit symbol. Unit symbol on a drawing is shown in a note [ALL DIMENSIONS ARE IN mm].

Elements of dimensioning are projection line, dimension line, leader line, termination of dimension line and dimensions. Projection lines limit the dimension lines. Leader lines are drawn as continuous thin lines with termination of leader by an arrow head or 45° oblique line. Dimension is a numerical value expressed in appropriate unit of measurement (Fig. 4.6).

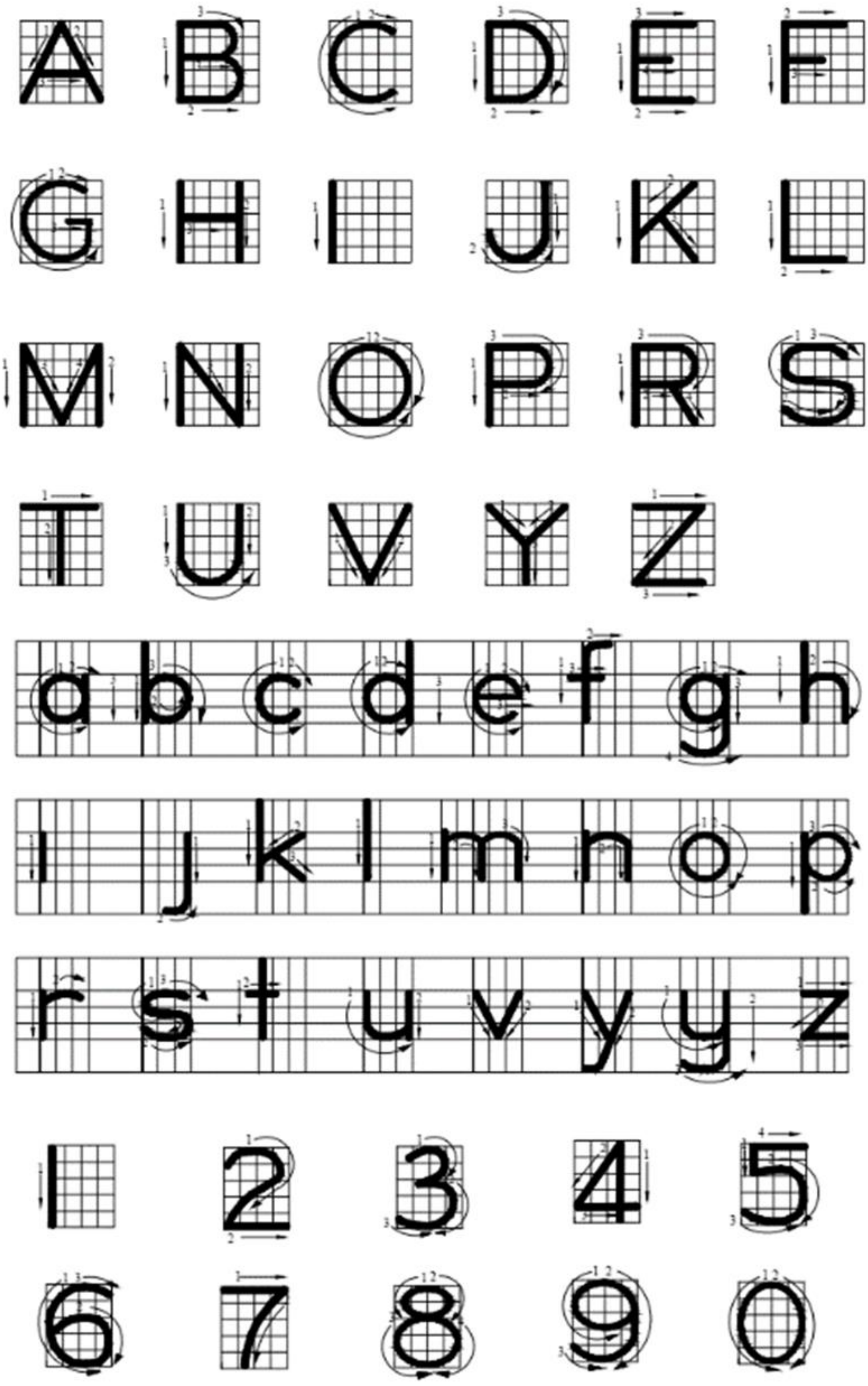


Fig. 4.5 Vertical letters and numbers

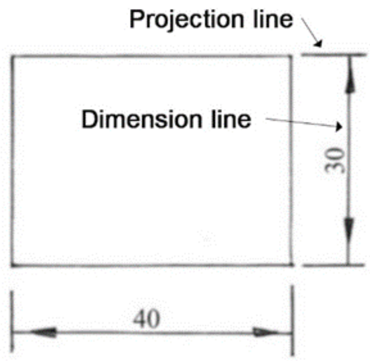


Fig. 4.6 Dimensioning elements

4.5.8 Title block

After folding the drawing sheet, upper folding should contain title block, which include title of the drawing, drawing number, scale, direction, symbol denoting the method of projection, name of the firm, and initials of staff who have designed, checked and approved.

The other part of the sheet includes the design, and the drawing, that is, in that part of the drawing a seal is placed containing general information about it in different styles (Fig. 4.7-4.8).

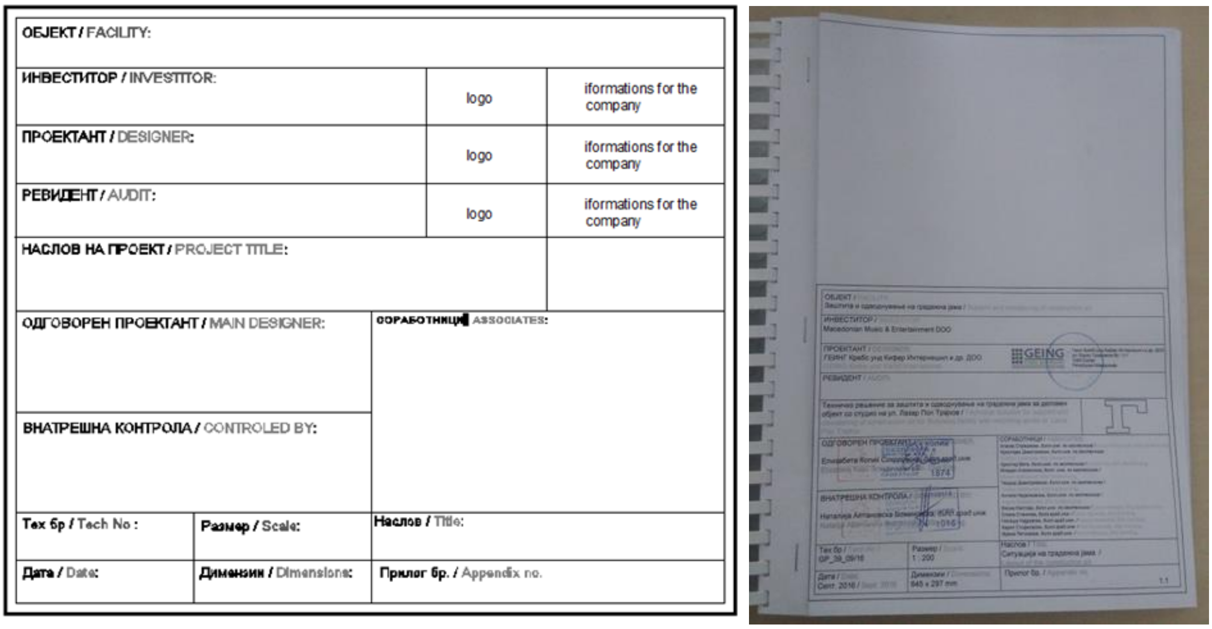


Fig. 4.7 An example of heading part of a drawing (Geing 2018)

The drawing should also contain a frame surrounding the drawing, which is usually set by leaving 5 mm from the outer sides and 25 mm from the inside of the drawing.

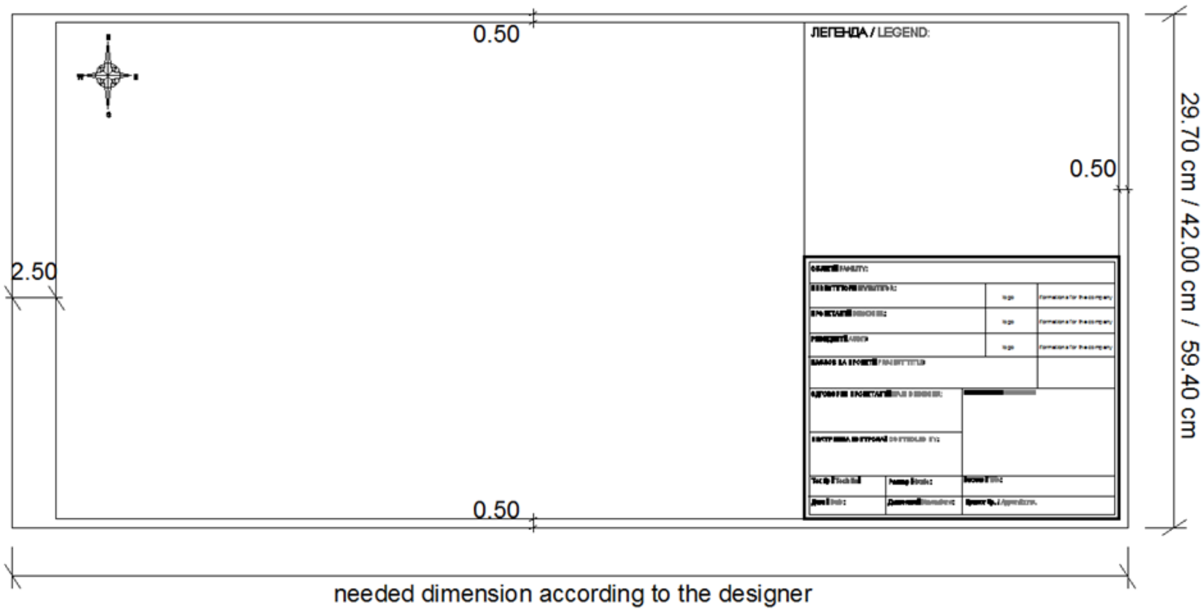


Fig. 4.8 Drawing a frame with the most commonly used dimensions

4.5.9 Scaling

The scale of a technical drawing depends on the requirements from the Terms of Reference, but it mainly depends on the designer. However, the ratio of the drawing must be set in order for it to be clear, functioning and comprehensible.

The ratio also depends on in which phase of preparation the design is. For example, when preparing a conceptual design, the drawings can be drawn in a smaller ratio so that the focus is placed on the location and appearance of an object/ structure, and in the next phase, the ratios are increased and details are being elaborated for which a bigger ratio is necessary so that a certain type of an object/ structure can be technically justified (Fig. 4.9).

During the preparation, different ratios are used, for example, 1: 100, 1: 500, 1: 10000 or larger ratios such as 1:50, 1:25 so that the engineer determines the ratio depending on how much a particular drawing needs to be clear. The ratio can be calculated according a formula with simple mathematical operations. For example, let's say that we need to show a particular structure with length of 10 km in one drawing, making it understandable and functional. If we decrease the structure 10 times in a drawing, we will get a 1000 m long drawing which is not right and is not functional, but if we reduce the same drawing 10 000 times, we will get a drawing of 1 m in length in which a 10 km structure can be presented. Therefore, the engineer needs to make an assessment in which ratio the structure is going to be presented (Fig. 4.10).

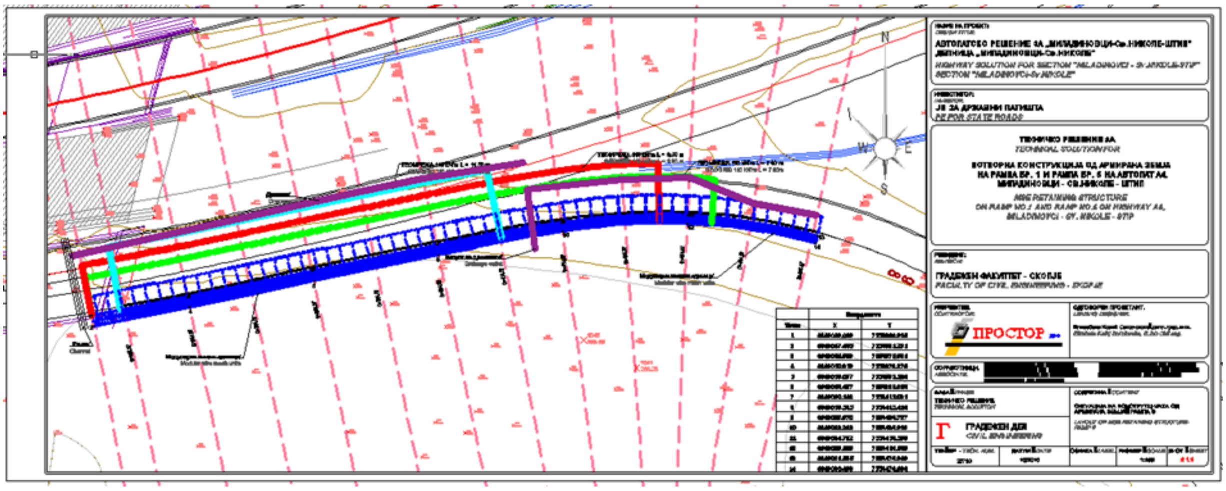


Fig. 4.9 An example of a scaled drawing (Geing 2018)

When drawing, these ratios are adjusted to the frame size, seal and the text in it, so that when printing the drawing, the size or dimensions will remain the same as previously mentioned in items 2 and 3.

To be even more precise, the font size of the design should remain the same all the time and the dimensions of the seal should remain the same so that the design (technical documentation) will have unified dimensions, font sizes, etc. Thus, we adjust the size according to the needs of the ratio.

Some figures may not be drawn by scale, so they include "not to scale" information.

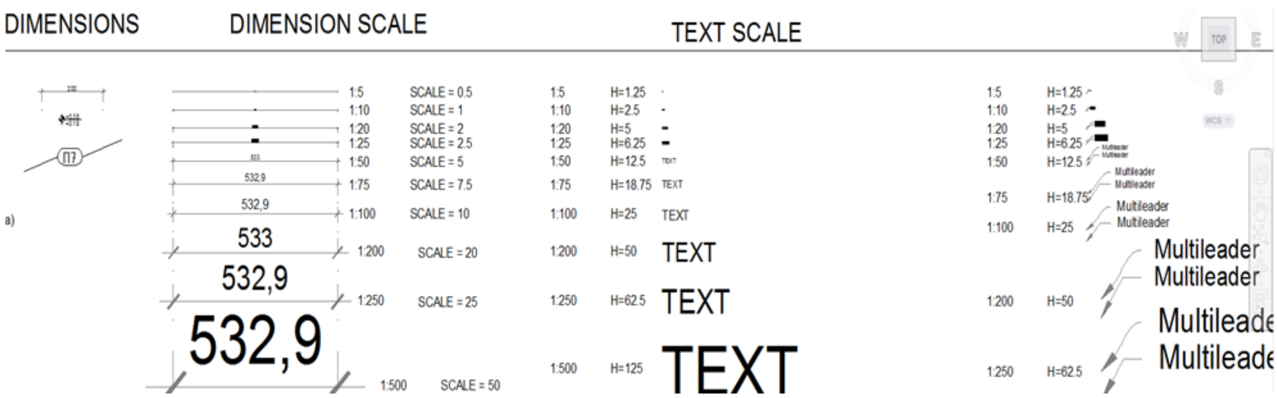


Fig. 4.10 Scale adjustment in technical drawings

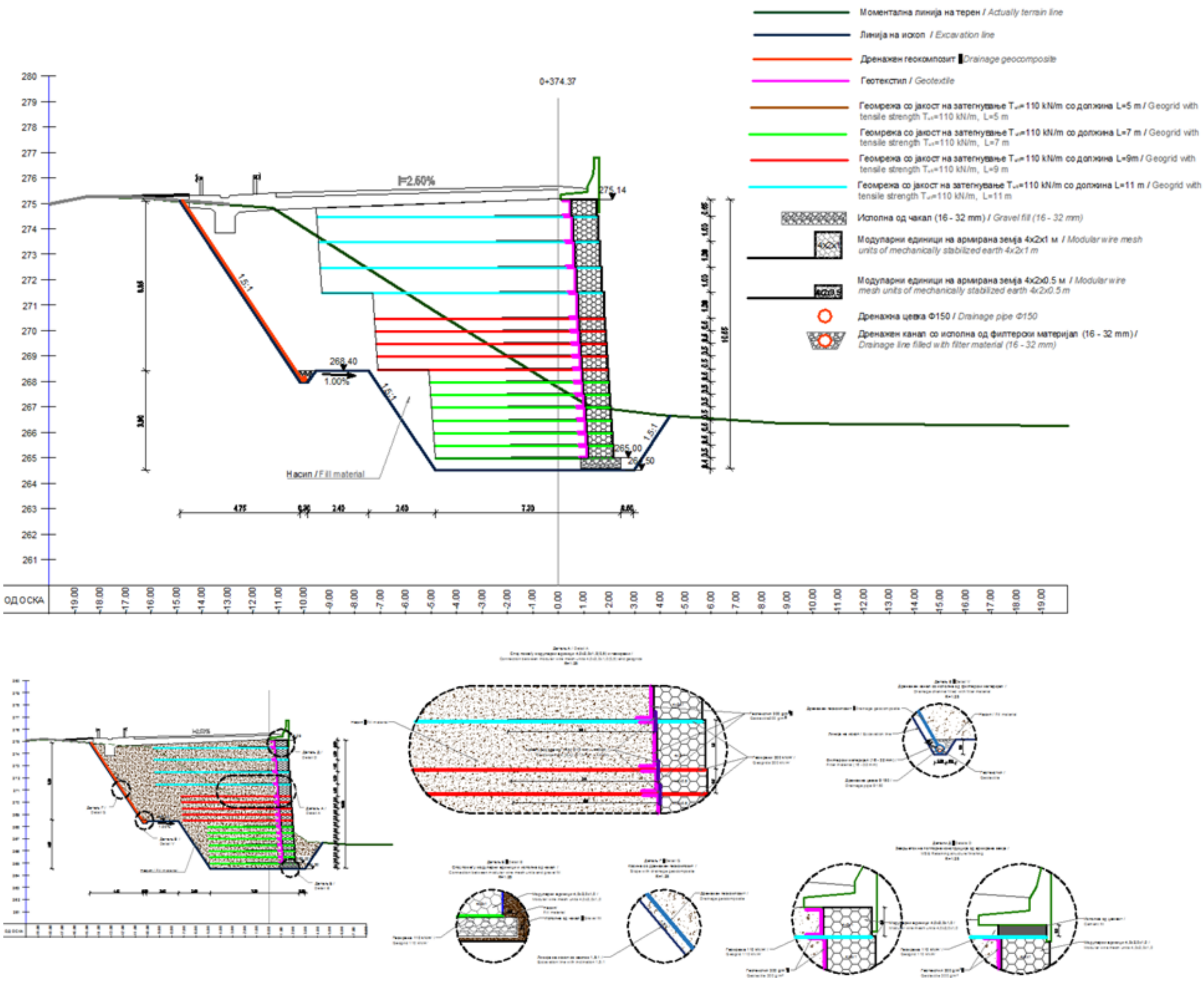


Fig. 4.11 An example of a scaled drawing and preparation of technical details (Geing 2018)

4.5.10 Lettering exercises

Write the following with 10 mm high vertical letters using graph paper:

SOIL AND WATER BIOENGINEERING

INGENIEUR BIOLOGIE

INGEGNERIA NATURALISTICA

LETTERING

ECOMED

Write the following with 7 mm high vertical letters using graph paper:

TECHNICAL DRAWING IS THE LANGUAGE OF ENGINEERS

HUMANKIND USE DRAWING FOR 20 TOUSAND YEARS

TO BE UNDERSTOOD WE HAVE TO USE TECNICAL DRAWING RULES

ALL DIMENSIONS ARE IN mm

WATTLE FENCE, CRIB WALL, HYDROSEEDING, JOINT PLANTING

LETTERS SHOULD BE PLAIN, VERTICAL AND UNIFORM

4.5.11 Drawing exercises

Draw thick horizontal lines in a 50 mm square with 10 mm spaces on a graph paper.

Draw thick vertical lines in a 50 mm square with 10 mm spaces on a graph paper.

Copy Fig. 4.12 with using thin lines with pen. Boxes are 10 by 10 cm.

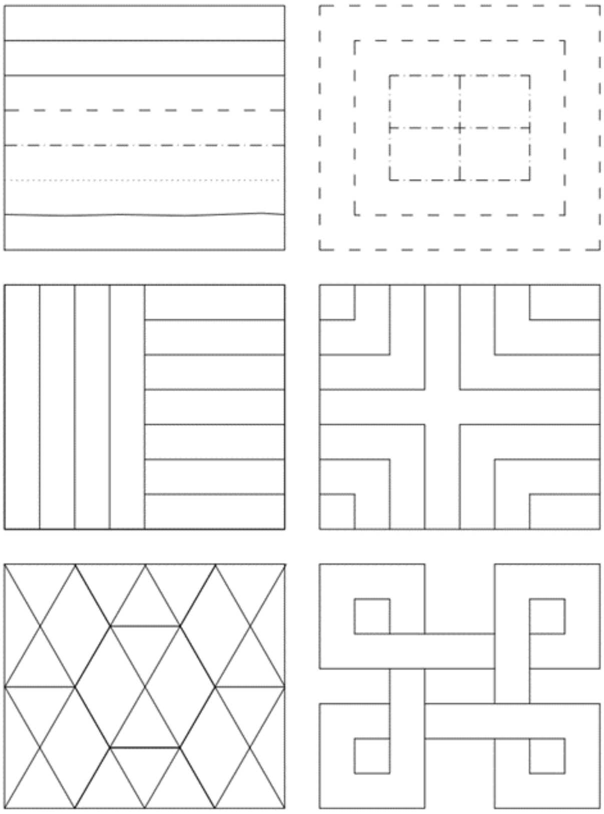


Fig. 4.12 Examples for line exercises

4.6 Orthographic Projections

The use of different views to describe an object, as seen previously, is based upon the principles of orthographic projection. Ortho- means 'straight or right angles' and -graphic means 'written or drawn'. Projection comes from two Latin words, 'pro' meaning 'forward' and 'jacere' meaning 'to through'. Thus, orthographic projection means 'through forward, drawn at right angles'. The following definition has been given: Orthographic projection is the method of representing the exact form of an object in two or more views on planes generally at right angles to each other, by dropping perpendiculars from the object to the planes (Rathnam 2018).

The most informative view of an object shall be used as the front or principal figure, taking into consideration, for example, its functioning position, position of manufacturing or mounting.

Each view, with the exception of the front or principal figure (view, plan, principal figure), shall be given clear identification with a capital letter, repeated near the reference arrow needed to indicate the direction of viewing for the relevant view. Whatever the direction of viewing, the capital letter shall always be positioned in normal relation to the direction of reading, and be indicated either above or on the right side of the reference arrow.

The designated views may be located irrespective of the principal figure. The capital letters identifying the referenced views shall be placed immediately above the relevant views (Fig. 4.13) (ISO 128-30:2001(E)).

When views (including cuts and sections) are needed, these shall be selected according to the following principles (ISO 128-30:2001(E)):

- limit the number of views (and cuts and sections) to the minimum necessary but sufficient to fully delineate the object without ambiguity;
- avoid the need for hidden outlines and edges;
- avoid unnecessary repetition of a detail.

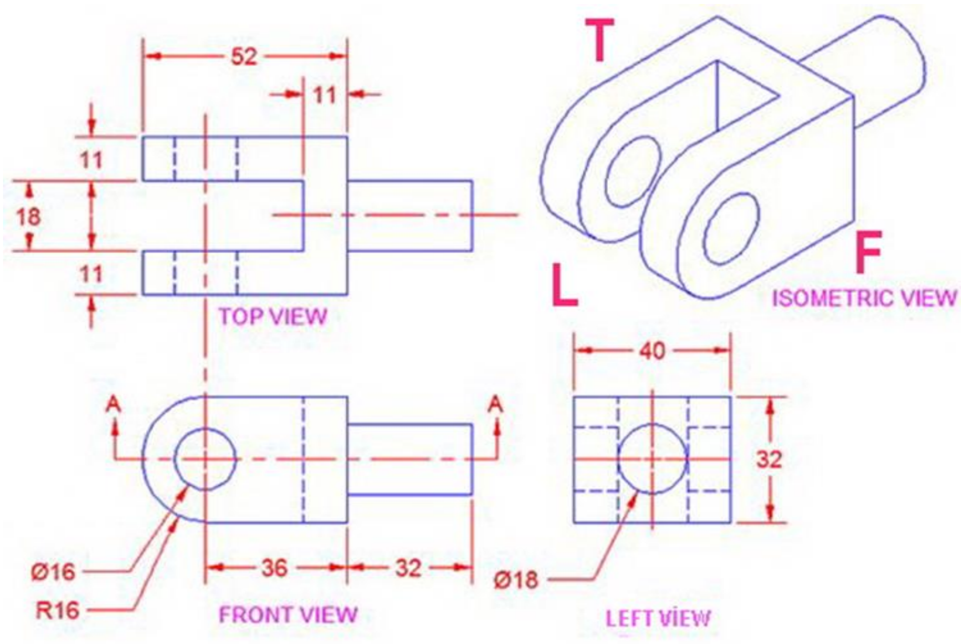


Fig. 4.13 Three different views of a model

4.6.1 Orthographic view exercises

Draw auxiliary views of Fig. 4.14 with pencil. Take the squares dimensioning the figures 1 by 1 cm by using graph paper.

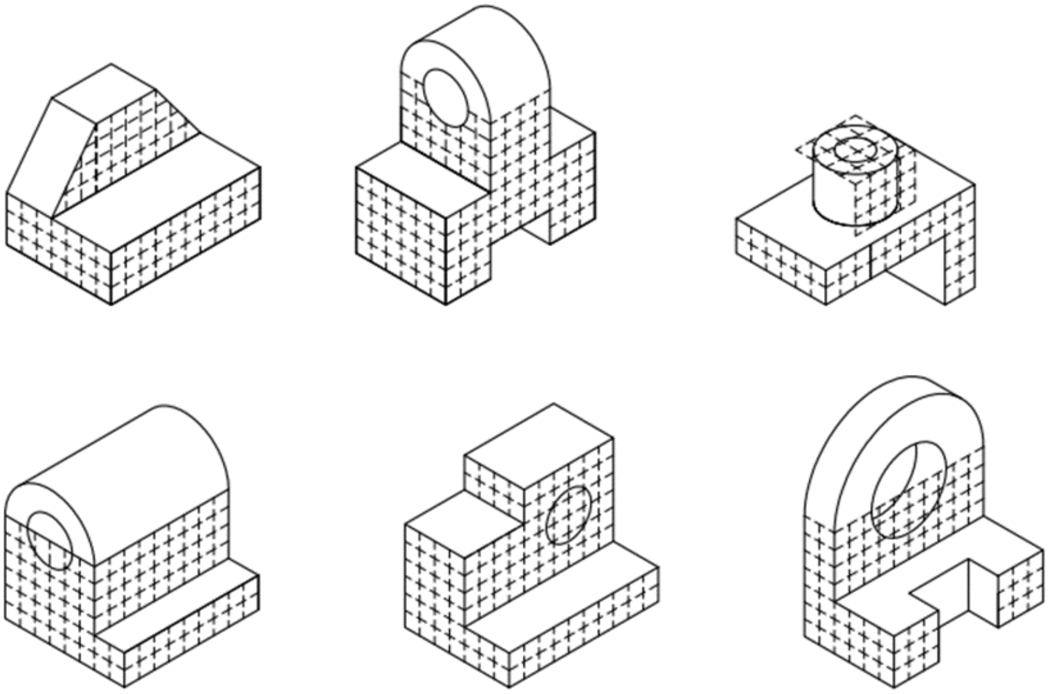


Fig. 4.14 Auxiliary view exercises

4.7 Composition of technical drawings

Composition of drawings is up to the project. If they are not specified in the contract designer should decide which sheets is necessary to tell the design perfectly. In general, set of drawings form of plans, sections and details.

4.7.1 Plans (Layout)

The information about the location of the structure in the space can usually be extracted from the layout, i.e. coordinates of the beginning and end of the structure, all the refractions etc. The same can be determined in the horizontal cross-sections at multiple levels depending on what should be shown in that cross-section, for example, the base of the foundation, the base of the columns, the base of the carriers (Fig. 4.15).

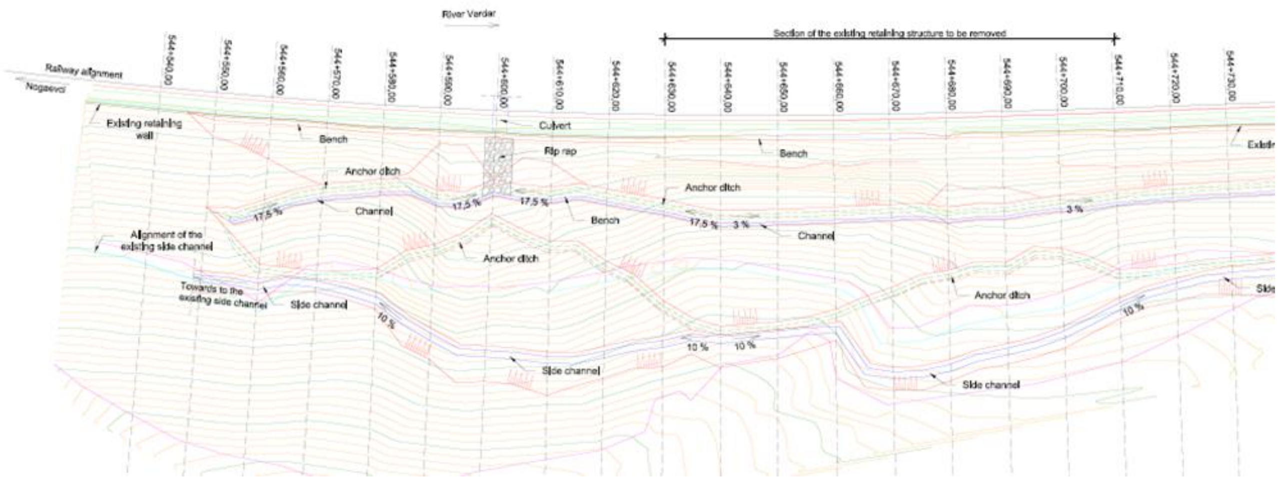


Fig. 4.15 Typical layout of a part of a structure (Geing 2018)

4.7.2 Sections

Sections are perfect tools to show the details of vertical elements, and relationship with horizontal elements. For different purposes, by cutting a solid object, a building, a landscape project or road project by a virtual plane and drawing maintained part is called section. Sections generally does not show the details before or after section line. In long sections, for example road longitudinal sections, vertical scale can be exaggerated for example ten times to see the details (Görcelioğlu and Çelik 2000)

According to contracting the standards for preparation of design documentation, the designer is obliged to draw cross-section or longitudinal section.

Identification of section place and direction and composition is up to the project. Sometime there is custom for taking section place and direction otherwise designer is free to better show the design.

The cross-section is drawn in a way that in the layout along the axis of the structure, normal cross-sections are made on that axis and then the structure is drawn in that section, so that what is cut with that line is shown on the drawing. Most often, cross-sections of characteristic locations are made, that is where the structure changes its characteristics in terms of geometry, material characteristics etc. From this cross-section, information is gathered regarding the level of foundation, the maximum height of the cross-section, the materials used in it etc. (Fig. 4.16).

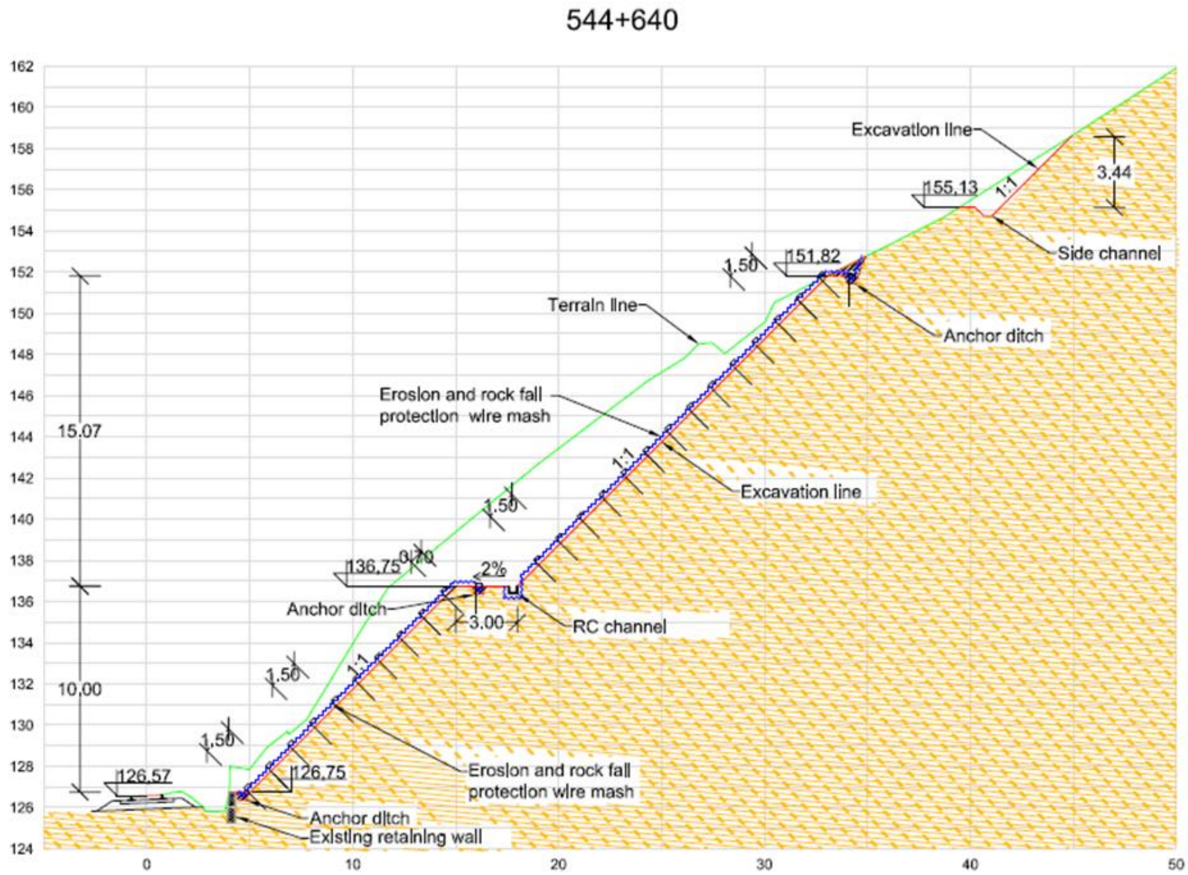


Fig. 4.16 Typical cross section of a stabilization project of a slope (Geing 2018)

The longitudinal section is created along the axis of the structure and its entire length and then it is cut with a vertical plane, thus we have information for its entire length, its positioning level and the change of its height along its length. Most often, a table is provided directly below the drawing with information about the structure (Fig. 4.17).

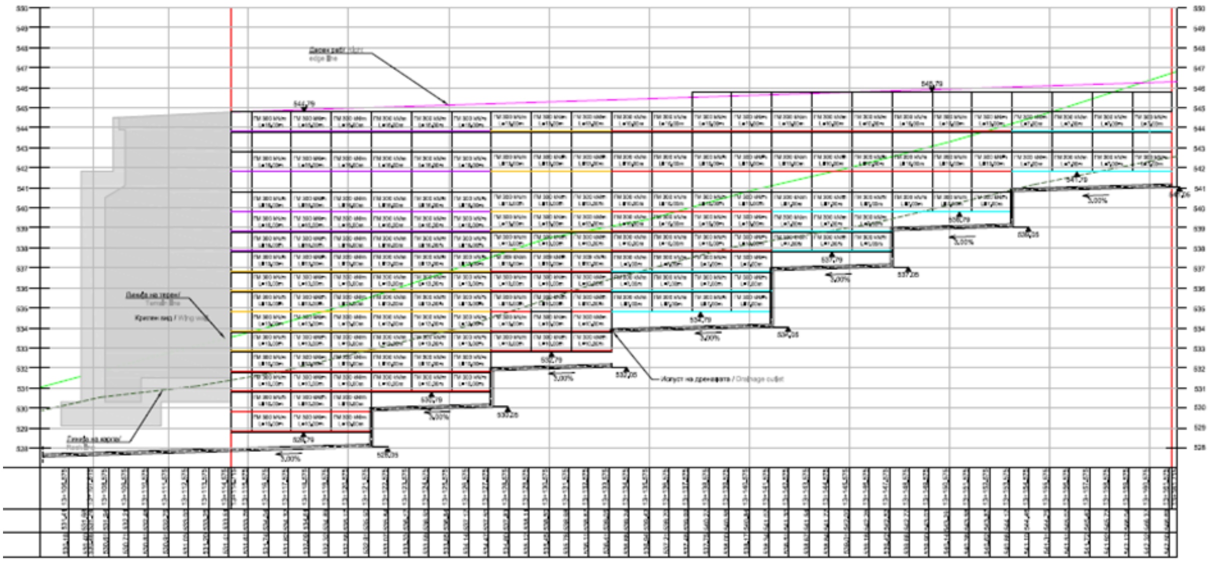


Fig. 4.17 Typical longitudinal section of a structure (Geing 2018)

4.8 Isometric Perspective

It is easy to draw the two principal views (plan and elevation) of an object from its pictorial representation. The reverse is not always easy to visualize the object from two of its principal views. A third view on the profile plane aids to visualize the exact shape of the object. Isometric projection is an orthographic projection of an object on the vertical plane showing its three dimensions in one view (elevation). To understand the principles of isometric projection, let us consider the auxiliary projection of a cube. The problem is one of drawing the projections of a cube when one of its solid diagonals is perpendicular to the vertical plane. The solution for this problem, which is self-explanatory, is given in Fig. 4.18.

The special features on the final elevation are summarized as follows:

1. The 12 edges of the cube are distinct.

2. Three edges d'h', e'h' and g'h' are invisible.

3. The 12 edges are equal in length and hence they are equally inclined to the VP.

4. The edges a'b', c'd', e'f' and g'h', which are parallel, are also parallel in the final

elevation.

5. The edges a'd', b'c', f'g' and e'h', which are parallel, are also parallel in the final

elevation.

6. The vertical edges a'e', b'f', c'g' and d'h' are also vertical in the final elevation.

7. The faces of the cube are equally inclined to the vertical plane.

8. The diagonal a'c' on the face a'b'c'd' is not foreshortened and is perpendicular

to the edge b'f'.

9. The diagonal a'f' on the face a'b'f'e' is not foreshortened and is perpendicular to

the edge b'c'.

10. The diagonal c'f' on the face b'c'g'f' is not foreshortened and is perpendicular to

the edge b'a'.

11. The edges b'f', b'c' and b'a' make equal inclination of each 120°.

The final elevation is the isometric projection of the cube (Rathnam 2018).

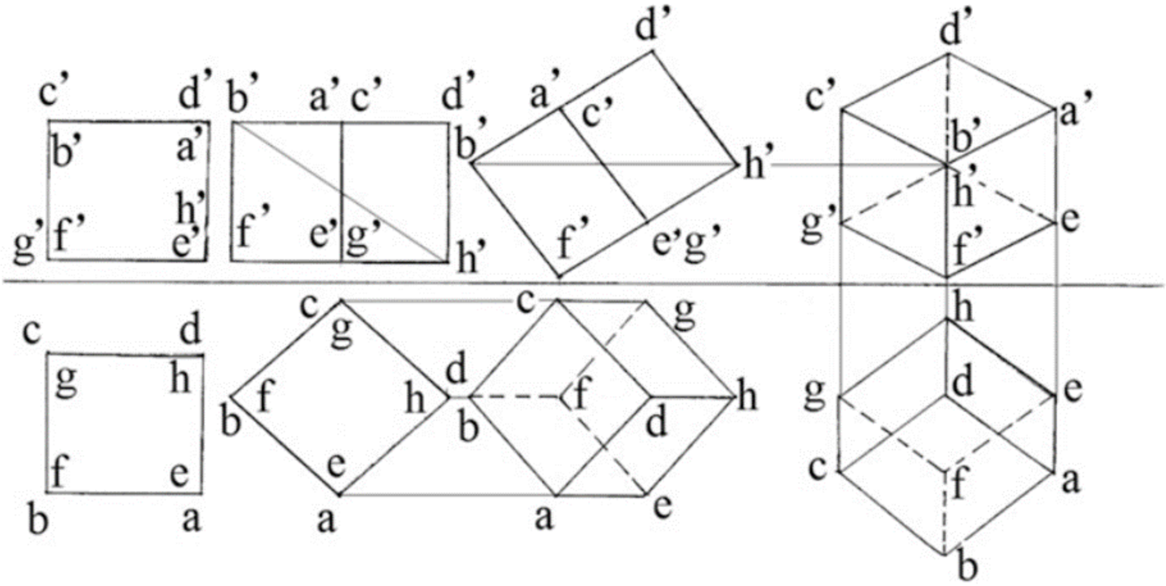


Fig. 4.18 Isometric perspective of a cube (Rathnam 2018)

4.9 Orientation and reading technical drawings

Generally, designer has no problem with the reading of his or her project. But sometimes project designer and practitioner are not same or after construction during the maintenance work you have to read a project not belong to you. Therefore, you have to be skilled in this area. Some part of the necessary information was given in the previous chapters.

North direction is indicated in the projects. To read the project correctly, it is mostly necessary to line the project.

To read a project properly, it is necessary to know the meanings of border, title block, revision block, scale, basic symbols, notation and units, circled numbers, projections and views and abbreviations. Some figures may not be drawn by scale, so they include "not to scale" information (Anonymous 2018)

The border sometimes includes letters and numbers to delineate zones, in the same way as a map, to help locate and pinpoint certain areas.

A title block will typically appear in the bottom-right corner of a drawing and contains information related to the drawing; name of the project, designer, scale, north direction etc.

Basic symbols are used to identify topography, construction, construction material etc.

Circled numbers directs the reader to details, because project scale generally not adequate to show necessary information.

Abbreviations are used to indicate elements and instructions to similar to circled numbers.

4.10 Freehand sketching

Freehand sketching is one of the effective methods to communicate ideas irrespective of the branch of study. The basic principles of drawing used in freehand sketching are similar to those used in drawings made with instruments (Reddy 2008). Even if you are expert on the any computer aided design drawing program, skilled freehand is again necessary, for example to tell a detail to a colleague, a client or labor in the construction site. Freehand perspective drawing skill also is very important because it is possible to understand the perspective drawings easily even by an ordinary people who is not familiar to technical drawing.

4.11 Computer Aided Design and Drawing (CADD)

According to Reddy (2008) in previous chapters we dealt with traditional drawings in which we use essentially drawing board tools such as paper, pencils, drafter, compasses, eraser, scale etc., which will take more time and tough in complex drawings. The most drawback with traditional drawing is INFORMATION SHARING i.e. if an engineer is drawing design of machine component and suddenly the manufacturer to modifies dimension of innermost part of the component; in such situations one cannot modify the drawing already drawn, he should redraw the component

CADD is an electronic tool that enables us to make quick and accurate drawings with the use of a computer. Drawings created with CADD have a number of advantages over drawings created on a drawing board. CADD drawings are neat, clean and highly presentable. Electronic drawings can be modified quite easily and can be presented in a variety of formats. There are hundreds of CADD programs available in the CADD industry today. Some are intended for general drawing work while others are focused on specific engineering applications. There are programs that enable you to do 2D drawings, 3D drawings, renderings, shadings, engineering calculations, space planning, structural design, piping layouts, plant design, project management, etc.

Examples of CAD softwares are: AutoCAD, PROIEngineer, IDEAS, UNIGRAPHICS, CATIA, Solid Works, etc.

Advantages of CAD are:

(i) Detail drawings may be created more quickly and making changes is more efficient than

correcting drawings drawn manually.

(ii) It allows different views of the same object and 3D pictorial visualization of drawings

(iii) Designs and symbols can be stored for easy recall and reuse.

(iv) By using the computer, the drawing can be produced with more accuracy.

(v) Drawings can be more conveniently filed, retrieved and transmitted on disk and tape.

(vi) Quick Design Analysis, also Simulation and Testing Possible (Reddy 2008).

4.12 Technical drawing in soil and water bioengineering (swb)

Technical drawing in swb is generally used for making plans, showing auxiliary views, sections and giving details about the project or structures of swb measures.

4.13 Sample of soil bioengineering projects and drawings

Example project:1

Bio-Materials in River Regulation: by GEING

People's century-long pursuit is to adapt water as a basic element of their survival to their needs. The objectives to be achieved should be supported by comprehensive and appropriate technical solutions based on well-studied layouts and wider interests of the community.

Rivers and their basins are an integral part of our daily existence, but the experience of managing these important resources in the past shows a number of disadvantages. Worldwide and in Macedonia, many rivers and basins are degraded by intensive human influence.

The effects of aquatic ecosystems impacts have taken an initiative in many countries at multiple levels of society emergency actions to prevent or reduce impacts and manage ecosystems in a sustainable way.

The character, the specificities and the nature of the watercourse must be taken into consideration during course regulation. Successful regulation requires a comprehensive analysis of natural factors and impacts, quantitative and qualitative analysis of the morphology of the riverbed, coastal area, environment, infrastructure, demography, population mentality, complex hydrological and hydraulic analysis and calculations, etc.

A 3D axonometric view of the regulated riverbed on which software analysis for hydraulic dimensioning with calculated maximum water was performed (Fig. 4.19).

The following parameters can be listed as input parameters: geometric data (recorded existing situation, newly designed cross sections and longitudinal fall, recorded existing concrete culverts), boundary flow conditions, height distribution of structures in the gulley, etc.

The output parameters that are obtained from the software are: water level in the watercourse, average Froude number, etc. from where the way of stabilizing the riverbed is defined, in accordance with the obtained values.

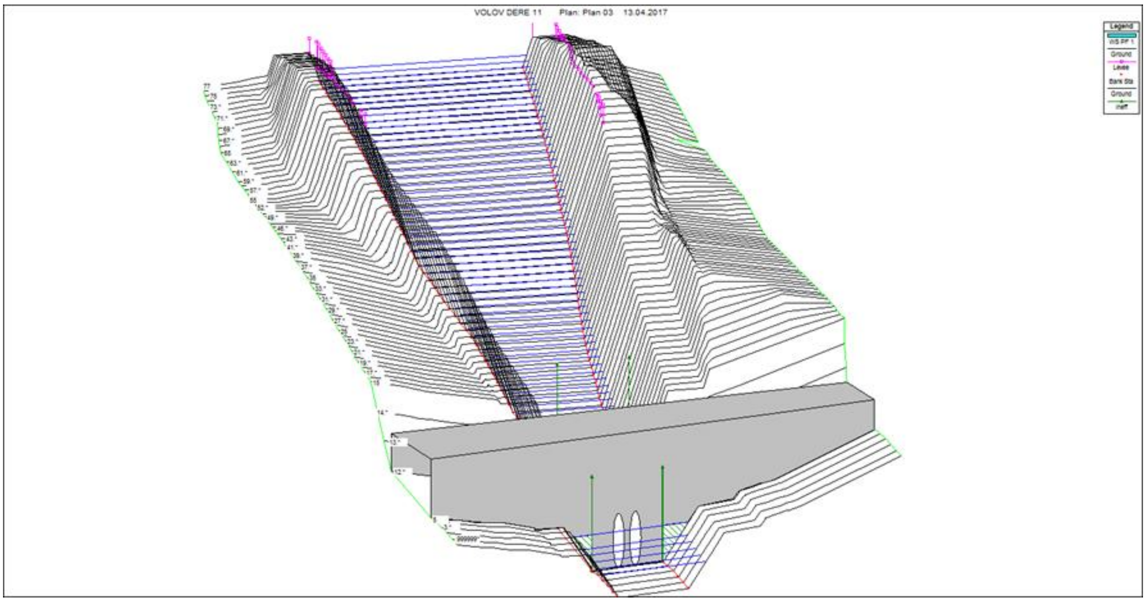


Fig. 4.19 Axonometric view of the regulated riverbed (Geing 2018)

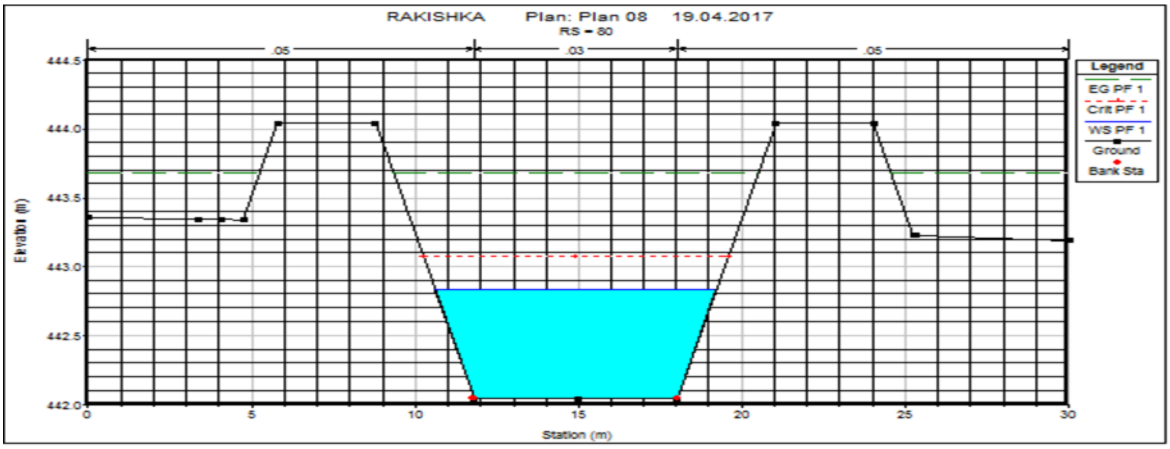


Fig. 4.20 Cross section of the regulated basin with hydraulic model outputs (Geing 2018).

At regulation - watercourses stabilization is regulated with or without the use of transverse objects and with or without the use of riverbed lining.

Also the regulation with use of transverse objects such as sills, check dams and belts, can be derived from concrete, gabions, and from biological materials such as local wood and a combination of wood and stone - stone boxes.

Wooden check dams consist of wooden piles - stakes, horizontal beams - shapes, supports – inclined support beams and base (Fig. 4.21).

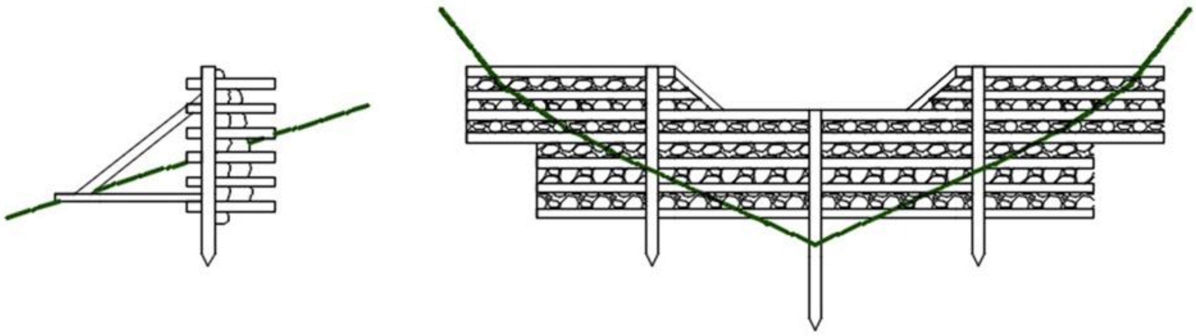


Fig. 4.21 Longitudinal and transversal cross - section of wooden check dams

Check dams from stone boxes actually represent wooden boxes filled with stacked stones (Fig. 4.22).

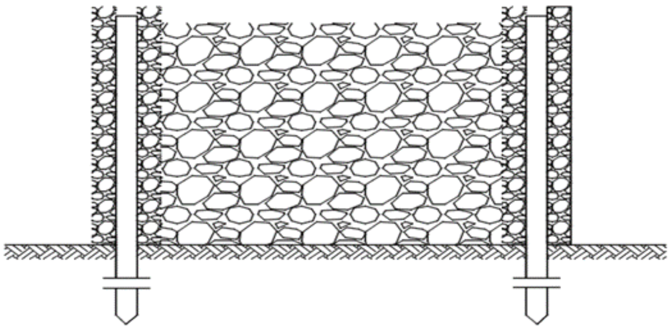
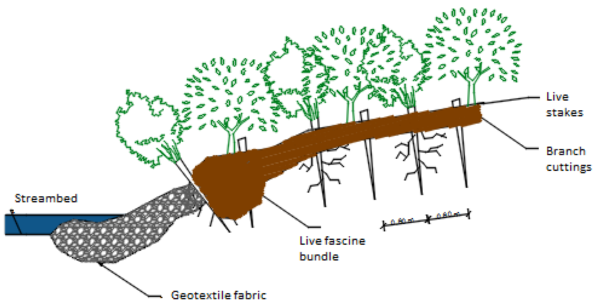


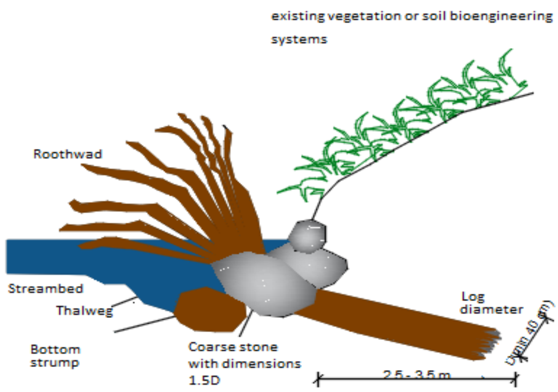
Fig. 4.22 Cross section of check dam stone boxes

As for the riverbed lining, if there is no natural local material lining the slopes are formed and settled, but this is used only in stable watercourses of plain character, if a lining is used for determination of the support beams inclination of the riverbed, it is performed by concrete plaster stone, concrete, gabions, mattresses as well as bio-materials.

Under inclined support beams lining with using of bio materials implies using stone (stacked or mounded) filled faggots with and without additional protection with stakes, logs, planting plants, fastening with live and dead stakes, canes, knitted bedding etc.

The following figures (Fig. 4.23-4.24) provide examples of determining the gradients with bio materials.





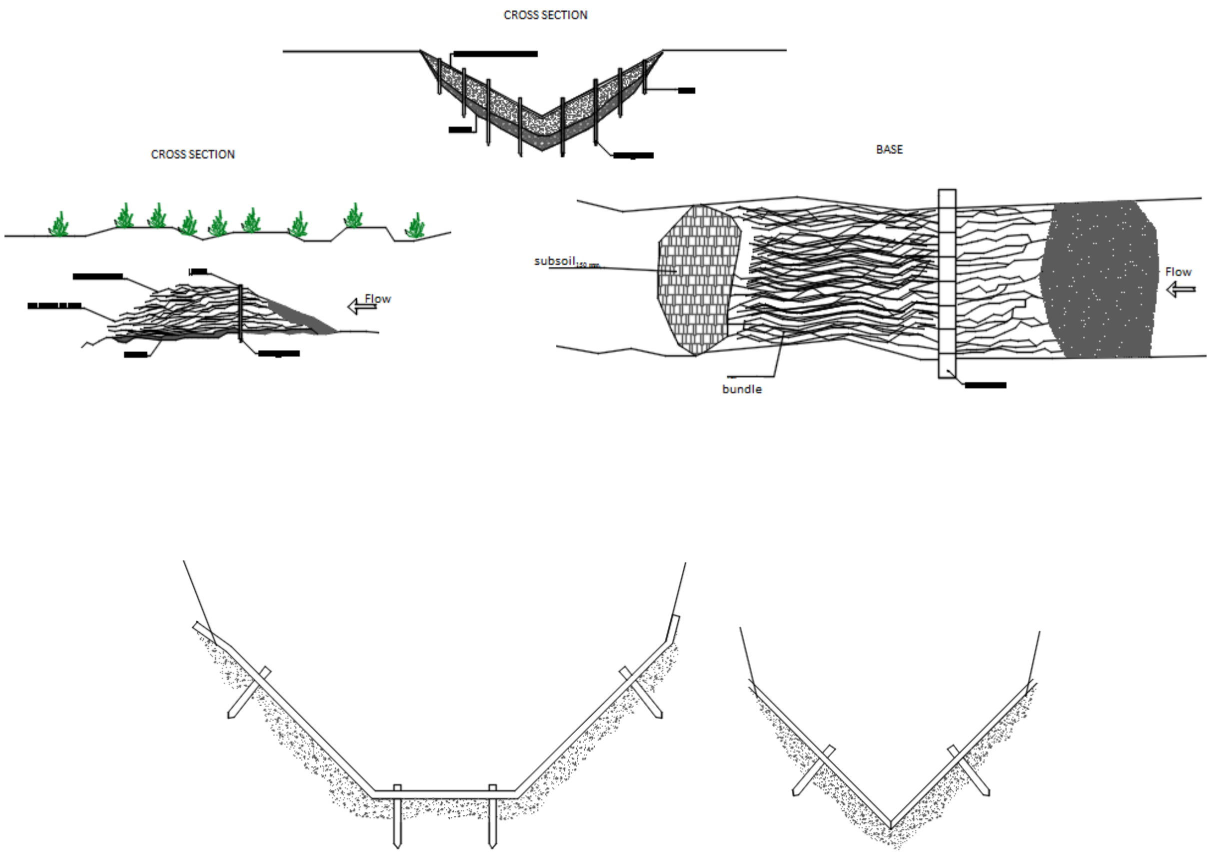


Fig. 4.23 Determining slope types with biomaterials (Geing 2018)

For the given example of the regulated riverbed, a lining of the available local material is selected, where the slopes of the riverbed are coated with faggots fastened in the coast with jute rope.

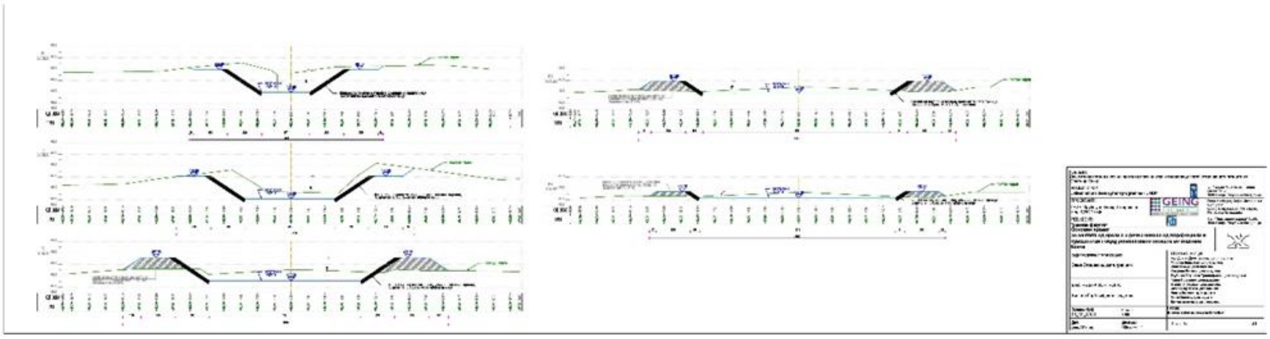


Fig. 4.24 Biomaterials regulated riverbed with cross sections (Geing 2018)

During the stabilization of riverbeds in gulley on steep and erosive slopes where the soil layer is very shallow and skeletal, therefore, there are no opportunities and conditions for direct afforestation and parallel-course structures are used to protect the slopes from erosion.

At locations where there is a stone in the regulation area or in the immediate surroundings, the advantage is given to the construction of rustic walls and mounded stone.

Also, in addition to the rustic walls, there are also dam from intertwined branches that can be with one and two rows. The dam from intertwined branches are in function of biological activities, that is, afforestation. As a result of the erosive processes on the slope there is a small floodplain forming on which the seedlings are planted, and if this does not happen, as well as in conditions of a time shortage for formation of a flood, behind the dam from intertwined branches (upstream side) with a hoe a small embankment is made, on which the seedlings are planted. One row dams from intertwined branches are built at a distance of 5 to 10 m. Their height is 30-50 cm. The function of these dam from intertwined branches in combination with afforestation, to solidify the land that is destroyed, that is, help restore the vegetation of steep and eroded slopes, where for various reasons it is destroyed. Will apply to lands where vegetation is destroyed, naturally, without the prior solidification of the terrain, it cannot be renewed, (revegetate). The two-rowed dam from intertwined branches will be applied on gully and gulley's. They fall into the category of temporary check dams, because they have a relatively low durability. They are built from hand-made material located on the site itself or in its immediate vicinity. The two-rowed dam from intertwined branches consists of two parallel one-row dam from intertwined branches (fences), and the interspace is filled with stone or gravel. The two-rowed dams from intertwined branches are longer lasting than the one-rowed. Deciduous tree species including oak, hornbeam, beech, ash, elm and acacia, willow and alder are used for their construction.

The purpose of the dam from intertwined branches (check dams) is to retain a certain amount of sediment and secure the bottom and gully coast from the erosive power of the waters. After the formation of the floodplain behind the two-row dam from intertwined branches, afforestation is carried out.

For installation of the dams from intertwined branches, stakes with a length of 1.5 to 2.0 m and a thickness of 10-15 cm are required. The distance between the compacted stakes is 40-60 cm. The stakes interweave with branches with a thickness of 2-3 cm and a length of 2-4 m. The distance between the two parallel one row dam from intertwined branches (fences) is 0,8-1,0 m. The useful height of the two-row dams from intertwined branches is not more than 1 m. The durability of the dams from intertwined branches depends on the type of wood from which they are built and the quality of the construction. The durability of the dams from intertwined branches (about 5 years) is enough time that allows the planted seedlings to take over the protective role of the land.

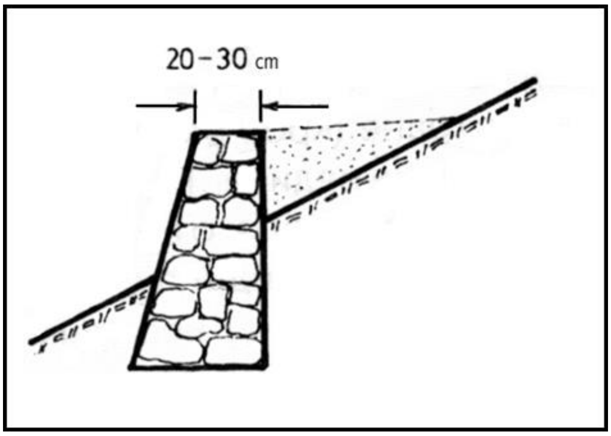


Fig. 4.25 Dry stonewall

Fig. 4.26 Erosive slopes treated with one-row dams from intertwined branches (followed by afforestation)

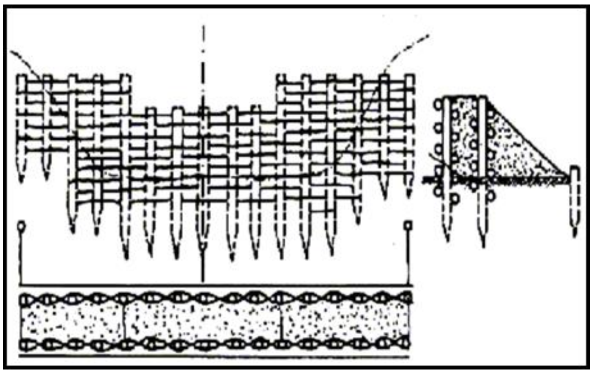


Fig. 4.27 Two row dam from intertwined branches

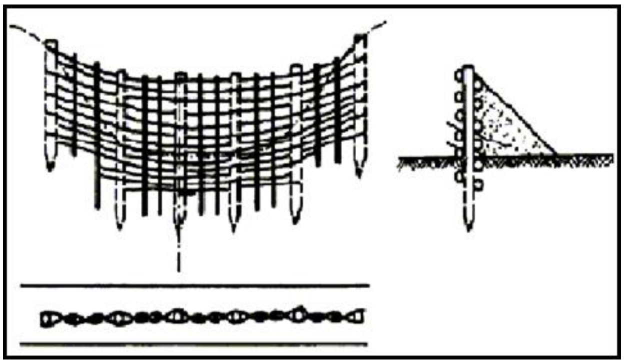


Fig. 4.28 One row dam from intertwined branches

Example project: 2 by GEING

In the following text an overview of a concrete example of the application of geosynthetics and bioengineering is given, where one example will be presented graphically in which all techniques and methods for technical drawing and presentation of complete design documentation is used.

The Landfill "Novo Konjsko" is selected because is a representative example of greenfield projects in the field of environmental protection.

Table 4.3 Some data about the Project (Geing 2018)

Landfill Site	Novo Konjsko (Gornichet)
Cadastral Unit	Novo Konjsko
Cadastral Plot	117
Total cadastral plot area	918.744 m^2
Landfill altitude	220 m
~ Total landfill area	29.500 m^2
~ Landfilling area only	11.450 m^2
~ Length of access road	1.540 m (alternative road from Moin 2.340 m)
~ Access Road Slope	8.0 % (alternative road 8.3 %)
~ Distance from municipal center	7 km

Project task and objective

During 2015 - 2016, due to the large wave of migrants from Syria who left their country in search of a new home and care in the countries of the European Union were stopped at the Macedonian - Greek border where they would have controlled entry in the European countries, however, during this period in the refugee camps at the border, a large amount of waste was produced that the regional landfills could not operate. For this reason, the need for designing a landfill for non-hazardous waste has arisen to accommodate the excess waste from this region.

The projected landfill was supposed to have a capacity of min 60 000 m3 waste located on an area of 11 000 m2, to pinpoint out technology and to apply materials that will ensure prompt and unobstructed construction of the landfill, which will be put into operation in the shortest possible time, and at the same time to meet all the European environmental conditions and standards and to meet the criteria for designing landfills.

At the beginning of the design of such a structure, the area and the structure location is first determined, parcel is demarcated i.e. it defines the structure scope and within that limit the landfill is constructed with all its accompanying structures. For this purpose, situational overview of the location with marked scope of the object was made. In the first phase of designing while the project is in idea, smaller scale is used to define the location, the orientation of the structure and the structure appearance. Preliminary geometry or geometric variants of the landfill body are proposed, for this purpose, cross and longitudinal sections are prepared in order and for the purpose of presenting the shape and landfill form. Variants are also proposed for types of materials that would be combined in accordance with the rulebooks and standards that are relevant in our regulation. Terrain investigation was made for possible risks and hazards that would occur in case of landfill system failure, etc.

Situational display of the geometric excavation variant and display of the landfill in its final phase (after exploitation), i.e. closing. Situations are in scale 1:500 information only on the location and method of excavation formation and landfill covering can be obtained from them.

Fig. 4.29 General layouts for positioning the landfill (Geing 2018)

The drawings above give the preliminary appearance of the landfill without many technical details for precise geometry, etc. at this stage the landfill is positioned and the structures that will be further developed in the next phase of the project are deployed. Also at this stage, cross sections of segments with sealing and covering variants are given, with all their advantages and disadvantages. In the concrete case, three variants are proposed for the two systems, where one of the variants is guided by conventional methods, and the other two variants are combinations of geosynthetics and geosynergies to provide waterproofness and stabilization of the slopes.

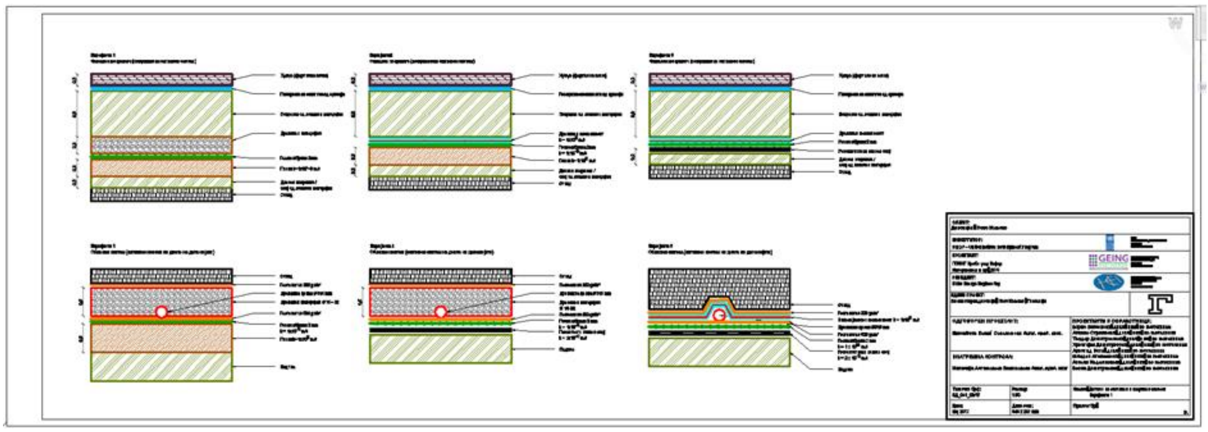


Fig. 4.30 Variant solutions for sealing and covering systems (Geing 2018)

Conventional methods for sealing and covering of landfills include natural materials that would be provided from the environment of various borrowings, while geosynthetics are artificially produced materials that have the same function as natural materials with much stronger characteristics and are laboratory controlled in production, they come in rolls and do not require special installation equipment while, the use of natural materials, i.e. clay sands, involves great mechanization that makes the performance of the future object more difficult and prolongs the deadline for construction, and it requires a greater number of workers, including opening of new borrowings that would endanger the environment. Another aspect of the application of geosynthetics is that it also gets to the volume of a useful waste disposal site, because geosynthetics are very small in thickness of max 2,00 cm. In summary, the use of geosynthetics that is environmentally friendly, more applicable, better and faster execution, saves a large amount of money that in the concrete case from the techno economic analysis was calculated savings of approximately 15% of the total amount.

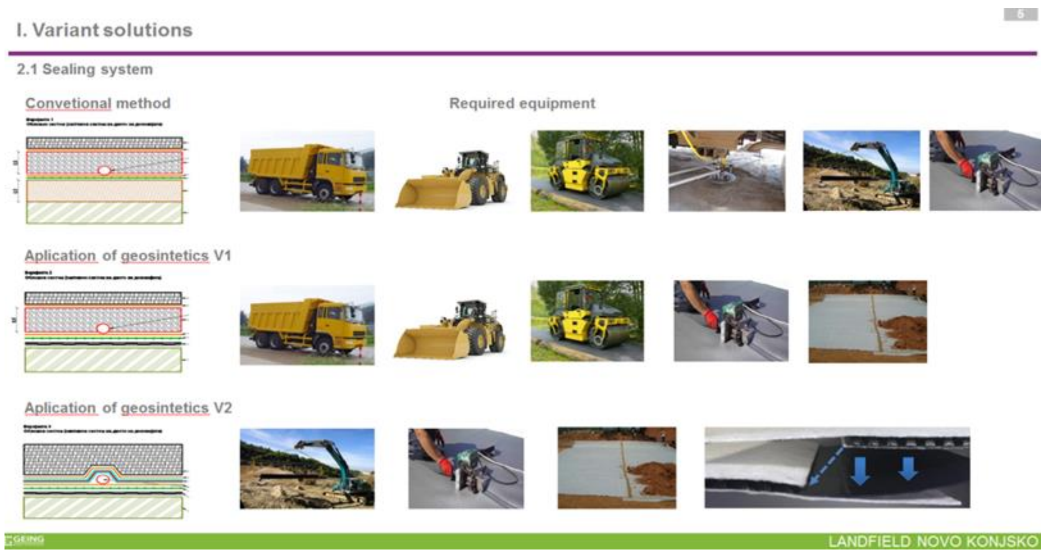
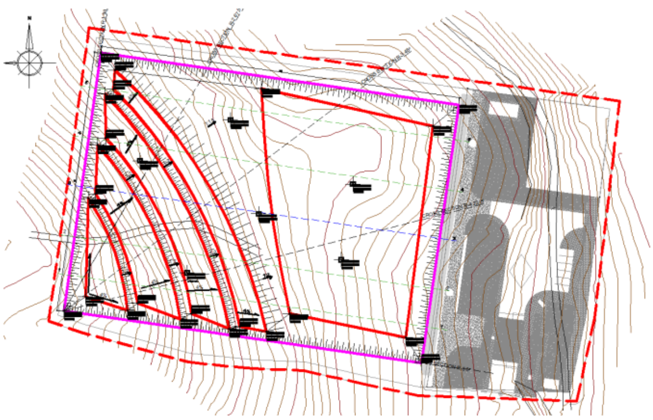
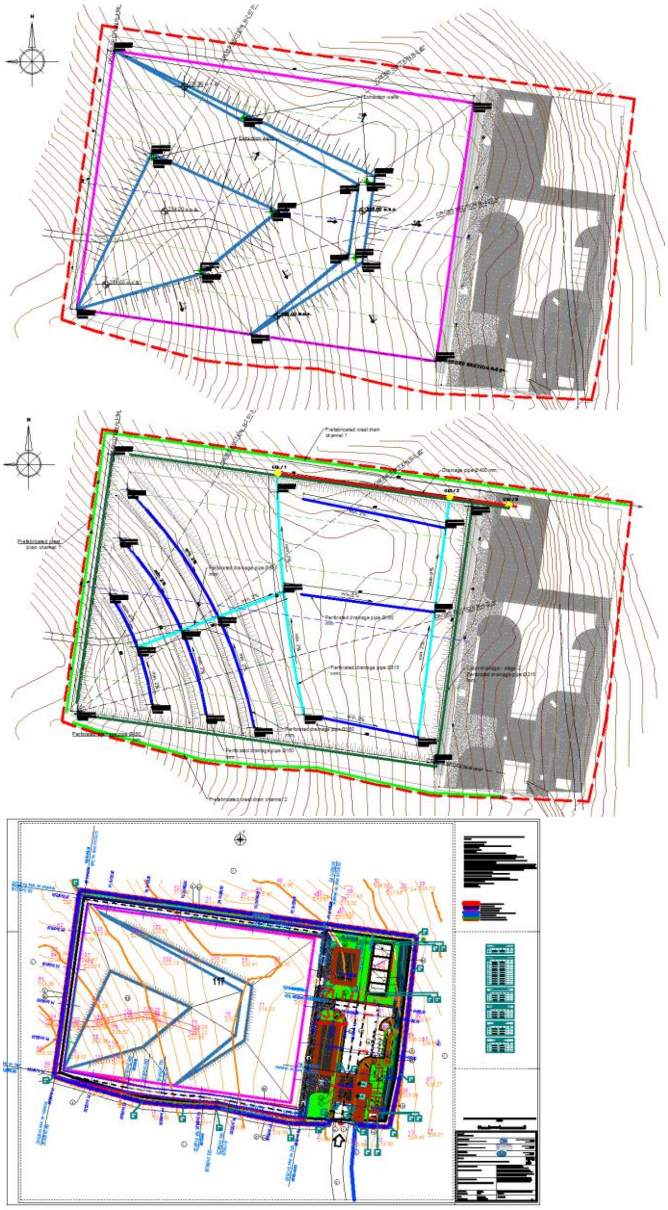


Fig. 4.31 Required equipment for executing the construction (Geing 2018)

Once a geometric variant and use of geosynthetics has been selected, a more detailed development of the project documentation is being prepared, where larger scale drawings are detailed, landfill capacity calculations were made, calculations for slopes stability formed during excavation and landfill exploitation i.e., (deposited waste). Waste segregation analysis, that is, subsidence control and how much it affects the applied materials, quantity of process water generated from the decomposition of the waste, defines the materials (geosynthetics) what are the required minimum characteristics, the construction of access roads around the landfill which make it functional and at the end the bill of quantities of materials needed to build such a structure.



Situation 1 which shows the excavation for installation of the sealing system drawn in scale 1:100 from where we can get information about the excavation depth, coordinates of each overlapping surfaces points, etc.



Situation 2 in scale 1:100 which shows the covering system for landfill closing, from here we can obtain information about the coordinates height position of the biotrns (degassing) for gases capture, area size of and etc.

Situation 3 in scale 1:100 which shows the drainage system for collecting the process and surface waters, the installation depth, the coordinates of each breakpoint, pipe type and size, revision manholes position and type, etc.

Summary situation 4 in scale 1:250, a situation that represents the final phase of landfill usage i.e. the appearance after its closure, the necessary structures during exploitation, etc.

Fig. 4.32 Grading plan (Geing 2018)

On the cross sections, the excavation, the sealing system, the covering system is drawn, and through them the waste amount that would be deposited in the landfill is calculated, from here you can get data on the slopes inclinations, the dimensions in that cross-section, and the progress of height during landfill exploitation, etc.

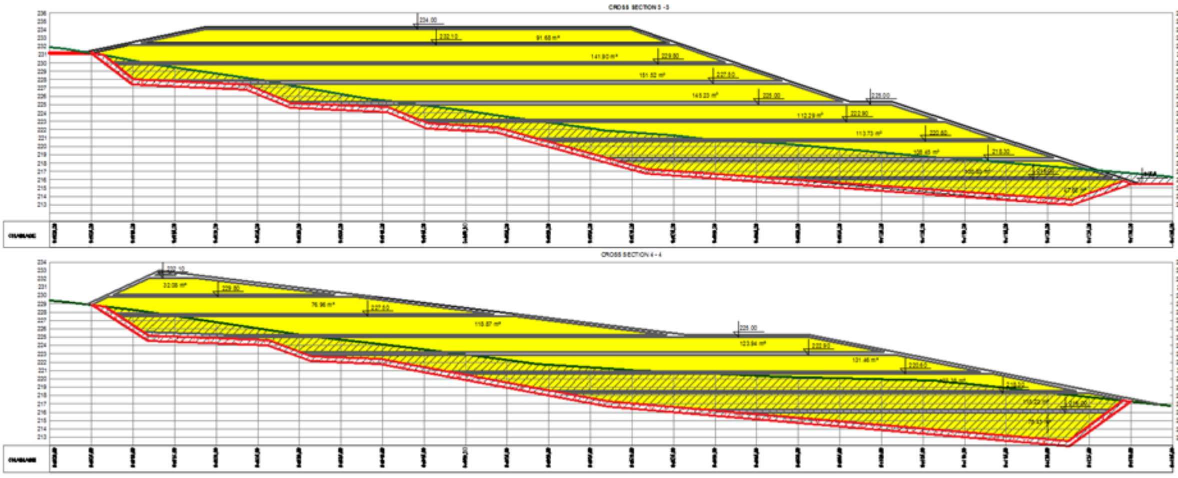


Fig. 4.33 Typical cross sections of the landfill (Geing 2018)

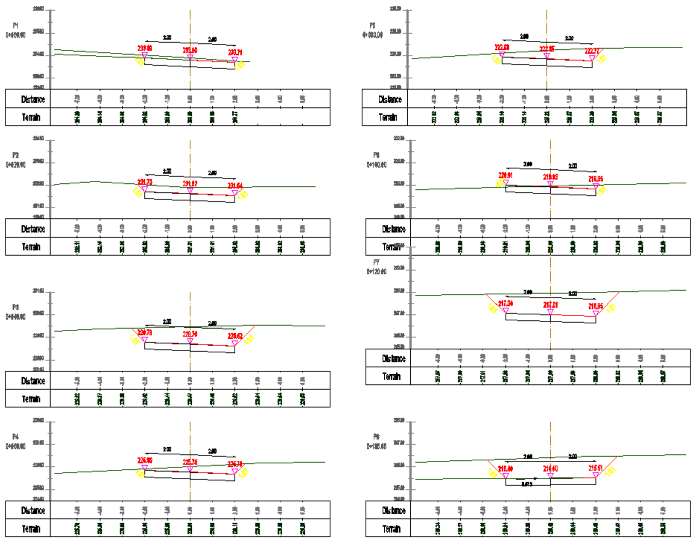


Fig. 4.34 Cross sections of road construction (Geing 2018)

From these cross sections, information can be obtained about the intersection of the access road, its intersection height positioning, collecting channels and the surface of excavation or embankment in that particular section. Also, from these sections, we can see the improvement of the substrate under the pavement structure, etc.

The longitudinal sections below show the access roads around the landfill making the same operational (waste transport trucks can be rotated here, temporary overlays etc.). From these drawings information can be obtained about the finished grade inclination (transversal and longitudinal), excavation quantities, that is, embankment for formation of the access around the landfill, etc.

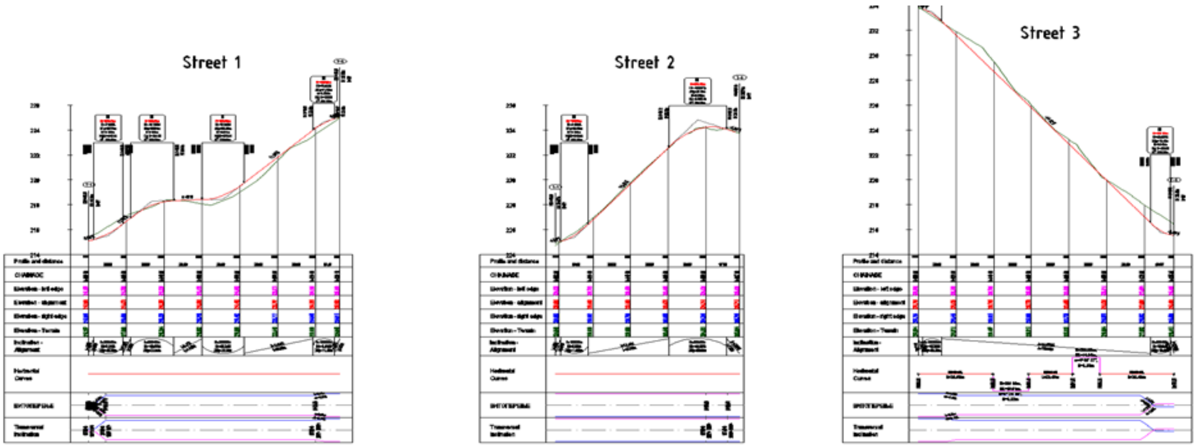


Fig. 4.35 Longitudinal profiles of the road construction (Geing 2018)

In the presented situational plans below, calculation of the necessary areas for formation of the sealing and covering system of the landfill are given. They are displayed on a smaller scale of 1: 500 because they are used only for calculation and nothing is displayed that would be detailed on a larger scale.

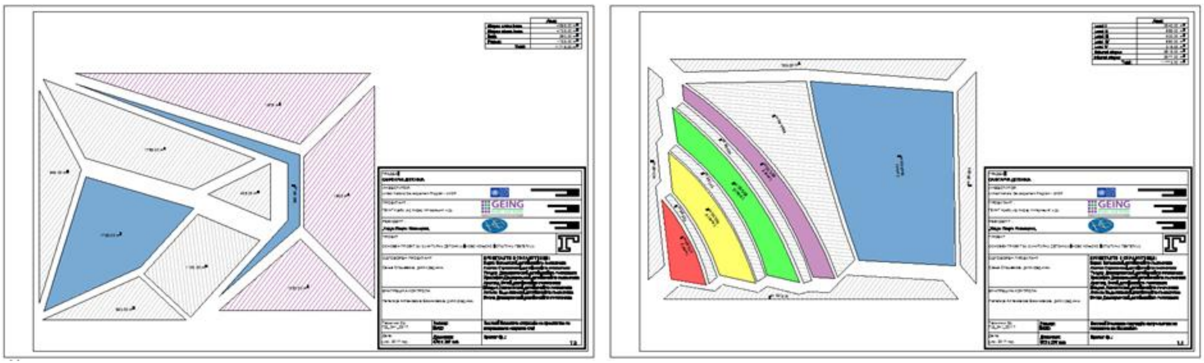


Fig. 4.36 Layouts for calculating areas of the sealing and covering systems (Geing 2018)

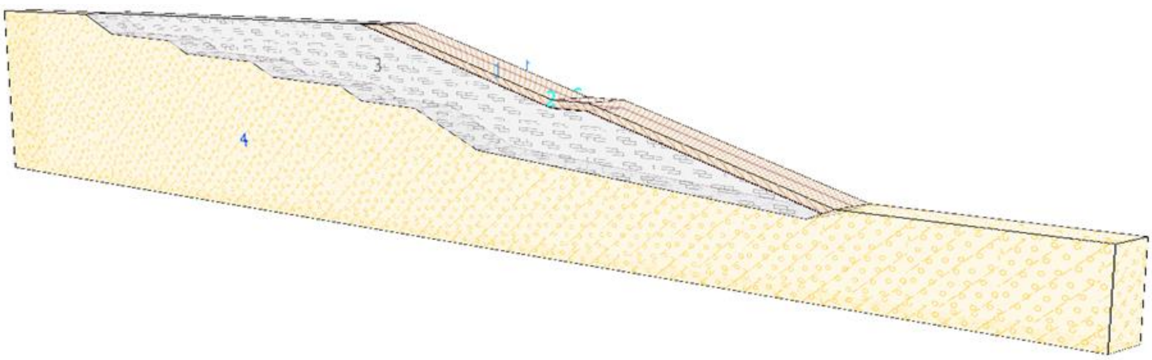


Fig. 4.37 3D design of the landfill (Geing 2018)

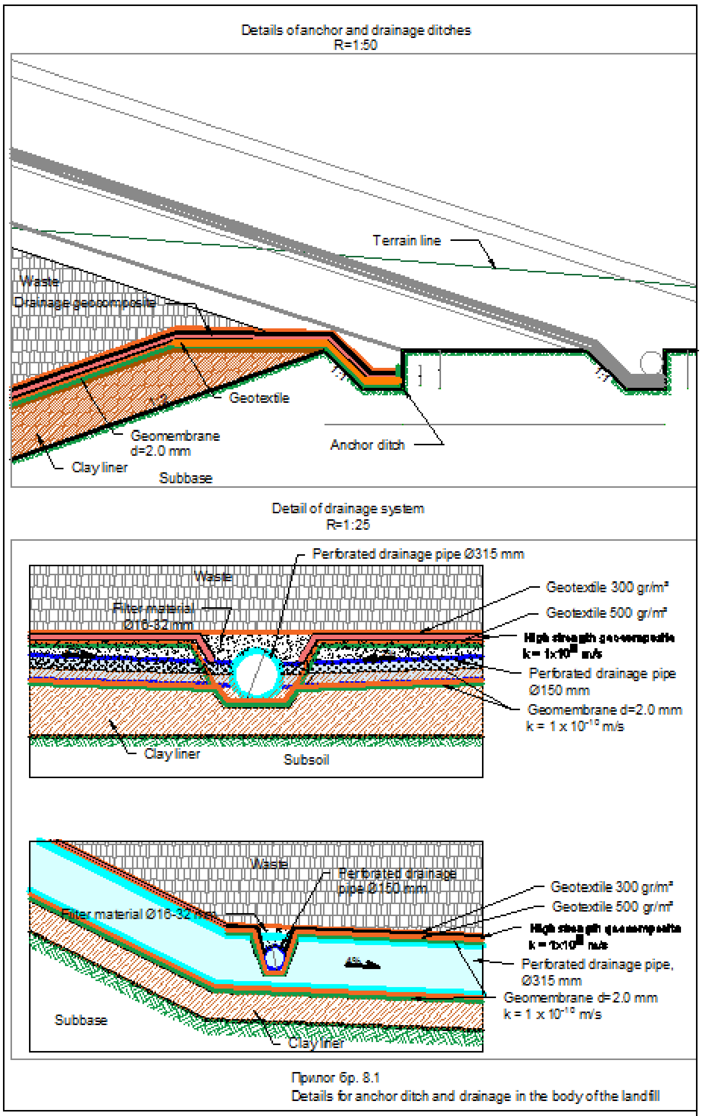


Fig. 4.38 Drainage system technical details (Geing 2018)

And as the final drawings in one project documentation are the details showing the sealing and covering system and their anchoring. The installation method, types and minimum characteristics of the materials used during the design, dimensions of the same, etc.

In summary, for preparation of such project documentation takes many calculations and drawings where everything it will be covered in detail for anyone involved to have a clear picture in the project, otherwise, there may be major hazards that endanger the environment in which factors are (people, animals, plants).

Ex. if the sealing system fails, drainage waters leakage from the landfill can occur, which can further come into contact with some underground water used for drinking or irrigation.

Or if there is a disruption of the covering system, evaporation of toxic gases can result, which can further cause various diseases of animals and plants. In any case, great and due attention is needed in developing such projects types that are essential for a society.

Example project 3: Kartaltepe Slope stabilization Project, Istanbul Turkey

In the slope stabilization of Kartaltepe metro station, wattle fences were used to annihilate the gullies and to prevent the surface erosion in 1988. Behind the 3 m interval wattle fences, trees planted. To cover the surface some legume and graminea species seeded (Fig. 4.39-4.40)

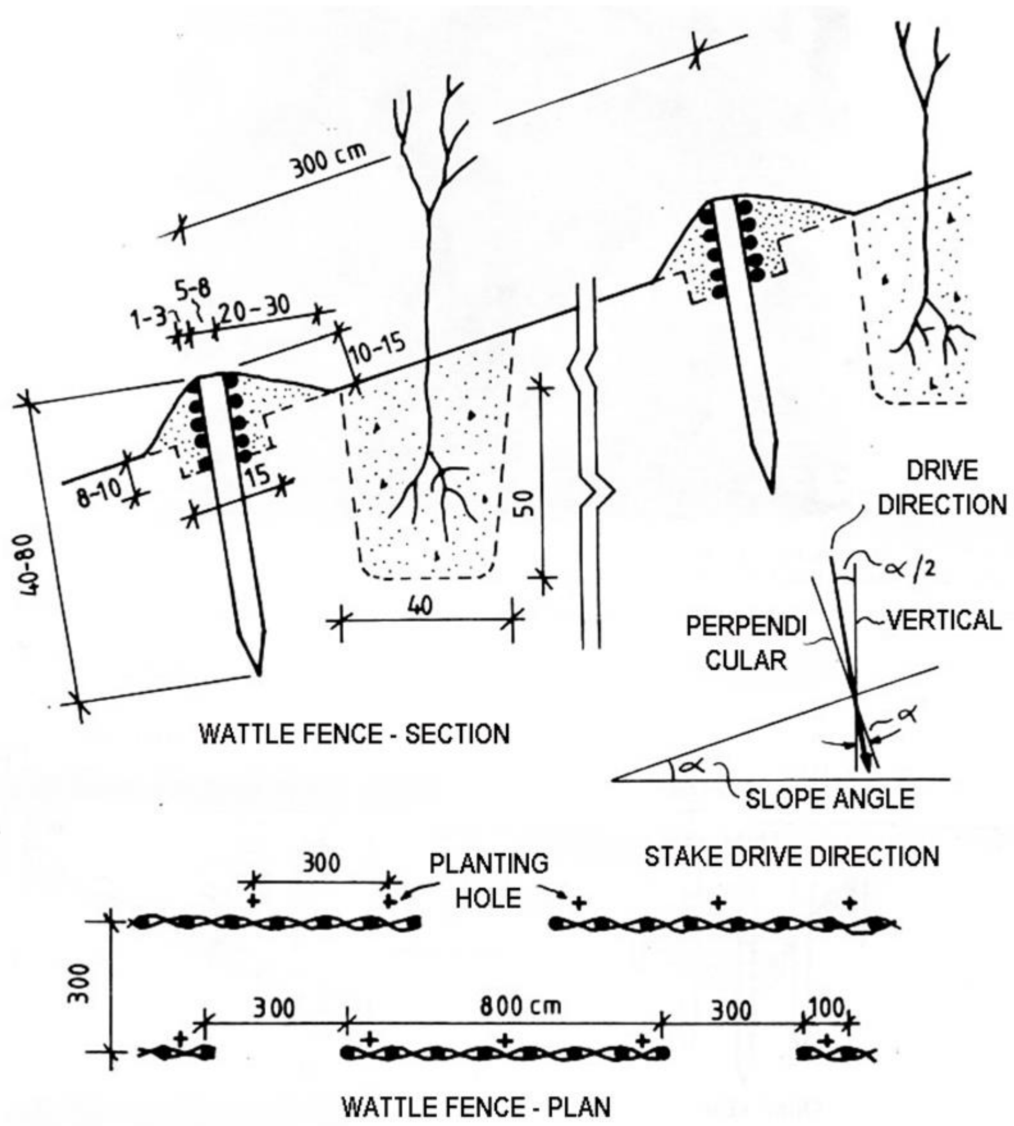


Fig. 4.39 Wattle fence application, section and plan at Kartaltepe-Istanbul by Istanbul University Faculty of Forestry

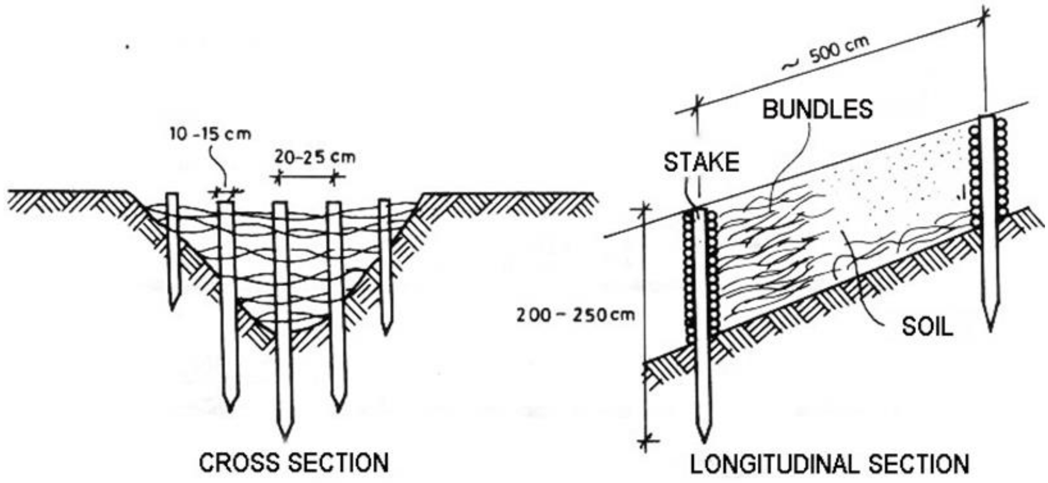


Fig. 4.40 Wattle fences for annihilation of gullies at Kartaltepe-Istanbul by Istanbul University Faculty of Forestry

DIAGRAMS OF SOME SOIL BIOENGINEERING STRUCTURES

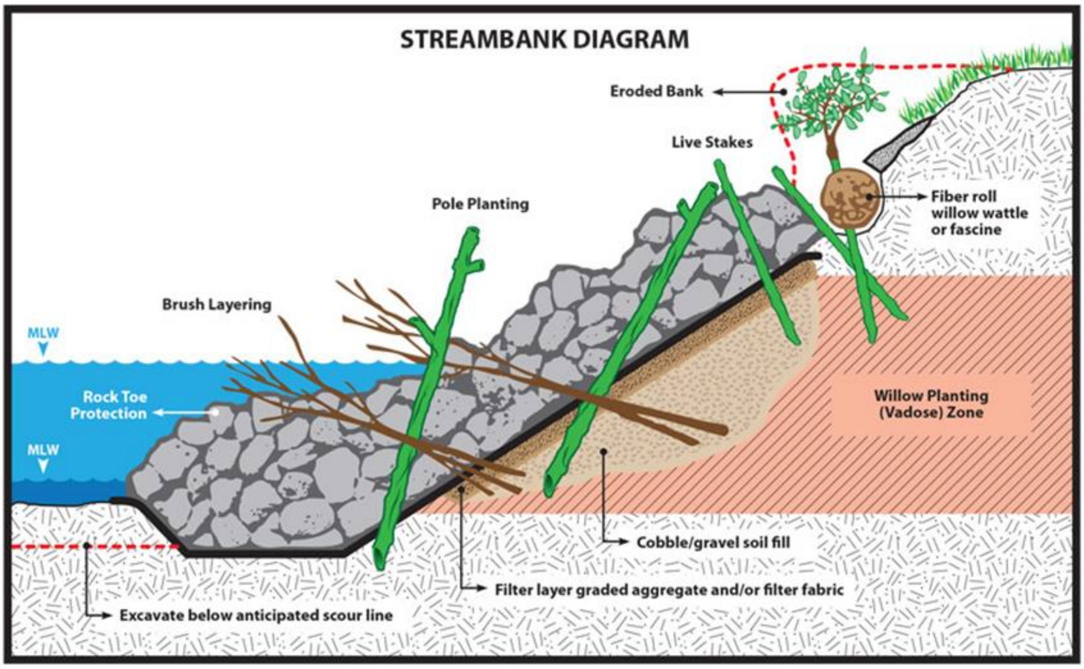


Fig. 4.41 Consolidation of the toe of a bank by using rock and live cuttings, not to scale, https://www.ernstseed.com/products/bioengineering-materials/

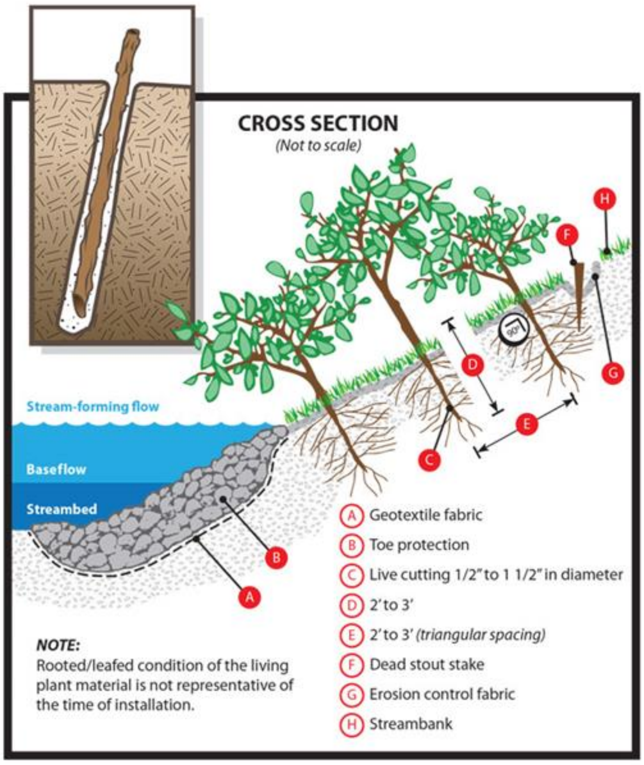


Fig. 4.42 Consolidation of the stream bank by using rock and live stakes, not to scale,
https://www.ernstseed.com/products/bioengineering-materials/

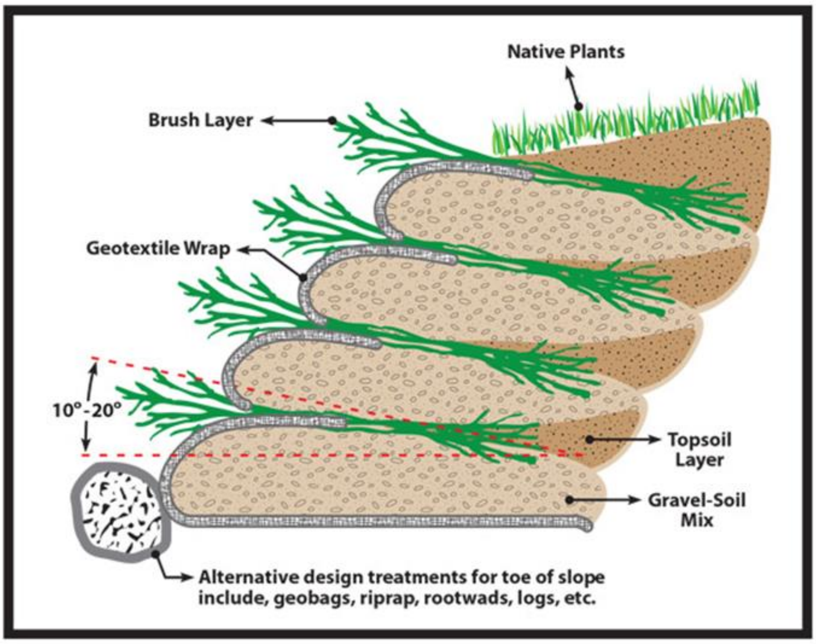


Fig. 4.43 Toe stabilization by geotextile wrap and soil+gravel, not to scale,
https://www.ernstseed.com/products/bioengineering-materials/

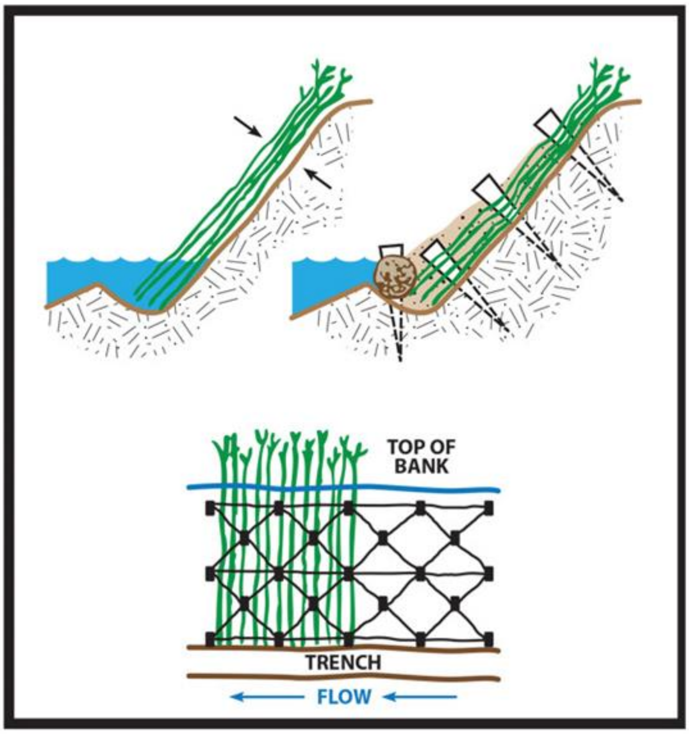


Fig. 4.44 Bank revetment with branches, not to scale, https://www.ernstseed.com/products/bioengineering-materials/

Fig. 4.45 Fascine, https://www.ernstseed.com/products/bioengineering-materials/

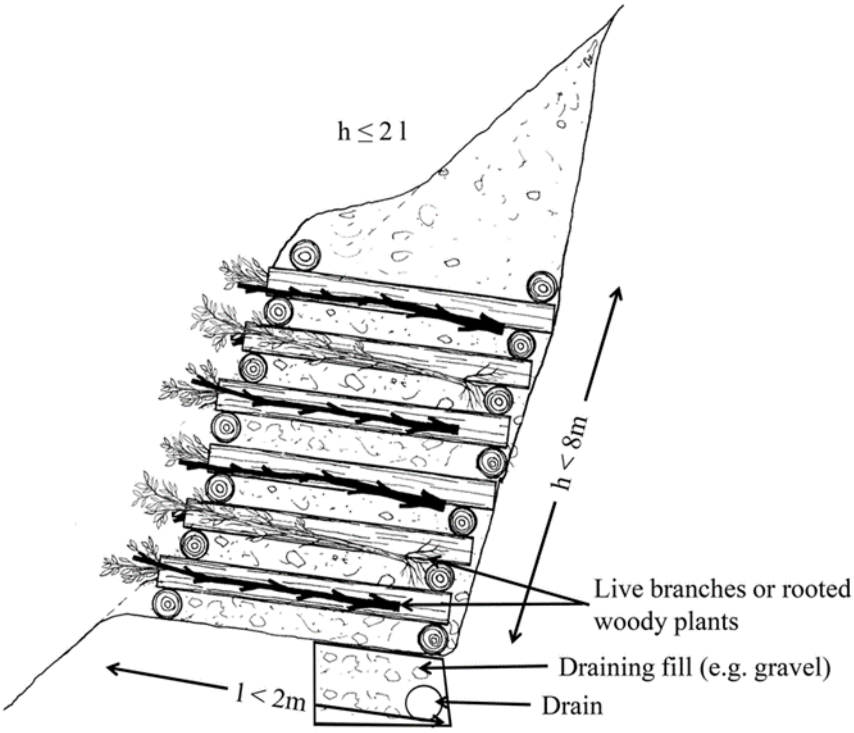


Fig. 4.46 Log crib wall, (Fernandes and Nuno 2016)

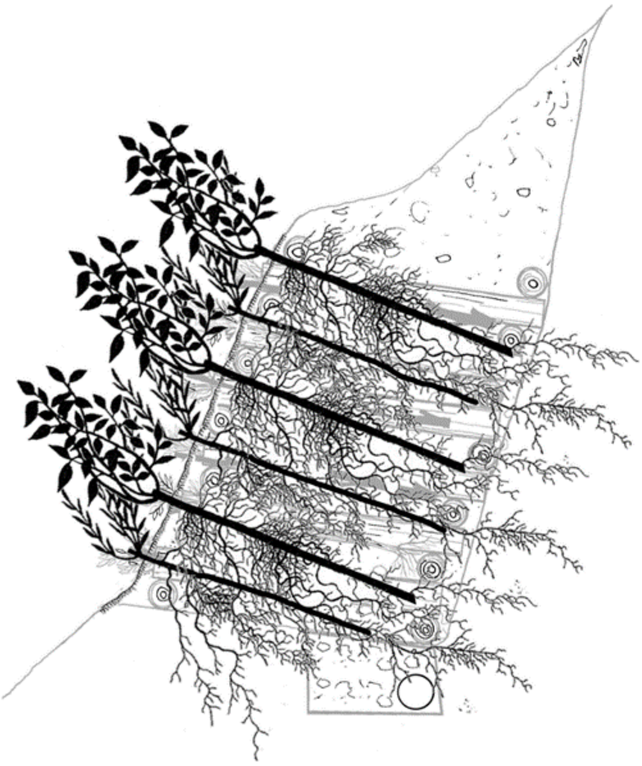


Fig. 4.47 Vegetated crib wall, (Fernandes and Nuno 2016)

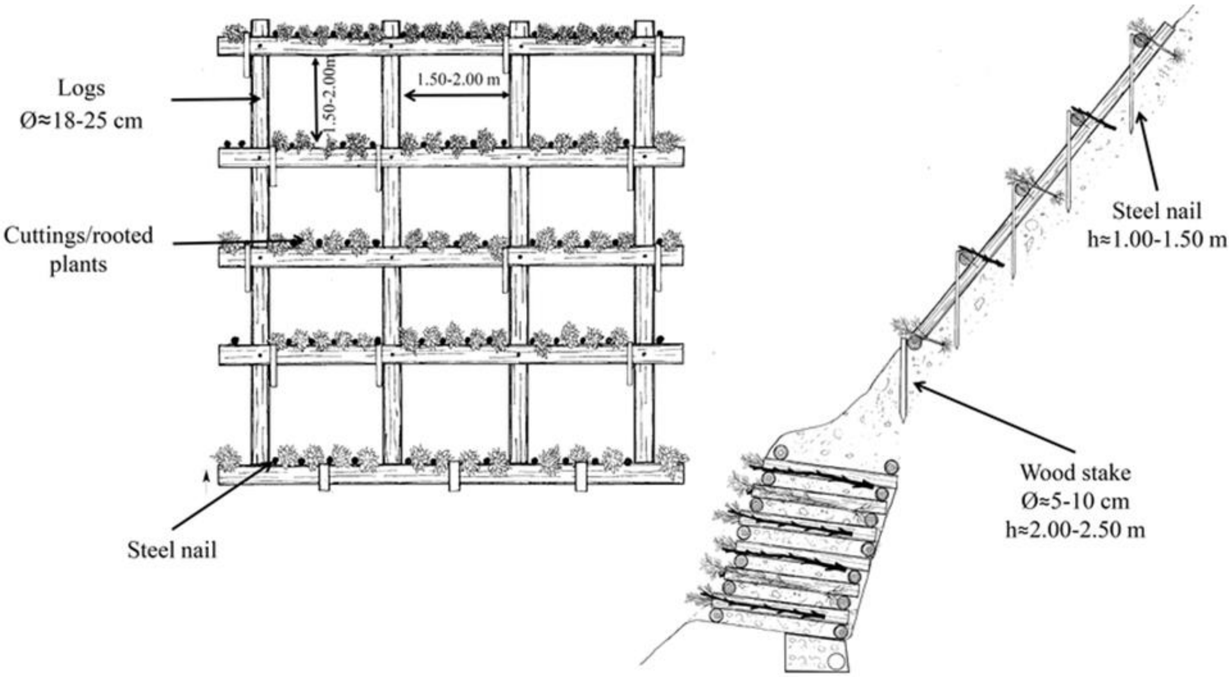


Fig. 4.48 Single live log grid, (Fernandes and Nuno 2016)

5. REFERENCES (SUGGESTED READINGS)

5.1 For E-Learning

Allen, M.W. 2007. Designing successful e-learning. John Wiley and Sons Inc.

Attwell, G. 2006. Evaluating E-learning. A Guide to the Evaluation of E-learning, Evaluate Europe Handbook Series Volume 2, ISSN 1610-0875.

Bates, A.W. 2015.Teaching in a digital age. Guidelines for designing, teaching, and learning. http://opentextbc.ca/teachinginadigitalage/wp-content/uploads/sites/29/2015/04/Scenario-A.mp3

Demiray, U (ED.). 2010. E-learning practices. Cases on challenges facing e-learning and national development: institutional studies and practices. Anadolu University, Eskişehir-Turkey.

Guàrdia, L., Crisp, G. & Alsina, I. 2016. Trends and Challenges of e-Assessment to Enhance Student Learning in Higher Education. In E. Cano & G. Ion (Eds.), Innovative Practices for Higher Education Assessment and Measurement. Chapter 3, section 1. IGI Global. DOI: 10.4018/978-1-5225-0531-0

Guàrdia, L., Crisp, G. & Hillier, M. (Eds) 2016. Using e-Assessment To Enhance Student Learning And Evidence Learning Outcomes. Thematic series at SpringerOpen.

FAO, 2011. E-learning methodologies: A guide for designing and developing e-learning courses, ISBN 978-92-5-107097-0, Rome, Italy.

Howard, C. 2005. Encyclopedia of Distance Learning.IGI Global.

McQuiggan, S., Kosturko, L., McQuiggan, J., Sabourin, J. 2015. Mobile learning: a handbook for developers, educators, and learners. ISBN:9781118894309, SAS Institute Inc.

Moore, K., Hanfland, F., Shank, P., Young, L., Dublin, L., Watkins, R., Corry, M. 2007. The eLearning Guild's Handbook of e-Learning Strategy, Santa Rosa. Brandon, B. (Ed). 375 E Street, Suite 200 Santa Rosa, CA 95404, www.elearningguild.com

OECD. 2010. The Nature Of Learning: Using Research To Inspire Practice.

Rao, R. 2011. Global e-learning: a phenomenological study, PhD Thesis, Colorado State University, Colorado, U.S.A.

Rosenberg, M.J. 2000. E-Learning: Strategies for Delivering Knowledge in the Digital Age, McGraw-Hill, New York.

Trivantis, 2016. E learning 101: A practical guide. Trivantis Coorporation.

5.2 For Data management

Elouazizi, N. 2014. Critical Factors in Data Governance for Learning Analytics. Journal of Learning Analytics, 1(3), 211-222.

Gordon, K. 2007. Principles of data management. The British Computer Society Publishing and Information Products, Swindon, UK.

Higs, C. R. 1993. Fundamental concepts in the design of experiments. Oxford University press, Inc. 198 Madison Avenue, New York.

ICGI, 2005. The principles of good data management. 2nd Edition, ODPM Publications, West Yorkshire, UK.

Singh, H. S. 1998. Data Warehousing: Concepts, Technologies, Implementations and Management. Prentice Hall, New Jersey, ISBN 0-13-591793-X

Soler, A.S., Ort, M., Steckel, J. 2016. An introduction to data management.

Van den Eynden, V., Corti, L., Woollard, M., Bishop., L., Horton, L. 2009. Managing and Sharing Data, Best Practices for Researchers, 3rd Edition, UK Data Archive, University of Essex. ISBN: 1-904059-78-3

Zar, J.H. 1996. Biostatistical Analysis. Prentice Hall. Upper Saddle River, New Jersey 07458.

5.3 For Technical Drawing

Anonymous 2018: How to read technical drawings, [Date accessed 30.06.2018], https://www.designingbuildings.co.uk/wiki/How_to_read_technical_drawings

British Columbian Forest Service, 1999. Forest Service Bridge Design and Construction Manual. Ministry of Forests, Lands and Natural Resource Operations, Engineering Branch.

BS EN ISO 128-20:2001: Technical drawings —General principles of presentation — Part 20: Basic conventions for lines

BS ISO 128-23:1999: Technical drawings — General principles of presentation — Part 23: Lines on construction drawings

BS ISO 128-30:2001: Technical drawings —General principles of presentation Part 30: Basic conventions for views

Fernandes, J. and, Nuno, G., 2016: Simulating the stabilization effect of soil bioengineering interventions in Mediterranean environments using limit equilibrium stability models and combinations of plant species. Ecological Engineering. 88. 122-142. 10.1016/j.ecoleng.2015.12.035.

Geing, 2018: Figures from projects carried out by Geing

Giesecke, F.E. (Ed.) 1986. Technical Drawing. Eight Edition, Macmillan Publishing Company, ISBN: 0-02-342600-4

Goetsch, D.L., Chalk, W.S., Nelson, 2010. Technical Drawing and Engineering Communication, Sixth Edition. ISBN: 1428335846.

Görcelioğlu, E., Çelik, H. E. 2000: Technical Drawing (Turkish), Istanbul University Faculty of Forestry pub. No 464, ISBN 975-404-593-3, Istanbul.

Rathnam, K., 2018: A First Course in Engineering Drawing, Springer, ISBN 978-981-10-5358-0 (eBook), Singapore.

Reddy, K. V., 2008: Textbook of Engineering Drawing, BS Publications, Hyderabad.

Simons, C., Maguire, D., Phelps, N., 2012. Manual of Engineering Drawing. Fourth Edition, Elsevier Science & Technology, Oxford, U.K.

Victorian Curriculum and Assessment Authority, 2018. Technical Drawing Specifications Resources. A guide to support VCE Visual Communication Design, Design Study 2018–22.

5.4 Useful links

https://www.gfbio.org/documents/10184/22817/Reader_GFBio_BefMate_20160222/1ca43f24-2550-44b3-a05e-e180c3e544c0 (Accessed 03.30.2018)

Module contacts

Module leader: Hüseyin E. ÇELİK

Module tutor (academic): Ferhat GÖKBULAK

Module tutor (industry): Dragan DIMITRIEVSKI, Darko ILIEVSKI