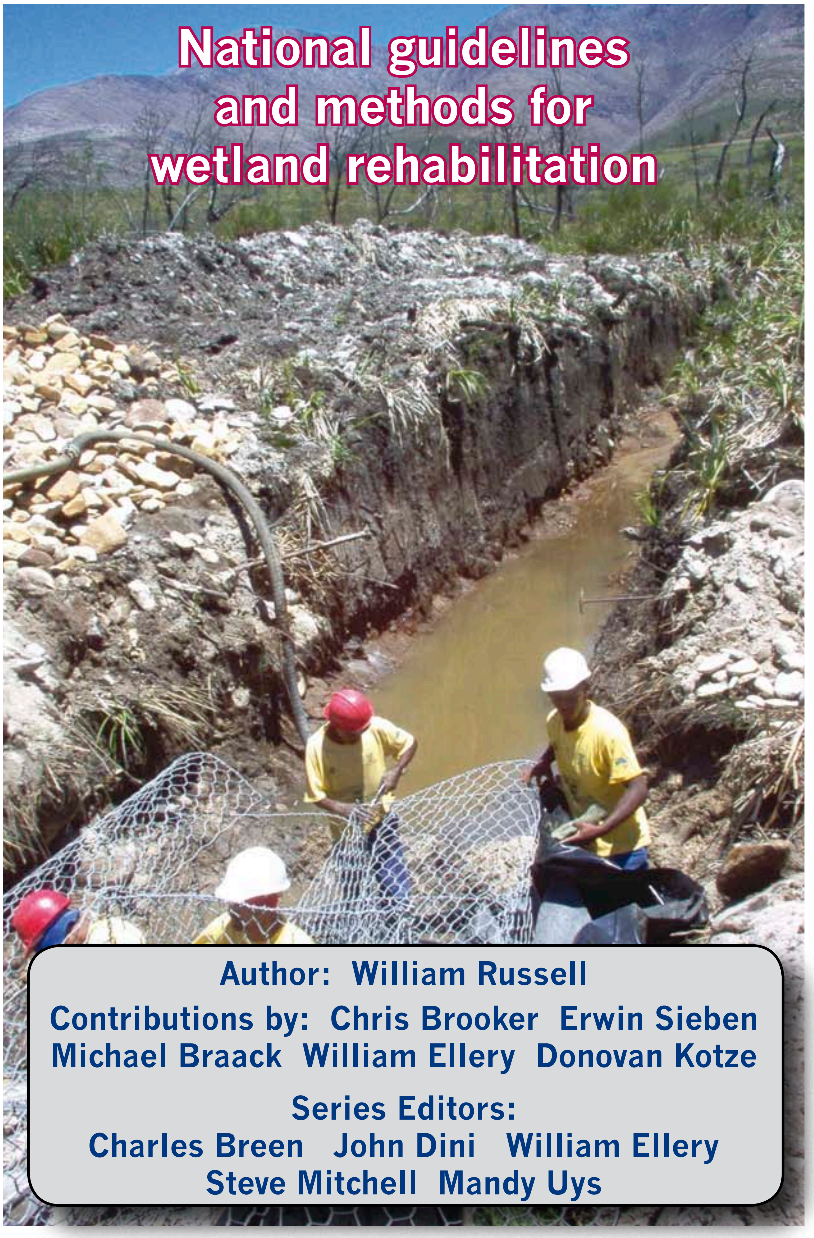
Wetland Management Series

WET-RehabMethods

National guidelines and methods for wetland rehabilitation



Author: William Russell

Contributions by: Chris Brooker Erwin Sieben Michael Braack William Ellery Donovan Kotze

Series Editors:
Charles Breen John Dini William Ellery
Steve Mitchell Mandy Uys

Environmental Affairs and Tourism
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South African National Biodiversity Institute SANBI

Working for Wetlands

University of KwaZulu-Natal

TT 341/09

Water Research Commission

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WRC Report TT 341/09
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UNIVERSITY OF KWAZULU-NATAL

Obtainable from:

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Private Bag X03
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Front cover: Excavation in the Kromme River Wetland and assembly and construction of gabion baskets in order to control headward erosion and raise the water table in the wetland such that the flood attenuation, streamflow regulation and erosion control functions are improved for the benefit of water users downstream.
Photograph: Japie Buckle

Inside front cover: Boneberg's frog (*Natalobatrachus bonebergi*), commonly known as Ngoye frog, is a threatened endemic species along the coastal region of KZN.
Photograph: Errol Douwes

Preface: Background to the *WET-Management* Series

The need for wetland rehabilitation in South Africa is compelling: loss and degradation of wetlands have been great and national policy and legislation provide clear direction and support for rehabilitation. However, rehabilitating wetlands is often complex because wetlands and their links with people are complex (e.g. through the ways that people use wetlands and the different benefits that people receive from the ecosystem services that wetlands supply). Thus a series of tools has been developed to assist those wishing to undertake wetland rehabilitation in a well-informed and effective way (Box 1P).

These tools were developed as part of a comprehensive nine-year research programme on wetland management which was initiated in 2003 by the Water Research Commission (WRC) and a range of partners that examines wetland rehabilitation, wetland health and integrity and the sustainable use of wetlands. The rehabilitation component, which was co-funded by the WRC and the Department of Environmental Affairs and Tourism, through the Working for Wetlands (WfWetlands) programme, was prioritised to take place first because of the need to provide a firm, scientific and technical foundation for the extensive rehabilitation work already under way.

The Working for Wetlands programme is a national initiative that seeks to promote the protection, rehabilitation and wise use of wetlands in South Africa. As part of this initiative, WfWetlands has a national programme for the rehabilitation of wetlands, including a structured process of prioritising rehabilitation sites and supporting their rehabilitation. At the same time, however, it is acknowledged that sustainable use of wetlands in the long term can be achieved only through the dedicated participation of civil society, whose wetland interests may have a strong local focus. Thus the tools have been developed in such a way that they can be applied outside of the Working for Wetlands programme, and without having to engage the process of national or provincial prioritisation should the user not desire to do so. Even so, the tools encourage local wetland rehabilitation efforts to strengthen links with the national initiative and the opportunity these provide for fruitful partnerships.

The series consists of a roadmap, two background documents, eight tools and an evaluation of the success of six individual projects (Box 1P). From Table 1P it can be seen that some of the tools (e.g. *WET-RehabMethods*) are designed to be used by those dealing specifically with wetland rehabilitation and its technical requirements. Other tools (e.g. *WET-Health*) have much wider application such as assessing impacts associated with current and future human activities in Environmental Impact Assessments (EIAs) or assessing the Present Ecological State (PES) of a wetland in an Ecological Reserve Determination (ERD).

One can locate the tools in terms of some basic 'who', 'what', 'where' and 'how' questions that any team undertaking wetland rehabilitation should be asking (Table 2P). Furthermore, each of the tools can be used individually, but there are close links between them (Figure 1P).

Box 1P: Overview of the *WET-Management* Series

The series includes documents that provide background information about wetlands and natural resource management, tools that can be used to guide decisions around wetland management, and an evaluation of rehabilitation outcomes in a number of case studies.

WET-Roadmap

WET-Roadmap provides an introduction to the *WET-Management* tools and includes:

- a brief outline of the documents and tools in the *WET-Management* series and how they inter-relate
- an index of wetland rehabilitation related terms
- reference to specific sections in the relevant tools.

WET-Origins

WET-Origins describes the remarkable geological and geomorphological processes that give rise to wetlands in South Africa, and provides a background description of:

- the geology, geomorphology, climate and drainage of southern Africa
- an introduction to wetland hydrology and hydraulics
- geomorphic controls on different wetland types
- wetland dynamics due to sedimentation and erosion.

It incorporates this understanding into a methodology that can be used to help develop insight into the hydrological and geomorphological factors that govern why a wetland occurs where it does, which is useful when planning rehabilitation.

WET-ManagementReview

WET-ManagementReview has four parts:

1. An assessment of effectiveness at programme level, including:
   - a national overview of land-uses affecting the status of wetlands and the institutional environment that affects wetlands.
   - an overview of five natural resource management programmes affecting wetlands and their impact in different land-use sectors; Working for Wetlands, Working for Water, LandCare, the Crane Conservation Programme of the Endangered Wildlife Trust, and the Mondi Wetlands Programme.
2. An assessment, using the *WET-EffectiveManage* tool, of the management effectiveness of 21 wetland sites in a variety of different land-use and land-tenure contexts.
3. An assessment of stakeholder participation in wetland rehabilitation at six wetland sites.
4. A framework for assessing the effectiveness of collaboration between partners, described and applied to a site where a rehabilitation project has been under way for several years.

WET-OutcomeEvaluate

WET-OutcomeEvaluate is an evaluation of the rehabilitation outcomes at six wetland sites in South Africa, including an evaluation of the economic value of rehabilitation. The six sites are:

1. Killarney Wetland
2. Manalana Wetland
3. Kromme River Wetland
4. Dartmoor Vlei
5. Kruisfontein Wetland
6. Wakkerstroom Vlei.

WET-RehabPlan

WET-RehabPlan offers a process that can be followed to develop comprehensive wetland rehabilitation plans. It has three main elements:

- Introduction to rehabilitation, planning and stakeholder involvement.
- General principles to follow in planning wetland rehabilitation.
- Step-by-step guidelines for undertaking the planning and implementation of wetland rehabilitation at a range of scales from national/provincial to catchment to local. It directs the user to the right tools and sections at appropriate points in the rehabilitation process.

Good planning ensures a rational and structured approach towards rehabilitation as well as a clear understanding of the reasons for rehabilitation, the actions and interventions required, and the benefits and beneficiaries.

WET-Prioritise

WET-Prioritise helps to identify where rehabilitation should take place once the objectives of rehabilitation are identified. It works at three spatial levels. At national and provincial level an interactive GIS modelling tool assists in identifying priority catchments by evaluating a range of scenarios, based on different combinations of 13 socio-economic and bio-physical criteria (e.g. Biodiversity Priority Areas, High Poverty Areas). Once a catchment is selected, the tool helps to identify areas for rehabilitation within that catchment. Finally, individual wetlands are selected based on the predicted cost-effectiveness and sustainability of rehabilitation.

WET-Prioritise provides step-by-step guidelines applicable at all three spatial scales, including:

- identifying objectives and an appropriate scale.
- developing prioritisation criteria.
- applying the criteria, usually in a two step process of rapidly screening all candidate sites to arrive at a preliminary set of sites, from which individual priority sites are selected.

Three case examples of prioritisation are described.

WET-Legal

WET-Legal presents South African legislation that is relevant to wetland rehabilitation, including the Conservation of Agricultural Resources Act (CARA), National Environmental Management Act (NEMA), and National Water Act (NWA), as well as relevant international agreements such as the Ramsar Convention on Wetlands. *WET-Legal* lists the environmental impacts potentially associated with typical wetland interventions and the legislative provisions that apply to each of these impacts. It also covers laws compelling rehabilitation and the legal responsibilities of different parties involved in rehabilitation.

WET-EcoServices

WET-EcoServices is used to assess the goods and services that individual wetlands provide, thereby aiding informed planning and decision-making. It is designed for a class of wetlands known as palustrine wetlands (i.e. marshes, floodplains, vleis or seeps). The tool provides guidelines for scoring the importance of a wetland in delivering each of 15 different ecosystem services (including flood attenuation, sediment trapping and provision of livestock grazing). The first step is to characterise wetlands according to their hydro-geomorphic setting (e.g. floodplain). Ecosystem service delivery is then assessed either at Level 1, based on existing knowledge, or at Level 2, based on a field assessment of key descriptors (e.g. flow pattern through the wetland).

WET-Health

WET-Health assists in assessing the health of wetlands using indicators based on geomorphology, hydrology and vegetation. For the purposes of rehabilitation planning and assessment, *WET-Health* helps users understand the condition of the wetland in order to determine whether it is beyond repair, whether it requires rehabilitation intervention, or whether, despite damage, it is perhaps healthy enough not to require intervention. It also helps diagnose the cause of wetland degradation so that rehabilitation workers can design appropriate interventions that treat both the symptoms and causes of degradation. *WET-Health* is tailored specifically for South African conditions and has wide application, including assessing the Present Ecological State of a wetland for purposes of Ecological Reserve Determination in terms of the National Water Act, and for environmental impact assessments. There are two levels of complexity: Level 1 is used for assessment at a broad catchment level and Level 2 provides detail and confidence for individual wetlands based on field assessment of indicators of degradation (e.g. presence of alien plants). A basic tertiary education in agriculture and/or environmental sciences is required to use it effectively.

WET-EffectiveManage

WET-EffectiveManage provides a framework that can be used to assess management effectiveness at individual wetlands based on 15 key criteria (e.g. the extent to which a regularly reviewed management plan is in place for the wetland). A scoring system is provided for rapidly assessing the criteria. This tool is Chapter 2 in the *WET-ManagementReview* manual.

WET-RehabMethods

WET-RehabMethods is used to guide the selection and implementation of rehabilitation methods that are appropriate for the particular problem being addressed and for the wetland and its catchment context. It provides detailed practical rehabilitation guidelines for inland palustrine wetlands and their catchments, and focuses particularly on wetlands associated with natural drainage networks. It can be adapted to meet specific needs. Some aspects of the tool require high levels of civil engineering expertise, but it is designed primarily for rehabilitation workers who have completed training in soil conservation, life sciences or engineering at a diploma level or higher, and who have practical field experience.

WET-RehabMethods includes the following:

- Key concepts relating to wetland degradation, particularly those resulting from erosion.

- Guidelines for the selection of an appropriate type of rehabilitation intervention (including both 'soft' and 'hard' engineering options).
- Detailed guidance, provided for designing a wide variety of intervention types (e.g. determining an adequate spillway to account for runoff intensity).
- Detailed guidance provided for the implementation of the different intervention types.

WET-RehabEvaluate

WET-RehabEvaluate is used to evaluate the success of rehabilitation projects, and is designed with the understanding that monitoring and evaluation are closely tied to planning, which, in turn, should accommodate monitoring and evaluation elements. *WET-RehabEvaluate* provides the following :

- Background to the importance of evaluation of wetland rehabilitation projects.
- Step-by-step guidelines for monitoring and evaluation of rehabilitation projects, both in terms of project outputs and outcomes. The outcomes are based on system integrity and the delivery of ecosystem services, and results from *WET-Health* and *WET-EcoServices* are therefore included. The guidelines include review project objectives, identify performance indicators and standards, develop and implement a monitoring and evaluation plan, and evaluate and report on performance.

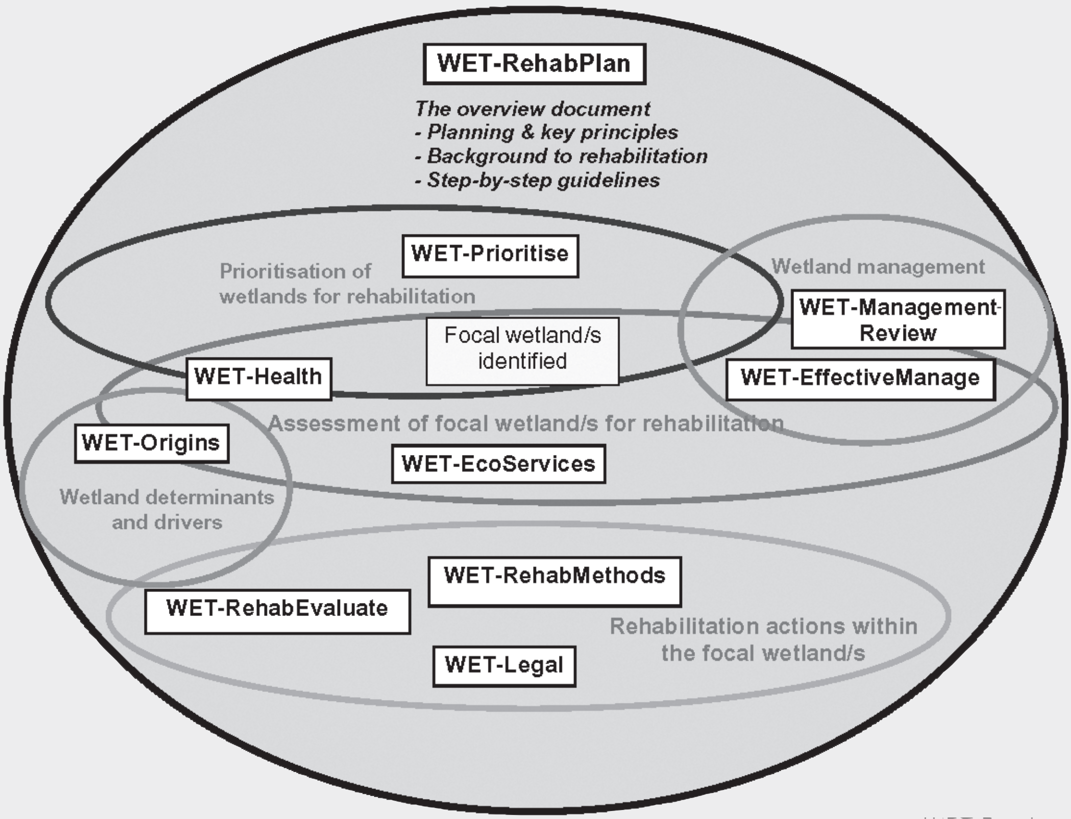

Figure 1P: How do the *WET-Management* tools relate to each other in a rehabilitation context?

Table 1P: Likely relevance of the background reading and tools in the ***WET-Management*** series to a variety of different potential uses

Potential users	*WET-Origins*	*WET-Management - Review*	*WET-RehabPlan*	*WET-Prioritise*	*WET-Effective-Manage*	*WET-Legal*	*WET-Rehab-Methods*	*WET-Eco-Services*[1]	*WET-Health*[2]	*WET-Rehab-Evaluate*
Rehabilitation planning - wetland specialist										
Rehabilitation planning - engineer		Part 1	Step 5							
Rehabilitation programme coordination - *national*										
Rehabilitation programme coordination - *provincial*										
Rehabilitation implementation			Step 5							
Impact assessment		Part 1						Level 1	Level 2	
Wetland management										
Ecological Reserve Determination - DWAF officials & consultants		Part 1						Level 1	Level 2	
Catchment planners - CMAs and others		Part 1								
Broad-scale biodiversity conservation planning		Part 1								

The tool is likely to have some relevance

The tool is likely to have a very high level of relevance

[1] *WET-EcoServices* is of particular relevance in determining the Ecological Importance and Sensitivity (EIS) of a wetland.
[2] *WET-Health* is of particular relevance ino determining the Present Ecological State (PES) of a wetland.

CMA = Catchment Management Agency
DWAF= Department of Water Affairs and Forestry

Table 2P: Rehabilitation-related questions typically posed at different spatial levels, and the tools most relevant to assisting the user in answering each question

Common questions	Tool/s likely to be relevant in addressing the question
Questions that might typically be asked at the national or regional level	
What is causing the degradation of wetlands?	*WET-Health* (Level 1) & *WET-ManagementReview*
Which are the most important wetlands?	*WET-Prioritise* & *WET-EcoServices* (Level 1)
Which wetlands should we rehabilitate?	*WET-Prioritise*
How should wetland rehabilitation be integrated within broad-scale catchment management?	*WET-Prioritise* & Dickens *et al*. (2003)
Questions that might typically be asked at the local level	
How effectively is the wetland being managed?	*WET-EffectiveManage*
What is causing the degradation of the wetland?	*WET-Health* (Level 2)
Is the wetland in need of rehabilitation?	*WET-Health* (Level 2) & *WET-Origins*
How do I decide what rehabilitation interventions will be appropriate for meeting my rehabilitation objectives?	*WET-RehabPlan* (Step 5F) & *WET-RehabMethods*
What are specific technical considerations I must make when designing a rehabilitation intervention?	*WET-RehabMethods*
Will the planned project be legally compliant?	*WET-Legal*
How do I evaluate my rehabilitation project?	*WET-RehabEvaluate*
Who should be involved in the rehabilitation project?	*WET-RehabPlan*
How do I align my rehabilitation project with catchment-, regional- or national-level programme/s?	*WET-RehabPlan* & WfWetlands Strategy (Working for Wetlands, 2005)

The National Water Act defines wetlands as:

'....land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soils.'

This is the definition used by the *WET-Management* Series.

Acknowledgements

The Water Research Commission (WRC), South African National Biodiversity Instutute (SANBI) and Working for Wetlands (WfWetlands) are gratefully acknowledged for funding the development of this tool. The entire WfWetlands team has taken an active interest and participated in the development of this tool. The WRC has been very supportive in offering strategic and administrative assistance. The research programme was managed by Fred Ellery of the University of KwaZulu-Natal (UKZN), who was ably assisted by Kerry Philp. Karen Ellery provided substantial editorial input during the production of this document.

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Feedback

In South Africa the rehabilitation of wetland ecosystems is still in its infancy. In order to promote the growth of this activity, this manual needs to be revised by including the experiences of those individuals involved in wetland rehabilitation within South Africa. Any comments or advice can be sent to:

Fred Ellery
Rhodes University
e-mail: f.ellery@ru.ac.za

OR

Donovan Kotze
University of KwaZulu-Natal
e-mail: kotzed@ukzn.ac.za

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SECTION 1:
THE PLANNING PROCESS

The planning of wetland rehabilitation is a complex process that requires understanding of wetland origin and the causes of degradation, since the primary motivation for rehabilitation must be the treatment of cause/s and not just the symptom/s of degradation. The manual provides some of the necessary background, although much should come from the other tools and products that are being produced as part of this series.

The approach in this section of the manual is to provide insights into causes of wetland degradation, important concepts in erosion control and catchment conservation, broad approaches to addressing various problems that might exist in wetlands and some guidelines on choosing the most appropriate intervention. Section 2 deals with the design process and several appendices provide technical details that might be useful to implementers.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Over the past few centuries, many of South Africa's wetlands have been degraded or lost, largely through human activities. The degradation of South African wetlands is now recognized by government as demanding urgent action in order to improve water security in the face of dwindling water resources as well as to conserve biodiversity. Government has recognised the need to not only stem the loss of wetlands and promote their wise use, but also to rehabilitate those that have been degraded or lost.

In recent years, the rehabilitation of degraded wetlands has gained momentum on an international scale. Examples in Africa include the restoration of fisheries and pastoral lands in the mighty Logone Floodplain in Cameroon, and the rehabilitation of the Memelvlei in South Africa by the national Department of Agriculture. These projects provide tangible evidence of people's commitment to restore wetlands that have lost their functions and values due to previous mismanagement and development. This reflects a changing attitude towards wetlands which, have previously been regarded as wastelands. In the National Reports submitted by the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971) in 1999, 75 out of 107 Reports indicated that wetland restoration or rehabilitation was taking place in that country (Moller, 1999).

In South Africa, Working for Wetlands (WfW) is a statutory body within the South African National Biodiversity Institute that falls under the broad umbrella of the Department of Environmental Affairs and Tourism (DEAT). The current mandate of WfW is primarily to rehabilitate wetlands, thereby creating jobs, alleviating poverty and providing training in various skills. The current budget is of the order of R60 million per year, which is divided between all the provinces.

Unfortunately, wetland rehabilitation has the potential to be costly and the benefits gained against money spent on rehabilitation can vary greatly depending on the specific circumstances. It is therefore imperative that rehabilitation be carried out in an informed and cost-effective manner.

Despite the significant resources that have recently been directed towards wetland rehabilitation in South Africa, there is a severe lack of local research documenting the processes underlying the degradation of wetlands, and the most appropriate methods for addressing such degradation. There has also been no systematic approach to wetland rehabilitation with the aim of restoring ecosystem functioning and biodiversity. Research and guidelines are urgently required to provide a sound basis for sustainable rehabilitation actions within the WfW/DEAT initiative and other projects.

1.2 Objectives and scope of manual

This manual has been developed to assist field-workers and practitioners to understand causes of wetland degradation as well as choosing, planning and implementing rehabilitation methods appropriate both within the wetland itself as well as its catchment. Inasmuch as it deals with erosion control methods, it is compiled making maximum use of the soil conservation engineering criteria used by the National Department of Agriculture in South Africa.

Wetland rehabilitation projects can vary in scale from those costing less than a thousand Rand to those costing several million rand. This manual is aimed at an intermediate scale. It may seem too involved and detailed for small projects and not detailed enough for very large projects. However, the central principles and frameworks used, and many of the techniques described, are applicable across all scales. Thus, one should be able to adapt it to meet specific needs.

It is designed particularly for field-workers and project managers involved in wetland rehabilitation who have:

- a basic training in soil conservation, life-sciences or engineering at a diploma level or higher
- at least a month's training and a further month's practical field experience in wetland science
- attended an introductory course on wetland functioning, values and assessment, and a wetland rehabilitation course.

However, it will be noticed that the design and building of some of the wetland rehabilitation structures in this manual require high levels of civil engineering expertise and practical experience. A set of recommendations with respect to Level of Competency in this regard is outlined in Chapter 16, as well as a brief summary of the requirements of Act 46/2000: Engineering Profession Act.

The manual covers rehabilitation of inland palustrine (marsh/flood plain-type) wetlands across a range of landform settings, particularly those situations where the flow of water is characteristically diffuse. It focuses particularly on those wetlands associated with the natural drainage network. These wetlands have generally been subject to greater land-use impacts than those wetlands isolated from the drainage network, notably pans (Kotze *et al*., 1995).

The manual provides detailed practical guidelines on the rehabilitation of degraded wetlands and their catchments by means of management (e.g. excluding livestock from sensitive areas where feasible), bio-engineering (through the establishment of vegetation) and structures (e.g. weirs and chutes). Whilst mined peatlands are touched on briefly in Chapter 10, the main forms of degradation addressed by the manual are wetlands impacted by on-site erosion gullies and/or artificial drainage channels. This focus was chosen because drainage and erosion are recognized as two very important causes of on-site degradation of wetlands, and most current rehabilitation projects are addressing these causes. It is critical, however, that one should not be locked into the belief that the only problems worth addressing are drains and gullies. Clearly, the functioning of wetlands may be compromised by many other factors, each requiring particular rehabilitation actions. These include: the presence of water storage dams, in which case removal of the dam may be an appropriate rehabilitation measure for the wetland; the presence of alien plants, in which case clearing of aliens and implementing a burning and grazing management programme may be appropriate. Where cultivation in wetlands is taking place, the control and regulation of cropping, planting of indigenous plants with direct economic value to local people, and controlling alien plants may be appropriate trade-offs. This will, however, have to be done in collaboration with the local and national Departments of Agriculture. The Conservation of Agricultural Resources Act No. 43/83 controls the manipulation of wetlands. The overall framework of the manual for planning and implementing wetland rehabilitation is of relevance to the acceptable manipulation of wetlands that constitutes 'wise use'.

It is also important to raise a point that cannot be over-emphasized – rehabilitation of wetlands should not divert attention away from looking after those wetlands that are still in good condition! In order to be cost effective, wetland rehabilitation should be integrated with wetland conservation within a broad-scale, holistic wetland management programme that is, in turn, nested within a catchment management programme.

1.3 Definition of terms: what is wetland rehabilitation?

goal endpoint depends on what is achievable, given the site conditions, and those ecosystem attributes and servic As described in Section 1.2 of *WET-RehabPlan*, wetland rehabilitation refers to the process of assisting in: (1) the recovery of a degraded wetland's health and ecosystem service-delivery by reinstating the natural ecological driving forces or (2) halting the decline in health of a wetland that is in the process of degrading, so as to maintain its health and ecosystem service-delivery.

Certain key concepts are encompassed within this definition. Firstly, rehabilitation is not the static endpoint of a recipe-like process (Kusler and Kentula, 1990). Rather, it is a process in its own right, whereby the wetland system is given an opportunity for a new beginning (Grenfell *et al*., 2007).

Secondly, rehabilitation requires that we attempt to imitate natural processes and reinstate natural ecological driving forces in such a way that we aid the recovery (or maintenance) of dynamic systems so that, although they are unlikely to be identical to their natural counterparts, they will be comparable in critical ways so as to function similarly (Jordan *et al*., 1987).

Thirdly, we recognise that rehabilitation interventions may have different ecological starting points (ranging from totally degraded to slightly degraded) and different goal endpoints (ranging from a state that is close to the pristine to one which is still far from pristine, but nonetheless an improvement on the state of the system without any rehabilitation intervention). The chosen es that are considered most important. Any rehabilitation project should therefore be based on an understanding of both the ecological starting point and on a defined goal endpoint, and should accept that it is not possible to predict exactly how the wetland is likely to respond to the rehabilitation interventions.

The most typical rehabilitation interventions designed to assist in the recovery of degraded wetland ecosystems are 'plugs' constructed within artificial drainage channels. The 'plugs' are placed with the intention of re-instating a more natural hydrology. Typical interventions for maintaining the health wetland ecosystems that are in the process of degrading are the placement of erosion control structures which assist in halting the advance through a wetland of an erosion headcut. However, rehabilitation is not confined to physical structures, and rehabilitation may include interventions such as reducing livestock grazing-pressure or reducing the frequency of burning.

From the discussion above it can be seen that 'wetland rehabilitation' is very broadly defined. This broad definition of the term 'wetland rehabilitation' will be used in this document, and in all of the documents in the WET-Management series. A number of other authors (e.g. Grenfell *et al.*, 2007) have chosen to define rehabilitation more narrowly, through drawing a distinction between rehabilitation and other terms such as 'restoration'. Those readers interested in a detailed description of terminology, relevant to wetland rehabilitation, should refer to Grenfell *et al.* (2007).

Rehabilitation is a complex process and often it is more appropriate to focus on rreinstating functional values that on reinststing natural processes

Wetland rehabilitation is a complex undertaking as:

- Wetlands are complex and dynamic systems
- There is a lack of baseline information describing the state of wetlands prior to degradation
- Some attributes of wetlands have been changed irreversibly such that it is impractical to reverse all modifications contributing to degradation and loss of wetlands

Given these factors there may be an emphasis in rehabilitation – not so much on restoring natural processes – but accepting the irreversible nature of irreversible change and focusing on reinstating functional values.

1.4 Principles of wetland rehabilitation

The manner in which projects are initiated may vary considerably, as described in *WET–RehabPrioritise*. A national or regional organization may wish to compensate for anticipated or historic wetland degradation within a broad region or catchment. Alternatively, individual landowners may wish to re-establish the functioning of a specific degraded wetland for which they are responsible. However, at whatever scale rehabilitation is undertaken, the key guiding principles outlined in Table 1.1 should be of assistance.

In order to design measures and/or structures for the rehabilitation of a wetland it is very helpful to understand the driving forces behind the existence of the particular wetland. These are covered to a large degree in *WET–Origins*. Some fundamental conditions are required for a wetland to exist. These include a suitable geomorphological setting, favourable hydrology, and a substrate able to support hydrophytic vegetation. When these conditions are met, the physical, chemical and biological processes that make wetlands such valuable ecosystems are allowed to occur (Hayes, *et al.*, 2000). Establishing site conditions that support a set of desired functions and values over an extended period requires careful planning that utilizes the specific natural characteristics of each site. Owing to an incomplete understanding of wetlands, one cannot design rehabilitation projects that assure achievement of all project objectives. Thus, monitoring is required to determine the level to which objectives are being met (Hayes *et al.*, 2000).

Establishing favourable hydrological conditions is generally the key to wetland rehabilitation. Vegetation, other biota and wetland functions and their associated values will tend to follow with little additional external input required. It is generally best not to use extreme engineering solutions, elaborate control structures or intensive maintenance where it can be avoided. These are not only costly but are also unlikely to be sustainable in the long term. Furthermore, the large scale planting of vegetation is usually not required. Instead, planting of vegetation should be confined primarily to strategic areas under high threat of erosion that require rapid stabilisation. For the remainder of the wetland it will generally be enough to rely on natural colonisation by suitable plants.

The best wetland rehabilitation projects are usually those that require the least modification to existing conditions. Sites that have virtually all the components in place but that need only minor modifications offer the most cost effective solutions and are the most likely to be successful (Hayes *et al.*, 2000).

In the past the rehabilitation of wetland sites has generally taken place in isolation of the broader context of the site. A wetland site which is rehabilitated often forms part of a greater wetland area subject to a variety of disturbances and other factors influenced by management. Furthermore, all wetlands, whether pristine, degraded or rehabilitated, exist within catchments and landscapes that have an enormous influence on how the wetland functions and develops. Wetlands, at least those in riparian areas, are strongly connected to other components in the landscape, and wetland functioning is to a large extent determined by the properties and behaviour of the catchment. The wetland, in turn, often has an important influence on downstream aquatic, riparian and socio-economic systems.

1.5 Format of manual

In order to make the manual as user-friendly as possible, the conceptual understanding, background information and theory are located in the main body of the manual. The Appendices at the back have detailed information on methodologies, use of formulae, standards, norms and working examples.

Table 1.1: Principles of wetland rehabilitation*

General principles relating to wetland functioning and management	
Associated principles for implementing wetland rehabilitation	
Wetlands result from several driving forces, including geomorphological setting, hydrology, physical processes (e.g. fire, sediment movement), biogeochemical processes (e.g. nutrient cycling), and biological processes (e.g. colonization, competition, decomposition). These forces interact to result in the functions and services to society (e.g. water quality enhancement) associated with wetlands.	Rehabilitation is the reinstatement of these driving forces to a level close to the original system (but seldom fully attaining it) so as to improve the wetland's capacity for providing services to society.
Wetlands are dynamic, changing in time scales of days, seasons, years, decades, millennia and longer. Given sufficient time (i.e. geological time spans) all wetlands will ultimately decline as other wetlands develop elsewhere in the landscape.	The goal of wetland rehabilitation should not be to return and maintain a wetland in a static state but rather to achieve a persistent resilient system that is largely self-maintaining and can respond to change with little human intervention.
Wetlands are an integral part of catchments and broader landscapes, and the nature and rates of processes affecting wetlands can be (often are) influenced by human interventions within catchments and landscapes.	Wetland rehabilitation must be integrated with the surrounding landscape if it is to address the causes of wetland degradation and not just the symptoms.
All wetlands occur within some form of socio-economic context that may have a profound effect on management and land-use decisions affecting the functioning of the wetland.	If wetland rehabilitation projects are to be sustainable they must have meaningful ownership by local people and give adequate consideration to socio-economic factors, particularly those relating to the direct users of the wetland.
Wetland functioning and management is complex, and without effective planning, the effective management, monitoring and rehabilitation of wetlands are unlikely to be cost-effective.	Wetland rehabilitation should take place within a well structured planning, implementation and evaluation programme.

(*adapted from Kotze, 1999; Hayes *et al.*, 2000; Society Wetland Scientists Concerns Committee, 2000)

CHAPTER 2: CAUSES OF WETLAND DEGRADATION

In order to rectify damage in and to a wetland in the most efficient and economic manner it is important to understand the under-lying causes of the problem. They may be summarized as follows.

2.1 Increased runoff velocities

In an unspoiled wetland the soil-vegetation interplay is generally in equilibrium with the energy expended on them by the floodwaters that flow through them, and stability is maintained while conditions in the catchment remain static and in a good state of conservation.

However, when conditions in the catchment are degraded, some of the hydraulic/hydrological impacts that may occur are as follows:

- A decreased time of concentration of floodwaters results in a more rapid runoff response to intense storms of short duration. Higher peak discharges, and therefore possibly, higher velocity of flow, may thus occur. The concept of 'Time of Concentration' is described in Chapter 3 (Section 3.4).
- When this happens, a higher proportion of runoff to precipitation, and hence a higher peak discharge, is likely to occur from a given storm.
- Increased frequency of storm runoff from smaller storms results in shorter periods during which ground cover can recover from the effect of increased runoff.
- Velocity of the discharge entering a wetland is a function of that discharge (m^3/s) and the hydraulic characteristics of the wetland, such as width, slope, and surface roughness due to the density and rigidity of the vegetation growing in it.

When, as a result of a reduction in the amount of vegetation cover either in the catchment area upstream or in the wetland itself, the velocity of runoff from storm events increases. Soil is the basis of the wetland, and, as will be explained later, differing soils have varying degrees of resistance to the speed of the flowing water. Vegetation assists the soil to a remarkable degree in being able to withstand the erosive impact (i.e. kinetic energy) of falling rain and flowing water. If and when vegetation is degraded therefore, infiltration of rainwater into the soil profile is reduced, floodwater discharge and velocity increase, and erosion of the soil along the path of the floodwaters takes place. In this way degradation in the wetland may occur, with soil losses in the form of erosion gullies that tend to drain the wetland and cause deterioration in both the species composition and the density of the wetland vegetation (see Figure 2.1).

Higher flood peaks in streams and rivers will also result in streambank erosion, which will impinge on any wetland that lies adjacent to, or downstream of, such a stream or river.

2.2 Surface drainage

In an effort to increase agricultural production from what in the past were considered as 'wastelands', many wetlands have been drained through the excavation of drainage (also termed open site) ditches. The ditches capture surface water, causing a concentration of flow that results in the accumulated runoff passing through the wetland at a faster rate than was previously the case. The technique attempts to remove unwanted water before it can infiltrate into the soil surface and cause saturation of the profile to the detriment of the crops being cultivated in the wetland. This damage to functioning wetlands has been carried out by both agriculturists and by civil engineers

Figure 2.1: An erosion gully in a wetland

concerned with the construction of road and railway culverts and bridges; for the creation of housing sites; with the creation of parkland in municipal areas; and for sports fields worldwide (see Figure 2.2).

Another method of surface drainage entails the forming of the flat terrain of wetlands into what is termed 'ridge and furrow', or 'cambered bed' systems. The idea in this instance is to increase the local slope of the terrain by building narrow beds in the wetland with relatively steep side slopes, thereby causing rainwater to be speedily shed into adjacent furrows. These furrows are angled in the direction of the land slope in order to facilitate the removal of excess water as efficiently as possible.

In both instances the wetland tends to dry out partially, and even if the land is left unploughed, the resulting drier state of the soil profile results in a simplified vegetation composition establishing.

2.3 Sub-surface drainage

Cambered beds and open site drainage ditches are a problem for traffic in areas that have been drained for agricultural production. This is especially the case where the land is to be irrigated. Where high-income crops are warranted from an economic point of view, sub-surface drainage is installed. Pipe or tile drains are laid in trenches at some depth below the soil surface in order to remove excess moisture that regularly over-fills the soil profile and which causes waterlogging that is detrimental to the agricultural crop (although not to the wetland species). The wetland vegetation is once again deprived of sufficient water, and this condition is maintained as long as the pipes are regularly cleared of accumulations of sediment that would otherwise block them.

Figure 2.2: A drainage ditch in a wetland

2.4 Reduction/change in ground cover

Instances sometimes occur where the ground cover in the wetland itself has been changed or reduced in density in spite of a catchment area in good condition. The wetland is still subject to occasional flooding, and a poorer growth of vegetation may not be able to protect the underlying soil from erosion during the flood events. This change could be caused through overgrazing, damming up of the runoff upstream for utilization elsewhere, thereby causing artificial drought stress in the wetland, by the discharge of herbicide effluent into the stream, or by the change of use of the land to, for instance, forestry practices. The loss of vegetation diversity will result in the wetland not being able to retain its valuable functions as before, and erosion could also set in.

2.5 Sedimentation in the wetland

When the catchment area above the wetland is in a degraded state through poor farming methods, substandard mining waste disposal systems and poorly designed and maintained socio-economic housing settlements, soil erosion is rife. The sediment that is released as a result of erosion will be carried in the stream to settle in the wetland below. This causes smothering of the vegetation and its demise. In a large percentage of cases the sediment is dropped at the entrance to the wetland forming a sediment dome. It causes the floodwater to split into two streams, one to each side of the wetland. The typical damage that occurs causes the formation of gullies alongside one or both edges of the wetland. The sediment dome that is formed is better drained, comprises material of a nature different to that of the wetland soil, and a change to a poorer type of wetland vegetation also occurs.

2.6 Mining activities

Wetlands are often exploited as an important source of industrial materials such as peat (for the garden nursery industry), clay (for the pottery and brick-making industry) and sand (for the building industry). When this occurs the wetland is virtually destroyed, although in some instances partial restoration may be possible, but usually at a significant cost.

2.7 Other human-induced interventions

Wetlands are naturally a source of water. A ditch is sometimes dug to draw water in the wetland towards a well point from which the water can be pumped. This open ditch draws water along its gradient, thus robbing the wetland downstream of water and altering the even spread of floodwater over the width of the wetland. In turn, floodwaters are drawn along this line and both erosion and a change in the hydrology of the entire system can occur.

Wetlands are also still considered by some as wastelands, and many of them have been badly damaged by using them as dump sites. Municipal waste, building rubble, sawdust from sawmills, etc. are disposed of in the wetland, poisoning the waters of the stream flowing through them, changing the hydrology of the system. Many wetlands in urban areas are overloaded with sewage and pose a serious health hazard.

These are some of the many ways in which our valuable wetlands are stressed and degraded. In order to plan for their rehabilitation it is necessary to study the ways in which nature works (albeit at a much slower pace) to assist it in overcoming these constraints to their stability.

CHAPTER 3: CONCEPTS IN EROSION CONTROL AND GULLY REHABILITATION

3.1 Soil

Knowledge of soils and their classification is extremely important in the estimation of runoff intensity when designing water control structures. The engineering properties of soils when it is used as a building material, are as important (see Chapter 28). This includes those (usually duplex) soils that are fairly saturated with sodium salts, making them very erodible. Many of the wetland soils tend to have a high to very high organic content (e.g. Humics, Organics and Peat topsoils). Organic material as a component of soil makes for both a poor construction material as well as a weak foundation. Other types, like Melanic and Vertic topsoils, sometimes have other problems such as a moderate to high shrink-swell ratio that make them marginal for engineering purposes. They should be all treated with circumspection. These problems are dealt with in more detail in Chapter 28. For those interested in a broader knowledge of soils and their classification, the book by MacVicar *et al.* (1988) is recommended.

Also very important is the concept of a *maximum non-eroding velocity* for soils, based on their susceptibility to runoff erosion. Some soils can withstand only slow-moving water, while others are capable of remaining in place under fairly high water flow velocities (see Chapter 28 for more details on individual soils). The former will erode fairly easily while the latter soils will only start eroding as the water flow increases in velocity. On the other hand, a good covering of vegetation will help to reduce the impact of velocity to cause erosion, especially where sod-forming and rhizomatous vegetation is in place. This aspect of bio-engineering in erosion control is covered more fully in Chapter 6.

Dispersible soils will erode any hydraulic gradient. The soil particles enter suspension because of their inherent repulsion of each other and are carried away by any movement of water

3.2 The soil erosion process

As soil erosion tends to be the most significant manner in which wetlands are damaged, an understanding of the driving forces in the erosion process is necessary. The process is most simply explained by making use of the format of the Universal Soil Loss Equation, a model that was developed in the 1930s in the United States of America (Wischmeier and Suull, 1978). While it is widely used throughout the world in planning for erosion control on cultivated land, it is also useful for describing the elements of erosion in general, and helps the planner in considering the various ways in which rehabilitation could possibly be undertaken. The equation reads as follows:

A = R x K x S x L x C x P t/ha/annum, where

A = Long term soil loss, or in our context, the formation of gullies, the size of which will depend on the size of the various parameters on the right hand side of the equation.

R = Rainfall and runoff erosivity, or the energy of falling rain and velocity of flowing water, since fast flowing water causes erosion.

K = Soil erodibility, or the susceptibility of soil to erode under the influence of fast flowing water. As an element in the rehabilitation process it indicates the need to consider the strength of the construction material needed.

S = Slope of the ground. The steeper the slope, the greater will be the velocity of flowing water, and the greater, therefore, will be its erosivity. In the rehabilitation process it signifies the need to reduce slope.

L = Length of slope. The longer the length of slope, the more time there will be for flowing water to pick up speed on a given slope and gain erosive force.

C = Ground cover. This relates to both the protection that cover affords soil from the hammering action of falling rain drops (i.e. kinetic energy), and the manner in which vegetation slows down the velocity of flowing water, thereby reducing its erosivity.

P = Supporting practices such as the introduction of vegetation, and the construction of grade stabilisation structures.

To summarise, erosion of soil (and also, incidentally, of other construction materials that may be used in combating erosion) arises, and is intimately related to, the velocity (kinetic energy) of both the rainfall hitting the ground and the speed of the resultant runoff. It is also dependent on the susceptibility to destruction of the material (e.g. soil, concrete, rocks, etc.), called the erodibility of the material, over which the runoff water flows. The slope of the terrain is extremely important, as velocity is approximately equivalent to the square of the slope over which water flows. The length of slope has an influence as well. Runoff generally starts as overland flow and is controlled to an extent by the roughness of the surface over which it flows. As length increases, flow starts concentrating due to unevenness in the micro-topography, leading to an increasing velocity (and therefore erosivity) with increasing length. The effectiveness of vegetative cover that is present in both reducing the energy of the impacting rain and the resultant flow of water is critical. Finally, the ability of any structures that may be placed in the path of the flowing water to slow down its erosivity is important.

3.3 Rainfall

One of the basic and most common causes of degradation to a wetland is as a result of the formation of a gully or gullies cutting through the soil profile of the wetland, and draining it of both surface and sub-surface water. The reduction of the amount of moisture available to the wetland soils and plants then results in die-back of the vegetation and reduction of bio-diversity. Structures that are then built in the wetland in an attempt to stop the degradation, and to reverse the process, must be designed to control and re-distribute the available flow of water. The process of designing structures that will be strong enough and durable enough to withstand the flood events that occur in wetlands will of necessity require knowledge on the part of the designer as to the size of the flood events that flow through wetlands. It should be self-evident that the larger the flood peak, the greater the damage that could occur to both the wetland and the structure built to protect it. What causes some wetlands to have large flood peaks more regularly that other wetlands? Why, after a given amount of rain is the size of a flood sometimes different during another storm of similar size and in the same catchment (see sub-chapter 2.1) Factors that affect flood size are many and varied and are related to general rainfall patterns, size of particular rainfall events, as well as catchment characteristics.

In this context, the size of a rainfall event is generally important in respect of two main characteristics, *viz.* **the amount of rain** that falls, and the rate at which it falls (**rainfall intensity**).

Rainfall amount
(symbol **d**, measured in mm).

Rainfall amount is measured as the depth of rain that falls. It is measured in a cylindrical receptacle with a flat base and an open top, and is held vertically. At the end of the rainfall event, the depth of the water that has been captured by the cylinder is the 'amount' of rain (in millimetres) that fell. Consider a region that has an annual rainfall of 800 mm. If the total rainfall each year was captured in a cylindrical container where the effect of evaporation was excluded, and the depth measured was averaged over the number of years of observations, that average annual rainfall would fill the cylinder to a depth of 800 mm.

Rainfall intensity
(symbol **i**, measured in mm per hour).

Like rainfall amount, rainfall intensity also measures the depth of rain that falls using a cylindrical container, but with the addition of the measurement of time. For example, a storm of 50 mm (depth of rainfall) may have occurred over a period of 5 hours, or it may have occurred over a period of 1 hour. In the former instance the i value of the storm was 10 mm per hour (50 mm / 5 h = 10 mm / hr) and therefore a soft soaking rain. The latter storm would have an i value of 50 mm per hour, an exceedingly heavy storm resulting in a much higher flood peak, although both would have given the same amount (d) of rain. In curbing the amount of erosiveness of flowing water, the rainfall intensity is usually more important than the total amount of rain that may fall during a storm. High rainfall intensities are generally of short duration and cover small areas. Conversely, the more gentle rains tend to last longer and cover a much wider area. Furthermore, the higher the annual rainfall, the higher the intensities that can be expected, and *vice versa*.

Rainfall events of similar intensity and duration tend to occur at random. The heavier the rainfall, the less often they recur. So, for instance, in a given **climatic zone**, a rainfall event, for example, with an intensity of 50 mm per hour for a particular duration may recur on average once every two years. In the same climatic zone a heavier storm of 100 mm per hour for the same duration may occur once in only ten years. It is found that differing climatic regions experience different rainfall intensity-duration frequencies. The south western Cape (Winter Rainfall region) for instance experiences rainfall intensity-duration relationships that are considerably lower than those in Gauteng (Summer Rainfall region). The various rainfall intensity zones in South Africa are shown in Chapter 15 (Figure 15.2).

3.4 Infiltration, runoff and runoff intensity

The amount of rainfall and the rainfall intensity are not the only important parameters in determining the resultant size of a flood. Very important as well is what happens to the rain at the ground surface. In fact, some rainfall never reaches the ground at all, but is instead intercepted by vegetation. This water evaporates with time. Of the rain that falls on the ground some infiltrates the surface and the rest runs down slope on the soil surface. These are measured as **rainfall infiltration rate** and **runoff intensity** respectively.

Rainfall infiltration rate
(symbol **f**, measured in mm per hour).

Soils are, to a greater or lesser degree, absorbent, and will soak up rainwater at a certain rate dependent on certain characteristics. This is referred to as rainfall infiltration rate. This rate is dependent, in the first instance, on the texture of the soil. Sandy soils will absorb water at a fast rate generally, and clay soils at a slow one. Irrespective of texture, however, bare (and conventionally cultivated) soils will have a lower infiltration rate than those covered with vegetation or mulch, and the better the cover, the greater will be the infiltration rate and the lower will be the runoff.

Cultivated soils will have a lower infiltration rate than undisturbed ones. The larger voids (such as old root paths, animal and insect tunnels, etc.) that prior to cultivation provided storage space in the soil, will have been destroyed by the cultivation.

Very basically, when an open-ended glass cylinder is held upright on the soil surface and filled with water, the rate at which the water penetrates the soil surface can be measured (in millimetres) on the cylinder wall as the level drops and the time recorded with each successive measurement. The infiltration rate of most soils commences at a fairly rapid rate, but reduces with time, to a slower, fairly uniform one. Each soil has a specific **f** value, but as stated previously, it does depend upon its texture (i.e. distribution of particle sizes), amount of organic matter, land slope, amount and type of cover, and the presence of a limiting layer in the profile.

Runoff and runoff intensity
(symbol **Q**, measured in cubic metres per second)

It is perhaps best to first describe what runoff is and how it takes place.

If the rate of rain falling (i.e. i mm/hr) exceeds the rate of infiltration (i.e. f mm/hr), surface runoff (Q mm or m^3/hr) will occur.

i.e. $Q = i - f$ mm/hr

If a catchment area is rendered artificially impervious in some way or other, all the rain falling onto it will run off the land. If measured at a particular point along a stream that is issuing out of a catchment, it will be a mere trickle at first, being the discharge from only the closest area to the observation point. As time passes, however, and as the rainfall continues, the flood will build up, because more and more of the runoff from the most distant parts of the catchment are now converging at the observation point. After a period, and once runoff from all parts of the catchment are contributing flow to the measuring point, the rate of runoff will equal the rate of rainfall less the rate of infiltration, and the so-called highest discharge or flood peak will have been reached. The runoff builds up over time to its peak and then tails off as the rainfall rate decreases, generally at a slower rate than that at which it built up.

The time taken for the flood peak to be reached is termed the Time of Concentration, and this is a function of a number of factors:

- The **degree and effectiveness of soil cover**, either as a result of close-standing vegetation or crop residue lying on the surface slowing it down, while the lack of cover will result in an increase in runoff.
- The **soil type**, it's organic content, depth, specific infiltration rate value, and moisture content at the time of the rainfall event. Deep, well drained soils with high organic matter content, high inherent infiltration rate values and low moisture contents will result in a low runoff rate. The opposite will, of course, have the opposite effect.
- The type and intensity of **cultivation** practised. The various forms of conservation tillage will cause a reduction in the rate of runoff, while it is common knowledge that conventional tillage results in high rates of water loss because of the surface sealing effect when soil loses its organic matter through excessive aeration by ploughing with a sod-inverting plough.

- The amount of **erosion and degradation** existing in the catchment. These conditions are characterized by bare soil (often subsoil) and consequent sealing of the soil surface leading to low infiltration rates, leading to excessive and high velocity runoff.
- The amount of **surface storage** by way of dams and surface depressions slowing down the velocity.
- The **topography** of the catchment. Runoff flows more rapidly from steeper catchments.
- The amount of **urban development** with its associated soil sealing effect will cause high velocity of runoff.

For wetland rehabilitation purposes the rate at which runoff takes place (**runoff intensity, Q**) is critical. This is because any structure that is erected in a channel subject to flooding must be able to pass a flood of a certain size without it being damaged. The concept underpinning the estimation of runoff intensity is discussed in the following section. The actual methods are discussed in Chapter 15.

3.5 Estimating runoff intensity (the Q value): the concept

(see Appendix 4 for actual calculations)

Runoff intensity measurements can be carried out directly by setting up a weir and flow recording apparatus. A minimum period of time for a reasonably accurate average runoff intensity observation is twenty years. To gain a value for design purposes will take much longer. It should be quite obvious that the expense and time delay in direct measuring over a number of years will not be suitable for small scale wetland rehabilitation projects! If a responsible authority has measured the flood-flows over a long enough period in the past, the use of those records would be permissible.

For smaller structures it may be sufficient to calculate the Q value from high water marks on the side walls of gullys. This will involve the measurement of the shape and dimensions of the cross section of the gully, and the gradient of the section under review using Manning's Equation (see Chapter 17).

Runoff is dependent upon:

- Rainfall intensity – this is the driving force of the entire runoff process. Modifying the size of the runoff event are the following catchment-related parameters
- Size of catchment – within certain bounds, the larger the catchment area the larger will be the flood peak. As the catchment gets larger, however, so the Q value *per unit area* becomes smaller due to such factors as rainfall interception and surface ponding, slower flood flows where the topography flattens out allowing for more infiltration into the ground, and evaporation. The average rainfall intensity also decreases from the point value as the catchment size increases – the areal reduction factor (see Chapter 15).
- Shape of the catchment – the longer the route that flood waters have to travel to the measuring point (viz., the point where a structure is to be built) the lower will be the flood peak, compared to a more compact shape of watershed. The term used here is 'Catchment Lag' which, for the purposes of this manual, can be considered the same as Time of Concentration (used in some formulae).
- Slope of the catchment – the steeper the slope in the catchment the faster the runoff will move, resulting in less time for it to infiltrate the soil. Similarly, the steeper the slope the less surface storage there is and again, the more water that moves off. The result is that the steeper the slope the greater the flood peak that can be expected.
- Soil type – some soils absorb water faster than others, and some soils are

deeper than others. These two factors considered together will result in more or less of the rainfall being held back and stored underground, thus increasing or reducing the size of the flood respectively.

- Vegetation cover and conservation measures/practices – bare soil will rapidly seal under the force of torrential rainfall, resulting in increased runoff. A good cover of vegetation will reduce the impact effect of the falling rain through interception and energy dissipation, thereby reducing the sealing effect on the soil surface. A thick layer of organic litter left lying on the surface of crop land by one of the conservation tillage type methods, will radically improve the rate of infiltration into the soil, thus reducing the flood peak. Cultivated lands that have been protected by contour banks will also improve the situation to a certain extent.

All of these factors must be investigated as part of the site investigation when planning a wetland rehabilitation project.

There are numerous methods available for estimating Q; two of these methods, the Modified Soil Conservation Service Method and the Rational Method, are given in Chapter 15. Neither of them should be considered as perfectly accurate, and it is sometimes practice in small scale projects for experienced designers to compare the answer from these formulae with actual observations and measurements of the in situ high flood flows. Adjustments to the calculated value are then made where considered necessary.

It is common practice to calculate Q using several different methods and to decide on a design value by comparing the different results. Experience and observations by people living close to a stream can be useful. What is the maximum height that they have seen flood water reach? About how often does water reach a particular level, a couple of times a year, once a year, once in a couple of years?

3.6 The power of flowing water

Flowing water contains energy which is linked to erosivity. This energy may be calculated from the formula:

Energy = ½ (Mass x Velocity^2)

What this intimates is that energy is directly proportional to both the mass of the water and its velocity. More importantly, it is proportional to only the mass of the water, but proportional to the square of the velocity. In other words, the energy (read erosivity) of flowing water increases far more with an increase in its velocity than it does with an increase in the mass of the water flowing. Its ability to dislodge and transport large soil particles is increased exponentially with an increase in velocity. Table 3.1 below illustrates the relative change in the damaging effect of moving water as its velocity increases. *This is an extremely important concept in erosion control, both from a bio-engineering and from a civil engineering aspect.*

What this means is that as the velocity of flowing water doubles, its ability to cause erosion increases 4 times, resulting in a 32 time increase in its ability to transport material, and a 64 time increase in its ability to displace particles. Similarly, a 3-fold increase in velocity results in a 9-fold increase in erosivity, a 243-fold increase in its transportive ability and a 729-fold increase in its displacement ability. *Thus the ultimate solution to soil erosion as it impacts on wetlands therefore lies in the control of the size of floodwaters and the velocity at which they speed down the catchment, into and through the wetland*. In soil conservation on the other hand, the relationship also results in benefits when considered in reverse – by reducing the velocity of sediment laden runoff, the water is forced to reduce its bed load (and some of its suspended load) sediment, which must then be stabilised with vegetation. This deposition of sediment should either take place before the wetland is reached, or be used within the wetland to fill up gullies, depending on the situation there and the objectives of the project (see Chapter 4 for more detail).

Table 3.1: Relationship between slope, velocity of runoff, and its associated ability to cause soil erosion (SA Dept. of Agric. Tech. Services, undated)

Slope	Runoff velocity	Erosivity	Power of moving water	
			Transportive	Displacement
v^2	v	v^2	v^5	v^6
1	1	1	1	1
4	2	4	32	64
9	3	9	243	729

CHAPTER 4: PLANNING THE REHABILITATION OF AN ERODED SYSTEMON

4.1 Key structures used in wetland rehabilitation

This section very briefly outlines the types of structures that can be used in wetland rehabilitation. It deals only with mechanical structures, but it must be remembered that using vegetation is often preferable and must be considered as one of the options. This is dealt with in detail in Chapter 6. Also, you will recall, that this manual is dealing mainly with **gully** or drainage channel degradation.

There are two broad goals that planners attempt to achieve by erecting structures.

Goal 1: keep water out of gully

The first is to keep water out of the gully until its entrance into the gully can be managed effectively. Appropriate interventions in this case include:

- Filling in the gully (usually only in minor ditches, see Chapter 8),
- Placing earthen (or gabion or concrete) diversion embankments outside the gully to prevent or postpone movement of water into the gully, or
- Use of plugs within the gully to make water move back onto the wetland plain. Typical structures include earthen plugs, rock packs, timber or concrete panel weirs, gabion weirs and concrete weirs.

Goal 2: manage water in gully

The second broad goal planners attempt to achieve with structures is to manage the entrance of water into the gully in a manner that ensures the gully does not expand in any way, and once in the gully, to keep the water (or most of it) there. Appropriate interventions in this case include weirs, chutes or drop inlets.

In many instances these broad goals are less clearly defined when other objectives come to the fore. One may, for example, wish to get and keep base flow in the gully, but force additional flows into the wetland plain. Alternatively, one may wish to use structures typically used outside of the gully such as earthen embankments to force water into the gully and manage flows from there.

It should be clear by now that choosing the right intervention is not a simple matter and it is difficult to provide generalised guidelines. Issues such as current land use, existing infrastructure, wetland health and size, the location of the gully in relation to the wetland and stream, and objectives for rehabilitation (stabilisation of gully, raising water table, promoting diffuse flow, trapping sediment, etc.) all play a role in the choice. However, the decision trees presented as Figures 4.1 and 4.2 may prove useful in guiding the approach to a particular intervention on a particular site. The intention is to develop such decision trees further as part of ongoing research.

For comments in this regard please contact:
Donovan Kotze at kotzed@ukzn.ac.za or
Fred Ellery at f.ellery@ru.ac.za.

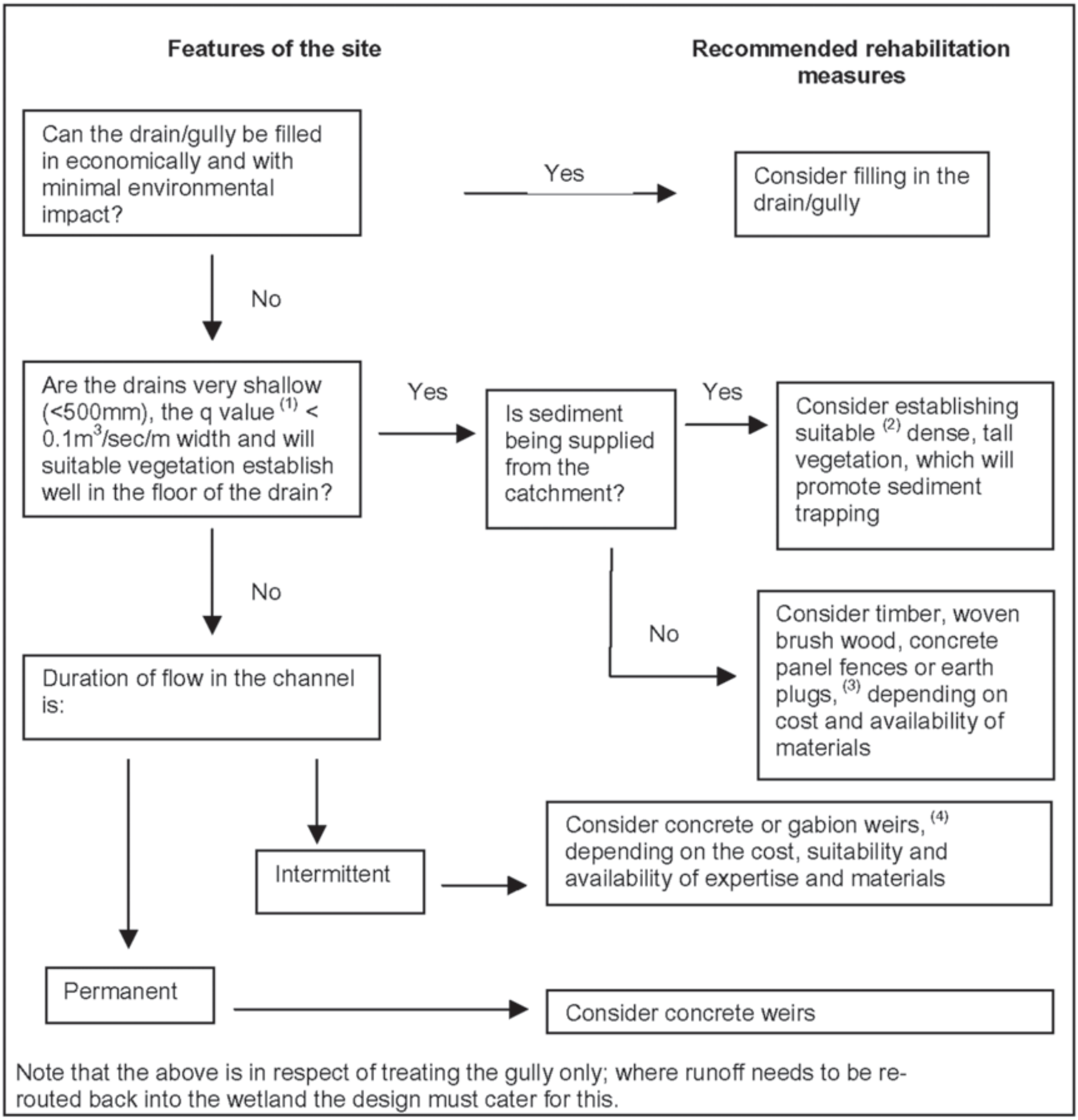


Figure 4.1: Decision tree for choosing appropriate rehabilitation measures for gullies and drainage ditches in wetlands

1. The q value is defined as the peak discharge divided by the width of the channel, i.e. q=Q/W, where W is the width of the gully.
2. Suitable in this context means vegetation that will not be killed by a smothering blanket of sediment, but which will grow through it and colonise the sediment.
3. Check the dispersivity of the soil. If at all dispersive (see Chapters 28; Section 28.1) treat the soil or reject this option.
4. Check the corrosivity of the water. If corrosive (see Chapter 28; Section 28.7) use PVC coated gabions or reject this option.

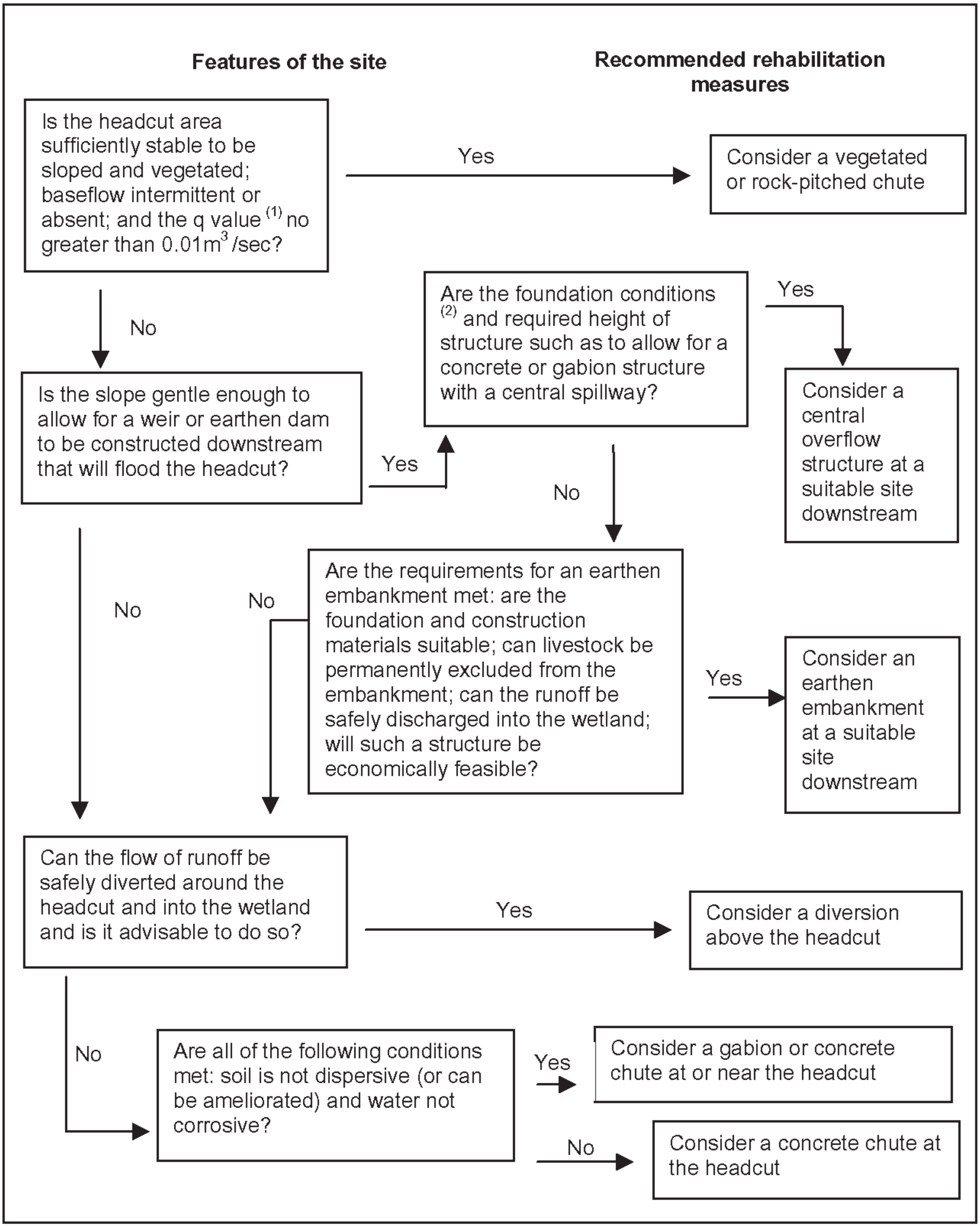


Figure 4.2: Decision tree for choosing a mechanism to stabilise active headcut erosion

1. The q value is defined as the peak discharge (Q) divided by the width (W) of the channel, i.e. q=Q/W.
2. Note that there are methods of overcoming the problem of soft foundations where concrete would be a better option; see Chapter 11.

4.2 Considerations in planning for erosion control

The exercise of rehabilitating any eroded system must, of necessity, be an holistic one, covering not only the degradation in the eroded area, but possible causative factors in the catchment area upstream. It must take cognisance of the type of problem, the factors that apparently caused the problem, the various possible solutions available, and the economics of the venture. In the context of wetlands it should also take cognisance of the type of wetland under consideration – whether it is (or was) permanently wet, seasonally wet, or temporarily wet. The wetland itself could comprise a combination of all three types. The solution to a given problem in a wetland therefore, should only be decided upon after a thorough investigation of both the entire wetland and its catchment.

Very pertinent, for example, is the decision on what to do with perennial or base flow in a stream or artificial channel that is to be blocked by a structure. In the case of a permanently wet wetland it is probably necessary that the base flow be diverted back into the wetland, to sustain once again that permanently wet area. On the other hand, where a temporary wetland is to be restored, the base flow may have to be (should be?) kept within the channel confines. This would be the case if the channel were the original flow path and not an artificial one. In addition, only a portion of the floodwaters would be diverted into the wetland, if any at all. The act of placing an obstruction, such as a weir, in a gully will result in reducing the flow capacity of the said gully to carry the larger floods over that stretch of gully. The result is then that, depending on the height of the structure (plus flow depth over the structure) in relation to the depth of the gully, some of the storm runoff will spill over into the adjacent wetland while the rest carries on down the gully. The higher the structure (plus flow depth) in relation to the depth of gully, the more the storm runoff will be diverted. The temporary type of non-floodplain wetland normally has a slight gradient towards the natural channel in order to drain off excess water, and this requirement must be built into the plan of action, unless the objectives demand otherwise.

As a wetland dries out, so the soils that comprise it may become unstable. Diverting large amounts of water back onto the wetland in one sudden operation could cause major problems, especially if the subsoil tends to be dispersive (see Section 28.1 for an explanation of this soil property) and large cracks exist along the gully edge. The design may then call for a basic structure(s) that will need to be increased in size (i.e. height) in order to divert an ever-increasing amount of runoff progressively into the wetland over a period of years as the soil returns to normal, and wetland vegetation starts re-colonising the area.

Large amounts of runoff diverted from a gully into its adjacent wetland, will very often tend to re-enter the gully at some point(s) downstream (Figure 4.3). Where this occurs a waterfall action as it re-enters will cause a lateral gully to develop. A detailed topographic survey of the wetland and gully will have identified this problem (see Appendix 2 on topographic surveying). Alternatively, and in the absence of a survey, a couple of years of monitoring the initial rehabilitation will pick up this problem. A subsidiary structure(s) may then be required to overcome the problem.

In the interests of economy the plan should attempt to accomplish as many of the objectives as possible with the minimum number of structures. For example, a single structure is sufficient in a gully with a flat slope since the sediment slope will drown the headcut (Figure 4.4b). For a steep gully a greater

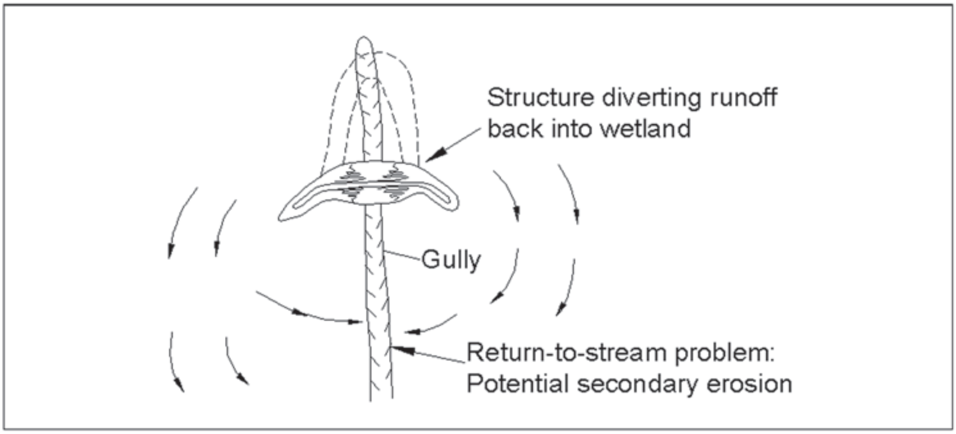


Figure 4.3: Plan view: flow returning to stream below structure

number of structures will be needed such that the sediment slope from a lower structure is coincident with the base of the next structure, and the uppermost structure partially 'drowns' the headcut (Figure 4.4a).

The maximum use should be made of suitable vegetation. Examples of using vegetation are in Chapter 6 and different types of structures and their uses are in Chapters 8 and 9.

Basically the plan should endeavour to:

- reduce the excessive flood peaks from the source area if they are one of the causes of the damage, by proposing remedial measures for erosion sites in the catchment area, and by promoting conservation farming there as well,
- reduce the transmission of excessive sediment into the wetland, if it will complicate the rehabilitation process, by both the catchment conservation measures indicated above and/or proposing a sediment trap in the channel upstream of the wetland. The sediment trap is generally sited within the gully in order to fill/partially fill it with sediment as a rooting medium for vegetation.
- stop any further erosion in the wetland, whether it be in the form of a head cut, a lateral cut, a deepening of the channel bed, or a combination of two or all three of them.
- restore the water table in the wetland, by either filling the channel with moisture (i.e. sub-surface recharge) or by supplying moisture through surface recharge by diverting runoff back onto the wetland. In many cases it will use both methods, and finally,
- restore the wetland vegetation that once occurred there by introducing suitable plant species.

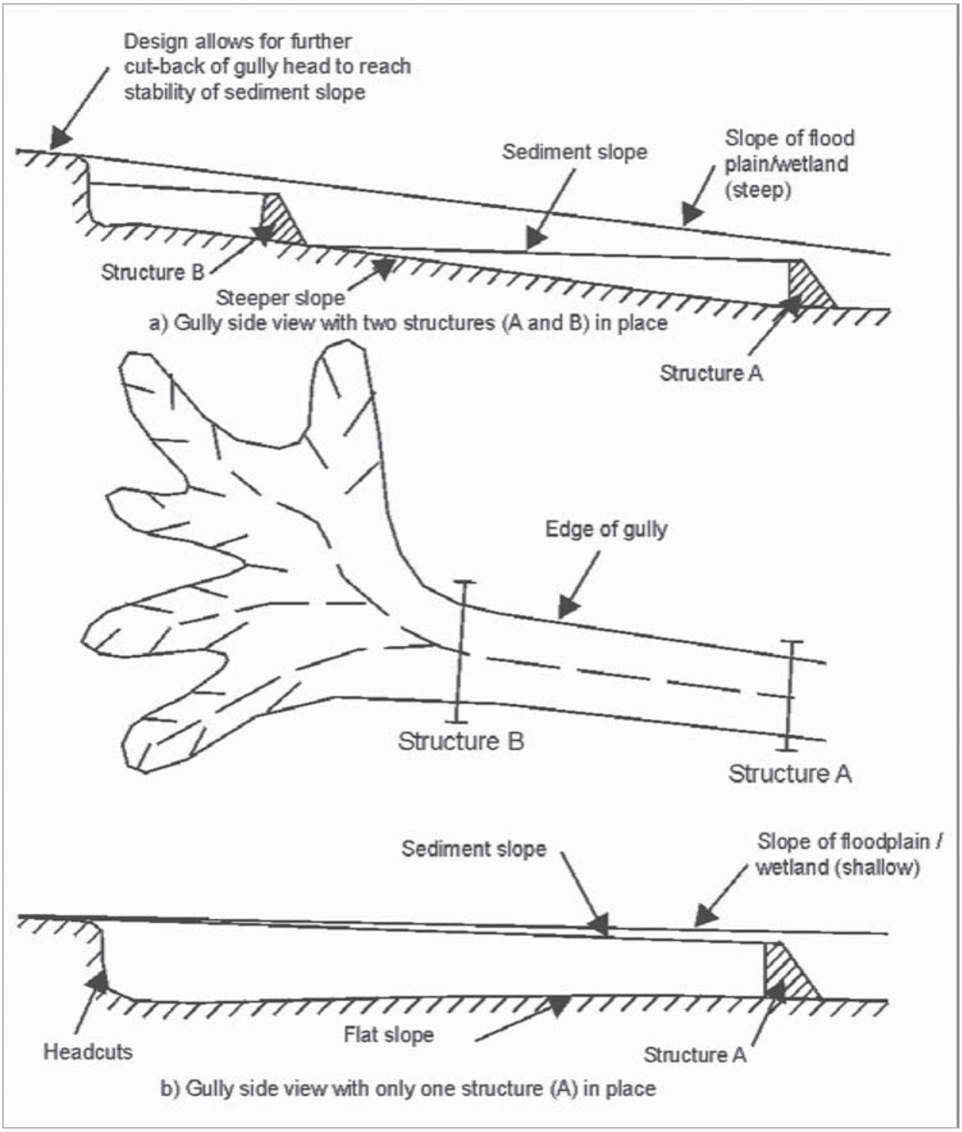


Figure 4.4: Gully side view showing siting of structures in relation to gully slope

4.3 Stabilisation versus restoration

However much one would wish to restore a deep and/or wide channel that is draining a wetland, funds for this type of work are often limiting. The cost of restoration should also be in proportion to the extent and/or quality of restoration gained. This aspect is very significant when considering eroded wetlands on a terrain slope in excess of 1:100 (1%) gradient. In this instance the size and number of structures (and therefore the cost) that will need to be built can be out of all proportion to the benefit gained. In this latter instance it would possibly be more cost effective to accept an objective of stabilisation rather than restoration. This would generally entail the construction of a series of smaller structures within the gully, which will catch up some sediment (Figure 4.5). The deposit of sediment is then stabilised with suitable vegetation that will eventually stabilise the gully walls as well. In all instances an effort should be made, at the planning stage, to compare a variety of solutions (based on objectives) and to compare the economics of each of those solutions.

In this same context, the attention of the reader is drawn to the problem of attempting to reclaim large gullies in wetlands or flood plains that have very large catchment areas. Typical examples of this situation are found in the extensive flood plains of the eastern Free State, the northern area of the Eastern Cape, and the Karroo. These are all areas with a fairly low to low rainfall and very erodible soils with relatively sparse vegetation cover, even within the wetlands. Ideally one would wish to build a structure with spillway height at original ground level, or just below it, in order to achieve total reclamation. The problem with this is that the structure will then have to accommodate the full flood peak from the catchment. When the catchment size is of the order of hundreds of square kilometres, a very expensive structure needs to be built. In order to ensure that all of the floodwater goes through or over the structure, long earthen berms (embankments) have to be constructed over the full width of the wetland (Figure 4.6). This cuts off the natural flow pattern of the floods and dries out the section below the berms. A series of culvert pipes can be inserted to spread flows and reduce drying out below the berms.

Culvert pipes will concentrate flow and encourage the formation of gullies. Care will have to be taken to dissipate the energy of water exiting from these structures. A better solution, if suitable material is available, would be to construct the bottom of the embankment of permeable rock fill over all or part of its length (Fig 4.7). Filter fabric layers would be required to separate the rock fill from the soil above and below.

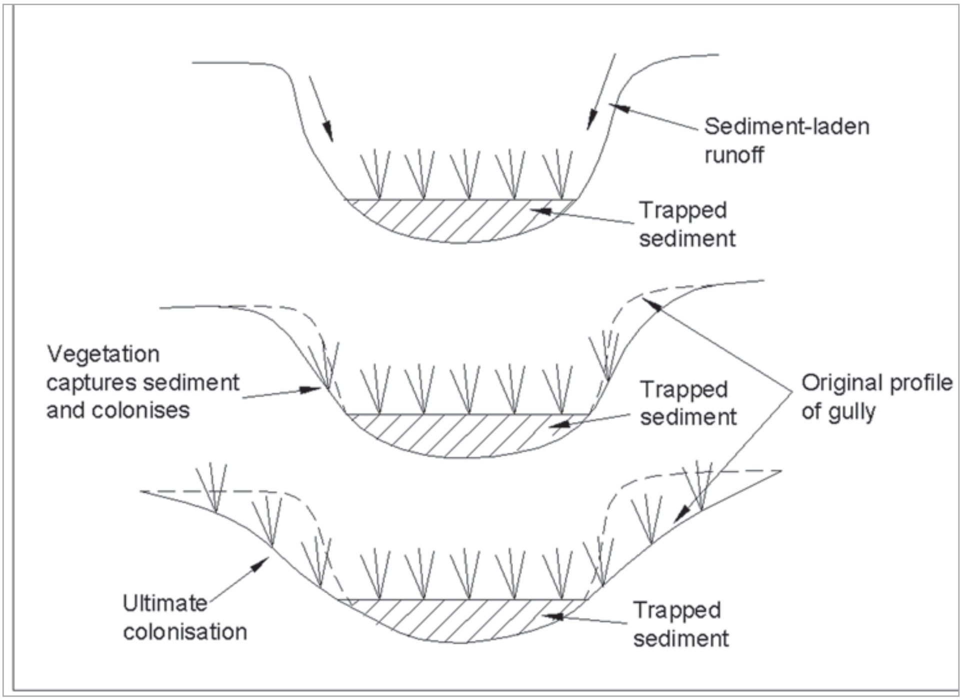


Figure 4.5: Cross-section with small structures within the gully, allowing vegetation colonisation

There will often be a need (objective) to regain the original conditions that existed in the wetland before degradation took place. In the instance where no free water surface existed before the damage, every effort should be made to ensure that as little damming up of water takes place with the restoration. Sediment from the catchment area is what is used to fill the gully behind the structure. Part of the investigation will then entail an estimation of the amount of sediment expected from the catchment, and comparison of this value with the amount needed to fill the basin behind the structure. To do this one will need to carry out a topographic survey of the basin, and with a map of the area plotted, use the contour lines to plan the best method of coping with the sediment (see Appendix 2).

The sediment trap-efficiency of any water control structure is improved when the floodwaters arrive at a basin that is empty, or nearly so. This is accomplished by building a structure with a 'drop inlet' behind it that will allow stored water to be siphoned off (Figure 4.8). As sediment deposition builds up in the basin so the tower of the drop inlet can be lifted. This idea has an extra benefit to the gully downstream of the structure. By storing a portion of the flood and allowing the stored water to be drawn off at a slower rate, the impact of the flood is reduced and moisture is made available over a longer period downstream. This benefits the growth of vegetation. Siphoning off too much water held back by an earthen embankment is not recommended. As the bank dries out it develops cracks.

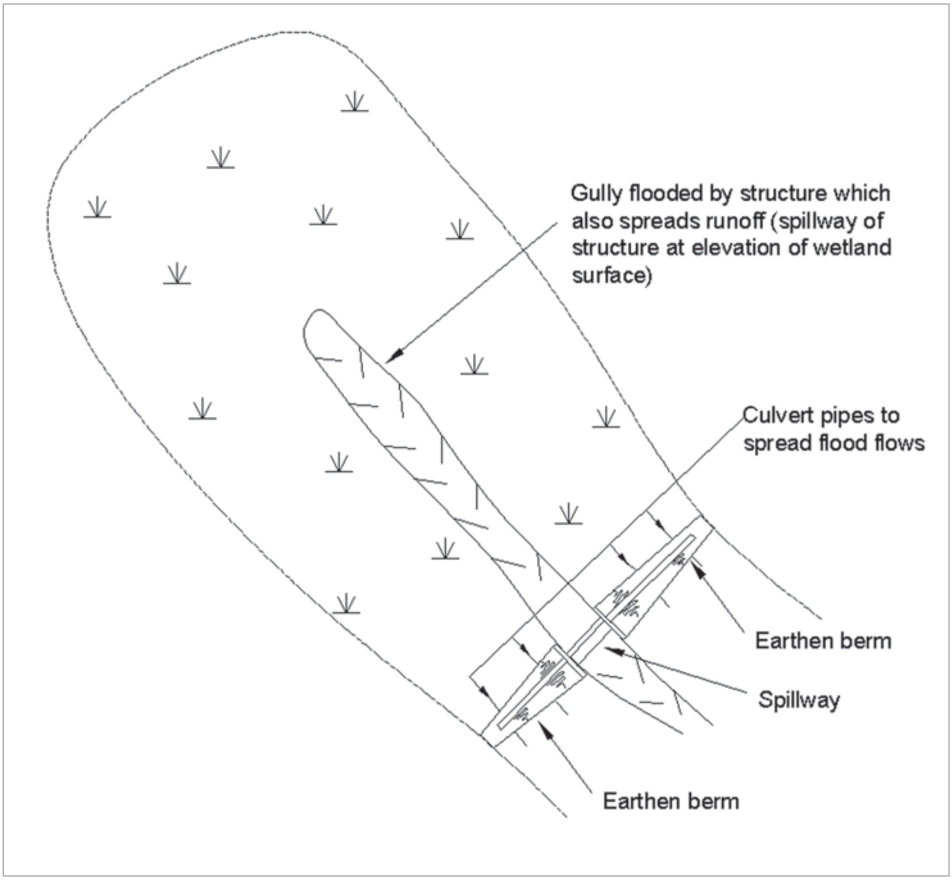


Figure 4.6: Plan view of gully in a wide floodplain with earthen berms across the whole width

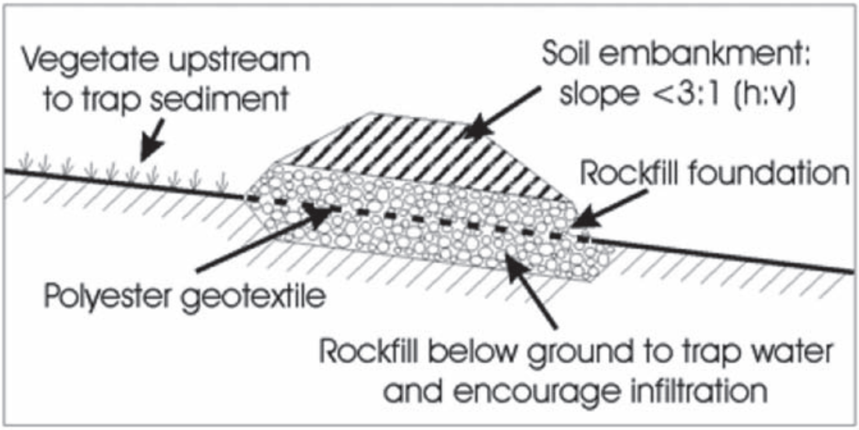


Figure 4.7: Side view of soil embankment with permeable rock fill foundation.

Termites have been known to colonise dry banks. In both instances the bank will be in danger of breaching.

It may not always be necessary to completely block the erosion channel. In wetlands that are only seasonally or temporarily wet, one should consider building a structure to such a height in the gully that only the heavier, less frequently occurring floodwaters are diverted on to the flood plain. Examples of the design of all the various structures are dealt with in Chapters 19 to 22.

Occasionally the situation, in combination with the objective(s), may suggest that only a head cut be stabilised without necessarily damming up water in the gulley. The structures typically used here are weirs and chutes that are built up against the head cut, and the floods that caused the problem are allowed to cascade over the structure without causing further damage to the soil profile (Figure 4.9). In spite of this seemingly simple solution it will always make good sense to check whether a structure further down the gully (and away from the headcut) may not prove to serve more than one purpose.

The erosion of the gully banks associated with the hydraulic jump that forms downstream of the toe of the step or chute is one of the most frequent causes of failure of these structures (Figure 4.10). The design must provide protection against this erosion and must ensure that the jump remains in the protected reach and does not wander off downstream. Use a counter weir and set the stilling pool below the channel bed level, or use thrust blocks to anchor the jump (Figure 4.11). A plunge pool with a depth of about half the height of the fall will provide effective energy dissipation.

Then again, and because of economics, instead of the construction of a number of head cut structures, it may be decided to divert the runoff from a number of head cuts, to one (or more) central one/s and erect a work for the purpose indicated in the paragraph above (Figure 4.9). It should be noted that this is not the best solution, and should only be contemplated as a last (and poorest) alternative. It is always more prudent to allow runoff to take its own path, based on the topography, rather than force runoff in a direction contrary to the natural one. Diversions generally need more maintenance because of the unnatural purpose to which they are put. If there is no more suitable solution, concrete structures will always be the better option here, because of the need for ongoing maintenance: a small concrete

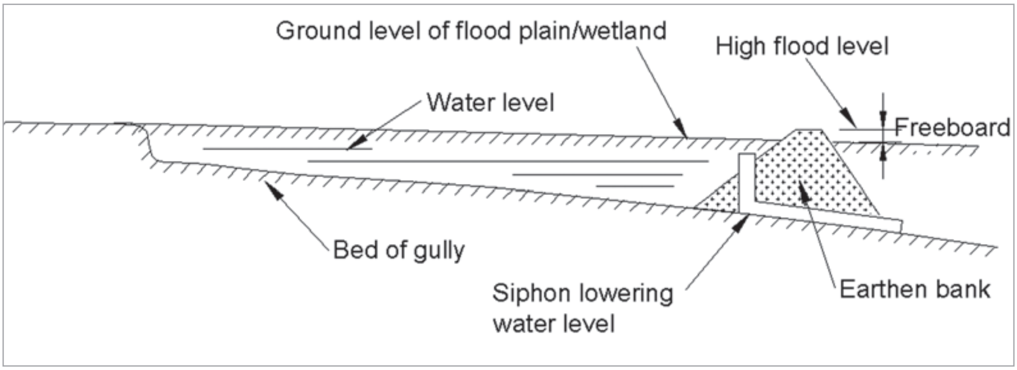


Figure 4.8: Side view showing drop inlet

wall as a diversion instead of an earthen storm water drain will require much less attention over the years.

In wetlands that have been drained by excavating ditches to enable agriculture to take place, the options are generally much simpler. Restoration can be a lot easier and more cost effective if the spoil that was excavated to form the ditch is still available alongside the channel. One merely pushes the soil back into the ditch, compacting it firmly and planting suitable vegetation. Similarly with cambered beds, a tractor and disc (preferably) or mouldboard plough can be used to close up the furrows, using the soil that was excavated originally to form the beds. In this case a large amount of planting will be required to re-establish suitable vegetation. Alternatively the furrows can be blocked every 25 to 50 metres with soil (depending on the slope of the wetland and the size of their mini-catchments) to dam up the runoff collected, and to discharge the overflow into the wetland. Just how this is accomplished is illustrated later in Chapter 8. Take note, however, of the need to compact soil correctly and to lengthen the earthen plugs so that the diverted runoff does not return to the drain. Where a drain has been excavated along the side of the wetland, the runoff will tend to flow away from it and safely into the wetland, because of the side slope.

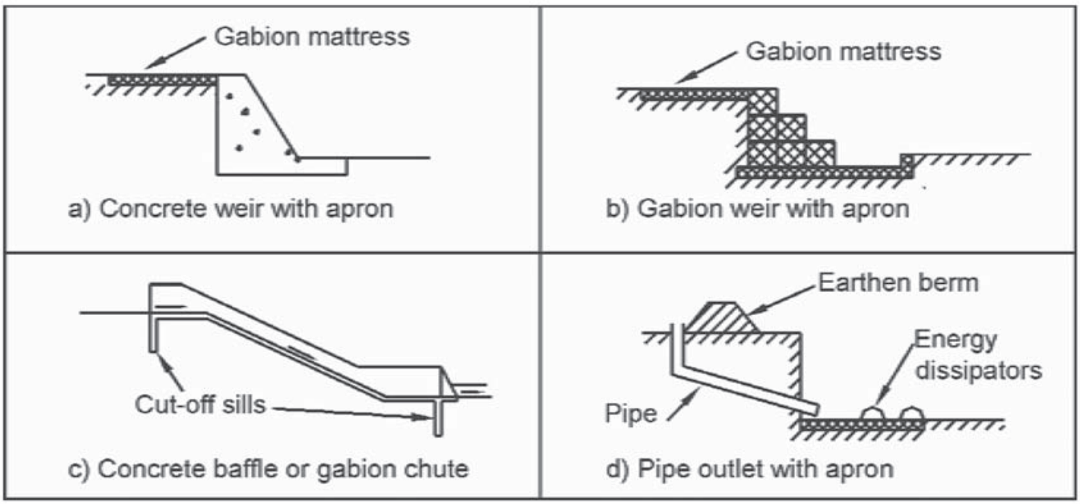


Figure 4.9: Side views of various structures to stabilize headcuts

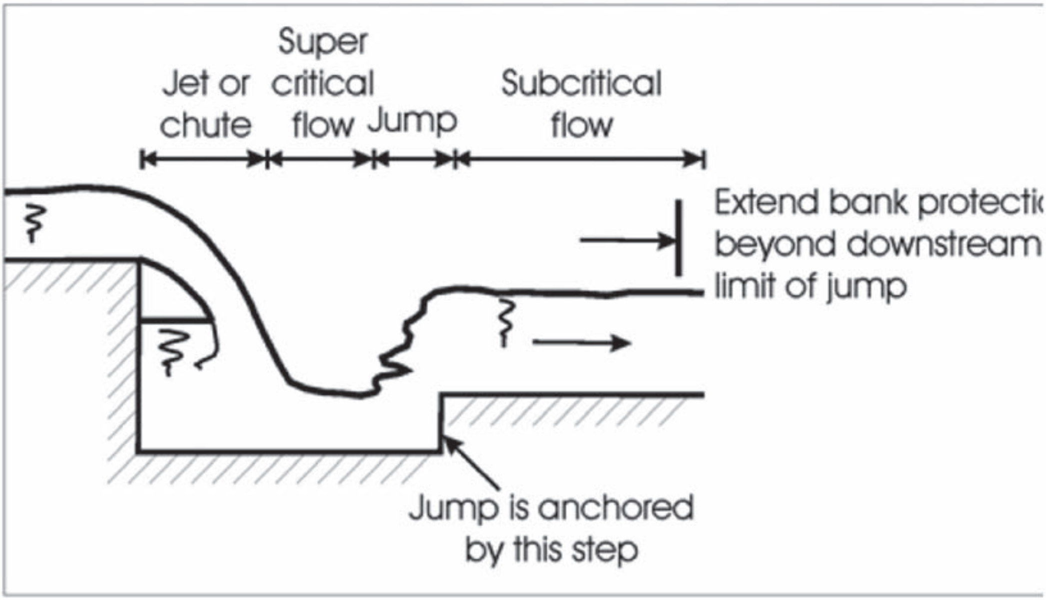


Figure 4.10: Side view of measures that need to be taken to manage flow over a step or chute

4.4 Impacts on neighbouring properties

The plan will sometimes call for structure(s) that will cause stored water or sediment to back up into adjoining property, into road reserves, underneath bridges, etc. or it may interfere with public utility equipment (Eskom power lines, Telkom telephone poles, etc.). It is imperative that this matter be discussed with the relevant land owners/authority before any structures are erected. Similarly, where it is planned to divert runoff across boundary fences, written permission from the relevant stakeholder(s) must be obtained.

4.5 Wetland rehabilitation and the law

In terms of existing legislation, any construction work in a public stream may only be carried out with the consent of three government departments. These include the administrators of the National Water Act (Department of Water Affairs and Forestry), the Environmental Conservation Act (provincial Departments of Environmental Affairs), and the Conservation of Agricultural Resources Act (Directorate of Agricultural Resources and Land Management in the national Department of Agriculture). Consult the *WET-Legal* (Armstrong, 2009) document from this series, which details the legal requirements in terms of wetland rehabilitation.

4.6 The locality map

It is imperative that all proposals for the rehabilitation of a wetland be recorded on a map so that whoever is to approve the work for funding, and the persons to supervise the construction, can ascertain its complexity. The use of a GPS or published map to enable the latitude and longitude of the site to be recorded will also be a great help in fixing the site(s). A further requirement would be a map to a smaller scale indicating the site in the context of the surrounding countryside, at least to the nearest town or village, and indicating public access to the site. This will ensure that whoever needs to go to site (e.g. funders, workers, building material delivery, etc.) should find the site easily. Appendix 1 has details on locating the different types of maps.

4.7 The rehabilitation plan

Working for Wetlands requires that a formal Rehabilitation Plan be completed and registered with them before any project can be approved for funding. The Plan is a document setting out the details of:

- the need for the intervention, i.e. why the project should be undertaken
- the wetland particulars – where it is, what river it is a part of, the DWAF quarternary catchment code, size of catchment etc.
- the details of land ownership and the part the owners/users will have in the intervention
- the partnerships that will eventuate during the intervention
- the impacts that the problem is presently having on the environment
- the impacts that the intervention will have on the environment
- the benefits that will be derived from the wetland as a result of the intervention

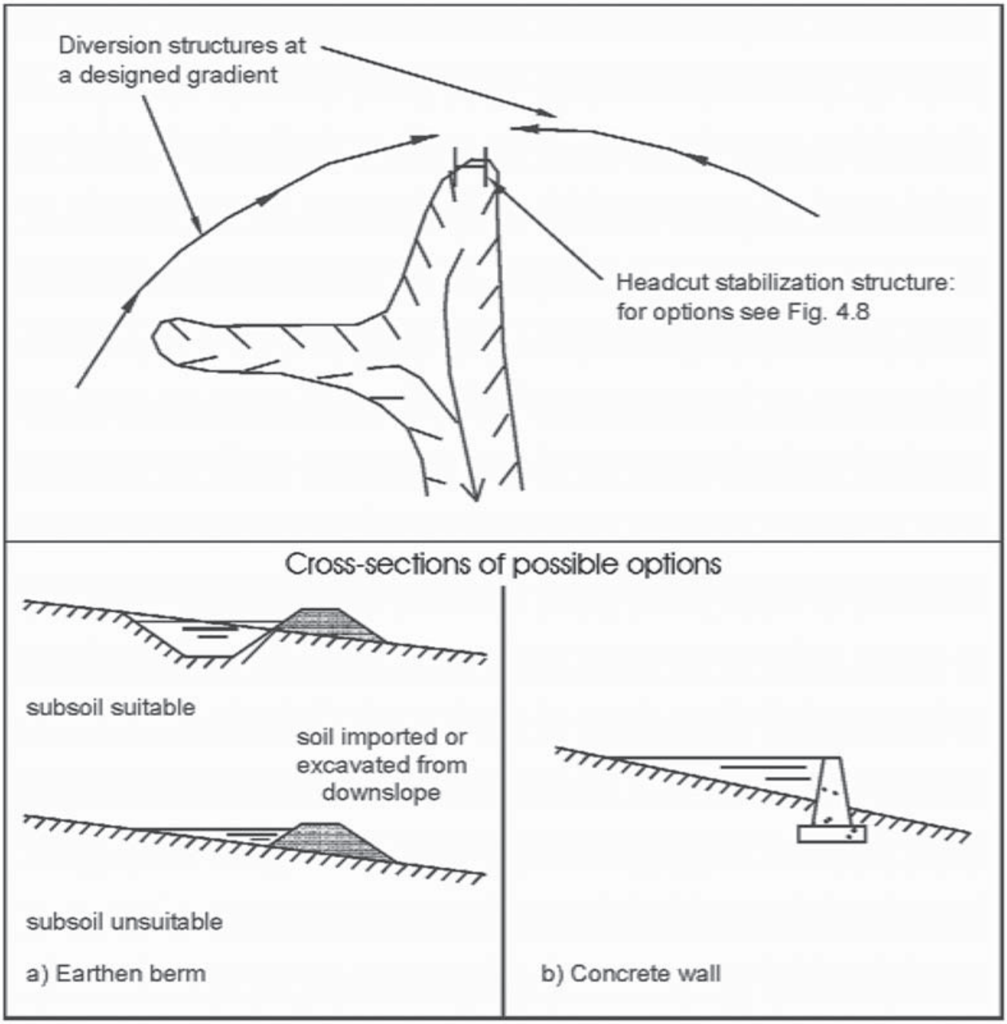


Figure 4.11: Plan and side view of types of diversion structures to protect lateral headcuts

- specific particulars of the type of intervention(s), the materials to be used, dimensions of the intervention proposed, and the total cost
- finally, the proposed monitoring that is planned, including the frequency of visits, what is to be monitored, who will carry out the monitoring, and the performance indicators that will intimate that the original objectives are in the process of being achieved.

4.8 The cluster business plan

The Cluster Business Plan is also a requirement by the Working for Wetlands organisation. It is in the form of a three-year accounting plan of how the funds to be provided will be spent. It records the following:

- The expenditure by item, breaking it up into such cost items as management, training, community facilitation, wages, administration, materials, equipment, transport, etc.
- The specific deliverables to be achieved, dividing them up into the various types of interventions.
- The type and number of workers to be used in the interventions are recorded, as well as the specific training they are to receive. The type and number of Small, Medium and Micro-Enterprises to be used during the interventions are also required to be recorded.

CHAPTER 5:
CONSERVATION IN THE CATCHMENT AREA

5.1 Grazing land

Increased runoff, which results in increased velocity of runoff and therefore increased erosion, occurs when overgrazing of the natural rangeland reduces the density of groundcover. In order to reduce the effects of overgrazing it is necessary to reduce the grazing pressure on the veld. Each veld type can support a certain number of grazing animals dependent on its condition, soil type and soil depth, slope steepness, aspect, and the amount and distribution pattern of rainfall during the growing season. Strict adherence to grazing capacity norms for each veld type and the condition in which it occurs, is mandatory in terms of the Conservation of Agricultural Resources Act No. 43 of 1983. They are available from the local Extension Offices of the Departments of Agriculture in each of the provinces, and from the national Department of Agriculture as well.

The rangeland must be given a chance to rest during the growing season in order to grow out and to strengthen the individual plants' root systems. This will allow them to maintain vigour and overcome the effects of short-duration droughts and grazing pressure. The plants must also receive rest periods during their seed-setting period. This can only be achieved under a properly planned system of grazing camps with judicious siting of permanent watering points that will allow the farmer the flexibility to withdraw his animals from degraded areas when the need arises.

It is usually necessary to separate different veld types with a fence, as some veld types are more palatable than others. Areas of grazing with radical differences in land slope, soil type, soil depth and aspect have both differing palatability and grazing capacities. If they are not separated the grazing animals will tend to overgraze the 'sweeter' areas and to under-graze the more 'sour' or less palatable areas of grassland. The sweeter grasses will then suffer from excessive defoliation and tend to die out. The sour grasses will then predominate, and this will lead to a reduction in grazing capacity and further degradation of the sward.

Very important in this context is the need to investigate the condition of the rangeland in relation to the norm or benchmark for the region. Veld condition assessment, with it's recognition of certain indicator species and their abundance in the sward composition that are peculiar to the specific veld type, will indicate to the investigator just how degraded the sward is. Its condition will also indicate the specific management practices that should be carried out in order to improve the situation.

Insufficient stock watering points, or watering facilities that are incorrectly placed, will cause the erosion hazard to increase through area selective grazing, trampling and the formation of paths. The placing of sufficient drinking points with a permanent water supply and at suitable sites is therefore considered a very important aspect in soil conservation farm planning, and will assist in ensuring a healthy sward, which will in turn increase rainfall infiltration and reduce runoff intensity. As indicated previously this will in turn be of benefit to the wetland downstream. A well-planned distribution of drinking troughs will ensure that the grass may be grazed when it is physiologically ready for grazing, and to facilitate an even movement of stock throughout the grazing camp. Ideally, each grazing camp should have at least two watering points (depending upon size of camp), so that animals can graze from one point to the other, and then return. Individual grazing camps should receive a full growing season's rest at least once in every four years.

There are many small stock watering dams in existence on farmland, especially on commercial farms, and these can help tremendously in reducing the extent of flooding from catchment areas. Fencing off their inlets and establishing suitable vegetation in the sediment that normally collects there will help in slowing down runoff and reducing sediment loads in streams. Better still is the practice of fencing off the entire wall and dam basin and supplying stock water to a drinking trough via a pipeline. Apart from helping to rehabilitate the streamlines on which they are built, the vegetation will reduce the rate at which the dams fill with sediment, and this will be of direct benefit to the farmer. An excellent ancillary to a storage dam is a draw-off pipe that will allow a portion of the stored water to trickle down the stream below the dam wall. It will be of benefit to the vegetation in this area.

The siting of dipping tanks is often a source of severe erosion. They are normally placed close to natural water sources, and regular trampling by stock being driven to the dipping facilities can cause severe gully erosion. Dipping facilities need to be sited with due care to the effect that regular stock movement will have on soil erosion; or suitable measures must be taken to ensure that erosion and runoff is not exacerbated. Equally important is ensuring that the contents of the dip tank do not pollute the adjacent stream.

Bush encroachment, if not combated, leads to a reduced grazing area, which in turn leads to overgrazing if stock numbers are not reduced accordingly. In controlling encroaching thorn bush these should be pruned rather than cut right down at ground level, unless goats can be utilised to control the re-growth, or suitable herbicides painted on the stumps.

Burning of natural veld in the high rainfall areas of the country is a very necessary management tool. It should be carried out for the specific purpose, however, of removing moribund grass, invader plants and an over-thick ground litter that is suffocating new growth, and for no other reason. If the grazing area is properly matched to the size of grazing herd, and proper rotational grazing is practised, the need to burn will be reduced to as little as once in four to five years in sourveld, and even less frequently in the sweeter veld regions. Burning in the lower rainfall areas should not be practised at all, unless bush encroachment is a problem.

Termite activity in winter, especially in the drier regions, leads to excessive removal of grass cover in rangeland. Every effort should be made to encourage the breeding and conservation of guinea fowl, francolin etc. as a means of combating them and protecting rangeland.

A recommended reading for this section is a document by the Co-ordinated Extension Committee of KwaZulu-Natal, 1999.

Erosion control on grazing land

Bare areas in rangeland result in rapid rainfall runoff. They should be ploughed/ripped up, fertilised and seeded to a suitable grass. This may be followed up, especially in the drier and more extensive grazing areas, by covering the treated area with brushwood. This latter measure will have the effect of trapping wind-blown seed, shading and protecting a seedbed environment, and will allow for natural re-establishment of the sward. Where the topsoil has been removed and the subsoil tends to be dispersive (see Chapter 28), a soil ameliorant such as gypsum (calcium sulphate), applied to the loosened surface (and not worked into the soil), has been found to give good results as far as improved rainfall infiltration is concerned. This will benefit the growing vegetation as well as reduce the rate of runoff. Most soils laboratories will be able to analyse a soil sample and make a recommendation on the amount of gypsum to apply.

Alternatively, and where conditions do not allow for the above-mentioned sediment trap fences of rocks, brushwood, shade cloth or specially marketed products may be erected on the contour at intervals down the slope to trap the eroded soil. These objects need be no higher than 250 mm, but must be porous and well anchored into the ground.

Gullies that have already developed through one or more of the bad practices mentioned above contribute large volumes of sediment to adjacent streams, and also speed up the drainage of the surrounding area. This in turn leads to higher flood peaks. The condition of the grazing around the gullies deteriorates. Animals walking in these vulnerable areas interfere with Nature's attempts to stabilise the erosion through re-colonisation by vegetation. The gullies should therefore be fenced off to stop animals trampling the area any further. This is especially important where the only source of water is in the eroded zone. Every effort must be made to keep animals out until such time as the area has properly stabilised. A watering point should be created outside of the vulnerable area and in such a position that it will not cause further erosion. The stabilisation process cannot occur if the soil surface in the damaged area is in a constant state of disturbance through trampling by stock.

By the same token, for vegetation to take hold (and re-colonisation should be the prime aim in stabilisation), there must be a suitable rooting medium with moisture and sufficient depth to it. This is normally achieved by constructing weirs in the gully bed to lower the gradient in the gully. The velocity of the floodwater is thereby reduced. Remembering what was said about runoff velocity and the ability of flowing water to carry sediment in suspension, the barriers will cause deposition of sediment behind them. It is then most important to ensure that suitable vegetation establishes in the sediment. This not only helps to keep the sediment in place, but also assists in slowing down runoff water even further, filtering out sediment in the process. New deposition therefore progresses upstream of the previous deposition, and vegetation advances upstream. In this way the effect of a barrier or grade stabilisation structure is extended well beyond its immediate environs.

The grade stabilisation structures themselves may be large or small, aiming to either restore the entire gully, or small enough merely to supply rooting depth and moisture for colonisation by vegetation. Whether large or small, however, they must be properly designed, and strong enough to withstand heavy amounts of runoff and excessive velocity. The design will depend upon the size and condition of the catchment area, the size and condition of the gully itself, the availability of suitable construction material, and the cost of construction in relation to the benefit to be derived from putting the structure(s) in place. For large catchment areas the runoff during heavy storms is excessive, and the services of a qualified technician or engineer to help with the planning and design of suitable structures should be sought. The various Departments of Agriculture in the provinces provide a soil conservation service free of charge, although applicants may have to wait a fair time for assistance. Plan well in advance for assistance.

The design chosen will take into account the availability and cost of local building material, and the structures themselves could comprise earthwork, grass establishment, rock packs, gabion work and/or concrete. The planning, design and construction of structures are discussed later.

5.2 Cultivated land

The conservation measures required on cultivated lands must also take cognisance of the principles of erosion control, i.e. reducing the impact of the energy of falling rain, of flowing water, and blowing wind. This will be accomplished either by practising some form of conservation tillage or, if forced to utilise sloping land, putting in contour banks or bench terraces in order to reduce the velocity of runoff, or preferably both.

Conservation tillage

The well-known structures called contour banks are, by themselves, not the complete answer to erosion control on cultivated land. Reference is made to what was said about the importance of cover, in the rangeland situation, in order to improve rainfall infiltration into the soil and reduce runoff over the land surface. The need for cover in the cultivated land situation is even more important. Farmers can simulate Nature's method of protecting the soil surface from the energy of falling raindrops and blowing wind by leaving a blanket of crop residue from the previous harvest on the soil surface and by reducing to a minimum the amount of tillage they carry out. Tillage in the conventional form destroys the vast network of subsurface channels made by earthworms and decayed plant roots. It also kills off the earthworms themselves that form these vertical tunnels. These channels make for excellent aeration and infiltration rates when the soil is not disturbed through ploughing. Ploughing loosens the soil, making it much more vulnerable to displacement by the erosive elements of falling rain, runoff and blowing wind. It also causes the destruction of important soil organic matter. High intensity storms cause sealing of the soil in the absence of a suitable cover, and excessive soil and moisture loss takes place under conventional forms of tillage.

A far better method is that of conservation tillage which incorporates techniques such as stubble mulch tillage, minimum tillage in sugarcane, and no-till (Figure 5.1). This approach reduces drastically both the rate at which valuable topsoil is washed away and the amount of runoff that leaves the field. The farmers' croplands will benefit from both results, but before they can do that they will have to learn how to use chemical weedicides on their lands in an effective manner. They will also have to invest in a special type of planter for best results. Further advantages to the use of this technology are a drastic decrease in power requirements and lower fuel consumption.

A recommended reading on conservation tillage is the *Guide to No-till Crop Production in KwaZulu-Natal.*

Contour banks

Contour banks are constructed on a slight gradient, at intervals down the slope, in order to intercept excess runoff and guide it away to a safe disposal point. They are of earthen construction and must be strongly built and with sufficient capacity to withstand storm rainfall runoff events. They are not suitable for land slopes in excess of 8%, and at the upper slope range will in any case not curb erosion sufficiently. It is recommended that they be built with a tractor and plough, and not with a grader, and certainly not by hand labour. Hand labour for this type of work is just not cost effective, and suitable compaction is never achieved with it. Once again, a soil conservation technician will be required to assist with at least the planning of the layout of the structures where extensive lands are encountered, and which will include provision for the safe disposal, into the nearest and most suitable water course(s), of the diverted runoff.

Farmers can easily be taught how to survey their own contour banks once the initial layout planning is done for them.

Land users are generally guilty of not carrying out annual maintenance on their contour banks, and when a heavy storm occurs and the structures are in a poor state of repair, severe damage can be caused by them overtopping. A cross-section of the recommended channel and

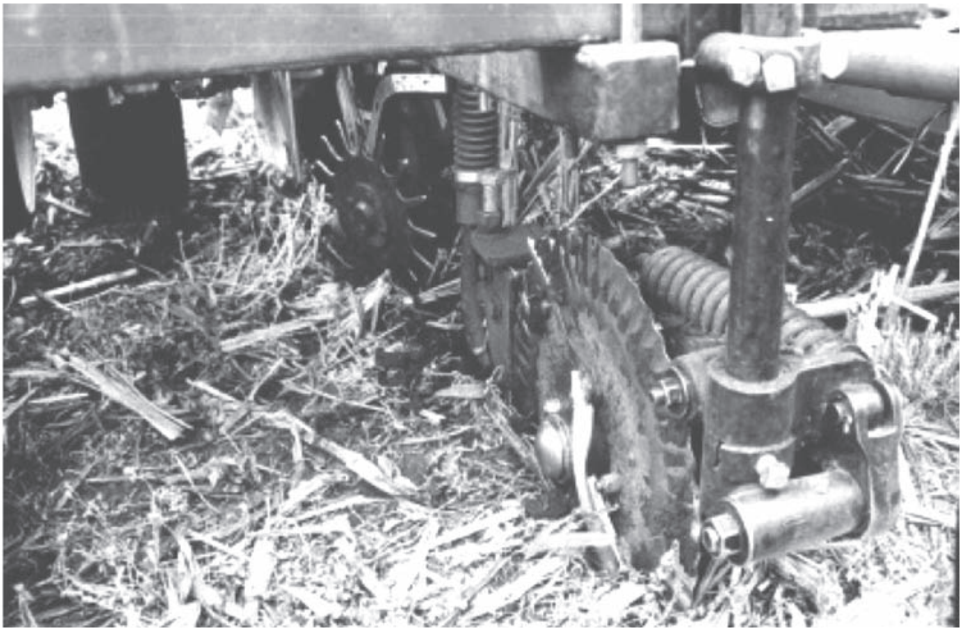


Figure 5.1: A no-till planter at work, showing the residue cover needed to reduce soil loss on crop land

bank combination is shown in Figure 5.2 below in order to acquaint the reader with the recommended size of the structures.

It has been proven incontrovertibly that soil movement between contour banks, albeit properly spaced and with due consideration of the erosion hazard due to soil type, cultivation method and land slope, is in most cases in excess of the rate of soil formation. The sediment resulting from high intensity storms tends to end up in the contour bank channel. This causes failure of the structure and points to the fact that, especially on slopes of 5% and steeper, one or other type of conservation tillage is also needed to curb excessive soil loss.

Artificial waterways and infield roads are integral parts of a contour bank system, and these should also be regularly maintained. The grass-lined waterways must NOT be used as roads, and any damage initiated in them must be repaired as a matter of urgency. If gully erosion in the waterway is allowed to develop unchecked it could result in severe damage to the land itself, or else expensive repairs will be required. In all these instances damage to the structures will result ultimately in increased flood peaks and consequent greater pressure on wetlands downstream.

Bench terracing

This involves the wholesale re-construction of the land profile into a series of stepped benches with a lateral gradient towards a suitable discharge point (Figure 5.3). While very expensive to carry out, it must be a consideration, especially where land slopes are very steep, crop residues for conservation tillage are insufficient, maintenance of contour banks are problematic, and high-value crops are grown. Once properly constructed however, and apart from protecting the steep faces of the benches with suitable permanent vegetation, the structures are virtually maintenance free. They also have the benefit of trapping maximum rainfall, so that in the context of moisture conservation alone they should be ideal for small scale farmers, on all types of slopes, especially in dry climates.

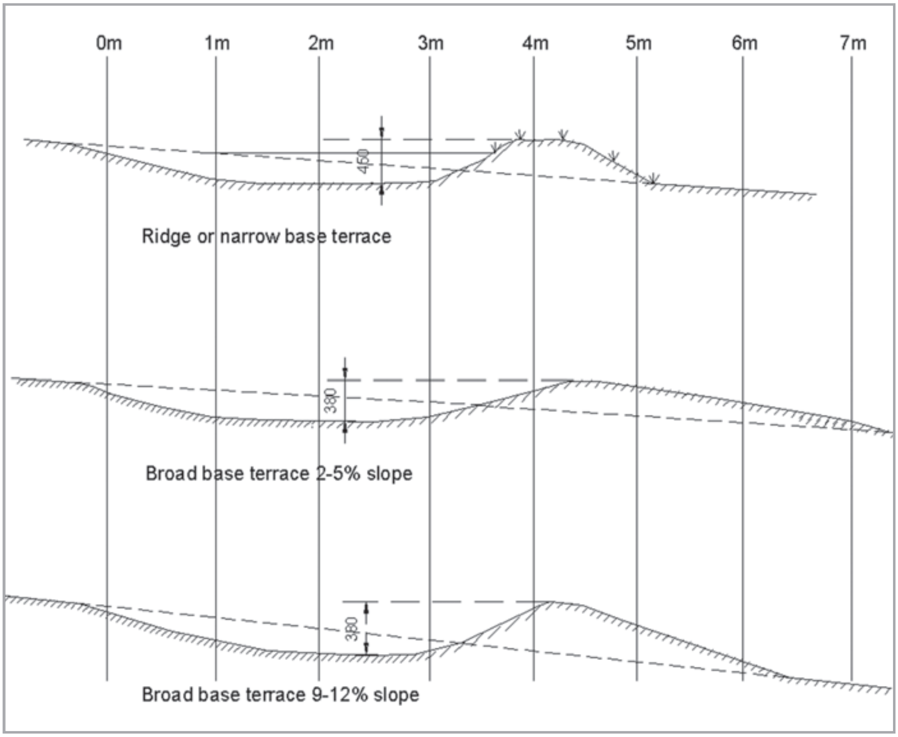


Figure 5.2: Cross-section through a standard contour bank of different types

Apart from the high cost of construction (a bulldozer will usually be needed) the only problem with them is the displacement of topsoil during construction. This will require a period of intensive soil improvement until the entire bench table surface has a uniform plant nutrient status.

5.3 Timber land

Soil erosion and consequent excessive runoff in timber plantations is of real concern only at planting time, directly after harvesting and for a couple of months thereafter until the trees have canopied. This is a problem mainly when steep hillsides are cleared in one operation, or when large areas on steep slopes are ploughed out.

The recommended manner of partially overcoming these situations is as follows:

- All residue or plantation slash from the harvested crop should be spread over the surface and left as a mulch instead of windrowing it in strips down the slope. This is more effective than the generally recommended practice of windrowing on the contour, as the cover helps to intercept raindrop splash and improves rainfall infiltration over the whole compartment, to the benefit of the following tree crop. Burning the plantation slash is a bad management practice for the environment as a whole, as it results in accelerated erosion, increased runoff, and air pollution.
- Re-establishment of plantations, wherever possible, should preferably take place in the low rainfall erosivity months of the year, i.e. between April and September in the summer rainfall areas, and during summer in the winter rainfall areas of the country.
- Both new plantations and re-established ones should, wherever possible, be carried out in contour panels no more than 250 metres wide across the slope, and adjacent panels down the slope should differ in age by at least six months. In this way, the better cover in the older

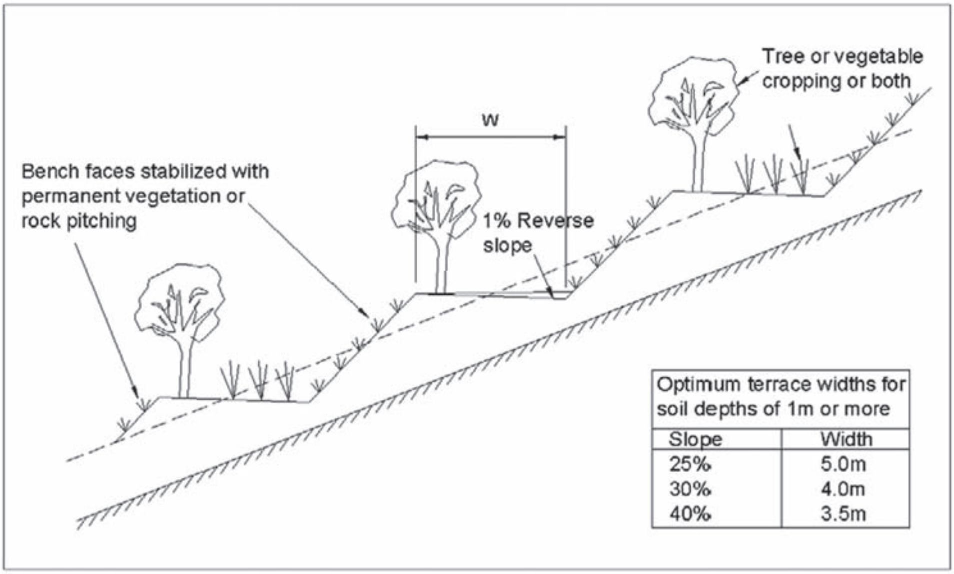


Figure 5.3: Bench terraces for protecting steeply sloping cropland

panels will help reduce the amount of runoff that could cause damage in the lower level panel, and ultimately in the wetland downstream.

By far the greatest effect timber plantations have on wetlands is the drying out effect that they have on water supplies to the wetland. The following are recommendations for reducing this effect.

- In terms of the Conservation of Agricultural Resources Act, No 43 of 1983, no one may cultivate any crop within natural watercourses, or within ten metres of the 1 in 10 year flood line of the watercourse. The planting permit for timber normally specifies an even greater distance, especially when the plantation is directly adjacent to a wetland. Where this condition has been ignored the attention of the inspectors of the Directorate of Agricultural Land Resource Management, and/or the officers of the Department of Water Affairs and Forestry should be called in to administer their respective Acts.
- It is a recognised fact that exotic evergreen timber plantations use a very large amount of water. Their effect on wetlands would therefore be to reduce the total amount of runoff available to the processes in the wetland. On the other hand, the combined effect of trampling and overgrazing by domestic herbivorous animals in grassland areas also has a negative effect on the hydrology of streams. The result is lower infiltration rates and higher flood peaks. When plantations are laid out with care, forethought, and strictly in accordance with the conditions contained in the planting permit, there should still be a relatively large area of under-utilised rangeland left between the timber compartments that may be undisturbed by grazing animals. This vacant land will be in a condition to soak up extra rainfall, leading to better basal streamflow, especially as plantation trees in the first four or five years of growth do not normally use an inordinate amount of water.
- If large areas that are to be planted up to timber plantations are planned over an extended period, the negative effect on wetlands could be greatly reduced by planting smaller compartments with a mosaic of different aged trees in each sub-catchment. The dearth of runoff water from the older compartments will then be at least partly offset by the

better water yields from the unused portions of original rangeland and the younger compartments.

A very significant effect that plantations have on wetlands stems from the nursery function when poorly managed timber sites provide for the build-up of alien plant invaders. Runoff and birds carry the seeds of these problem plants into the wetland where they proliferate and compete with the indigenous wetland vegetation.

5.4 Urban and other non-agricultural situations

There is seldom a culvert beneath a public road or rail, or issuing from an urban area, that is not characterised by a gully at it's lower end. This results in large amounts of sediment and increased flood flows being concentrated (and with flow velocities therefore increasing) that will impact negatively on wetlands downstream.

In the case of roads and rail, the reason for the gully is that the natural pattern of fairly widespread, shallow, and therefore low-velocity overland flow has been intercepted and concentrated at the culvert. Depending on available funds, engineers designing the road or rail are generally forced to reduce the number of culverts in order to stay within their budget. The further apart culverts are placed, the steeper the slope, the more erodible the soil, and the sparser the ground cover at the site of the culvert, the greater the erosion hazard. There are three or four possible options open to the planner for discussion with the landowners and the authorities, and one or more of them may solve the problem.

- Investigate ways and means of reducing the flood flows in the catchment area before they reach the culvert site. This involves the measures discussed earlier in this chapter.
- Negotiate with the authorities on the need to incorporate a greater number of culverts under the road and railway lines in order to reduce the individual point discharges of each culvert.
- Persuade the authorities to install energy dissipaters at the outlets of the culverts. Energy dissipaters are discussed in Chapter 21 (Section 21.4) in more detail.
- The concentrated, high-velocity runoff can be spread, and it's velocity thereby reduced, by excavating level spreader canals below the outlets, and earthen berms introduced lower down the slope to ensure that the runoff is dispersed as much as possible. The downside of this idea is that the spreader canals will require regular maintenance and cleaning out of sediments and debris. See design of spreader canals in Chapter 20.
- There is very little one can do to reduce the runoff intensity issuing out of urban areas unless the municipalities co-operate through regulating storm water management in their urban areas. Nowadays, and as part of the National Building Regulations, some local authorities require that the roof water from all new buildings be discharged into soak pits. This will help in reducing the Q value from an urban area, but not nearly sufficiently. Apart from attempting to persuade the specific local authority to adopt a similar policy, all culverts and stormwater discharge outlets should be fitted with energy dissipaters as with the recommendation for culverts beneath roads and railway lines.
- The local municipality should be urged to proclaim all streams and wetland areas in their suburban spheres of influence to be conservancies or nature reserves, with the local policing body instructed to include regular patrols in those areas as part of their duties. Adoption of these areas by the local communities, and especially local schools, should bring about a greater awareness of the problem, and inculcate eventually in the minds of the population a more careful approach to managing storm runoff.

CHAPTER 6: USING VEGETATION IN WETLAND REHABILITATION

EE Sieben, DC Kotze, WN Ellery & WB Russell

6.1 The role of vegetation in wetland rehabilitation

Vegetation plays an important role in natural wetland ecosystems. It holds soil together and slows down the flow of water, reducing the risk of erosion and promoting sediment deposition. Plants are the source of organic material in wetland soils, and form the organic soil in peat wetlands. Vegetation also has an impact on the quality of surface and subsurface water as it (1) provides soil organic matter required by microbes in order to assimilate nutrients and toxicants (2) provides habitat for the microbes in the soil immediately surrounding roots, and (3) contributes through direct uptake of nutrients and toxicants and incorporation of these into plant tissues.

It is important to recognize that because of its valuable role in wetlands, re-establishment of natural or semi-natural vegetation should be an important component of rehabilitation interventions. The establishment of plants can be a rehabilitation intervention in its own right or it can be used to complement other interventions that involve civil engineering.

In most cases of wetland rehabilitation, once the natural hydrology has been re-instated, wetland vegetation is likely to re-establish through natural recruitment by indigenous species. Therefore, planting of vegetation is generally not necessary. It is typically likely that alien and weedy species will arrive as well, but only a small number of these species will cause problems in the wetland in the long term.

Active revegetation, which refers to the manual planting of vegetation, is important if there are risks involved in waiting for natural recruitment to occur. It is important to assess such risks. The rehabilitation plan should specify the benefits of, as well as the risks of, not embarking on active revegetation as opposed to simply facilitating natural recolonisation. Nevertheless, the rehabilitation plan may overlook active revegetation as a component of rehabilitation of a site in situations where active revegetation may be useful or even necessary, depending upon the objectives of rehabilitation or the particular conditions at a rehabilitation site.

There are seven situations where revegetation should be considered:

1. **High-energy environments**: Where high current velocities are a potential threat to the wetland such as at gully headcuts, gully floors or on engineering structures, vegetation reduces current velocity, holds the soil together and thus reduces erosion risk. In many cases, vegetation can be used to augment existing engineering structures.
2. **Exposure of large areas of bare soil**: Following grading of a gully bank, removal of heavily polluted topsoil, or removal of alien vegetation, bare soil may be exposed. Threats that might occur if the wetland is left bare are sheet erosion, gully erosion or invasion by alien vegetation.
3. **Biodiversity concerns**: In areas where there are concerns about biodiversity conservation, such as in biosphere reserves, conservancies or national parks, rehabilitation should aim to restore the value of the wetland for biodiversity. Conservation agencies will likely have a stake in setting the rehabilitation objectives and should provide information about the habitat requirements of desired rare species, including plants and animals such as frogs and birds).

4. **Isolation**: Where wetlands are geographically isolated from other similar wetlands, such as in urban areas, natural recruitment may be hindered since propagules have to arrive from far away. Immigration of some desirable species that are only able to disperse over very short distances may be halted completely.
5. **Local economic benefits**: Areas where a local community has a certain requirement for biodiversity for economic benefits. In this case, the desires of the community need to be taken into account and those species that provide benefits for the community should be selected. These include reeds for weaving or medicinal plants.
6. **Water filtering capacity**: Areas where the wetland plays an important role in the enhancement of water quality from sources of pollution such as downstream of sewage treatment works, factories or mine dumps. All wetlands perform the role of biological filtering but wetland species and biogeochemical processes in wetlands are particularly well-equipped to remove even heavy metals such as zinc, cadmium, lead and mercury. In areas where this is an important wetland function, plant species for planting should be selected, to tolerate prevailing conditions and for their ability to perform this function.
7. **Aesthetic**: In areas where the wetland will be seen by many people, such as in urban areas, the expectation is for rapid results. People will react negatively to unplanted areas waiting for natural recolonisation. Work that is stopped without some attempt to revegetate bare areas will be viewed as unfinished.

Most revegetation measures that are taking place in South Africa are examples of the first two situations, where plants are used for erosion control, either in high or low energy situations. This use of vegetation is also referred to as 'bio-engineering'. Most of this chapter will deal with bio-engineering, but Sections 6.2 and 6.3 can be read in general terms of revegetation. Section 6.4 deals specifically with issues around revegetation for biodiversity issues, for local economic benefits and for water filtering capacity. Sections 6.5 and 6.6 consider the issues important for bio-engineering and the supporting structures for vegetation establishment are dealt with in Section 6.7.

6.2 Selection of plant species for revegetation

The situations in which revegetation is desirable, as described in the previous paragraph each put forward their own requirements on the plants that should be selected for revegetation (Table 6.1). The focus is either on the desired 'functional aspects' of a plant, (like the strength of the roots, the water filtering capacity, or the growth rate) or on the 'integrity' of the whole ecosystem that is associated with the planted species. Both aspects are important but the rehabilitation objectives should dictate whether functional or compositional aspects are given priority, and how compromises should be sought.

Whatever choice of species is made, it should always be borne in mind that diversity is the key to robustness. The characteristics of a system may change, sometimes very rapidly as in the case of wetlands susceptible to polluted runoff, and the greater the diversity of the species mix the greater the chance of the system surviving the stresses of changing characteristics. Monospecific planting must be avoided.

Once it has been decided to actively revegetate a site, the decision about which species to plant has to be made. In general, the species that are desirable to be planted are dominants, i.e. those species, that will contribute a large part of biomass or that will dominate overall vegetation structure. It is not usual to plant annuals or rare

Table 6.1 Demands on plants to use, depending on the objective of rehabilitation

	Demands on the plants to use, in general terms.
High-energy systems	Vigorous growth, strong roots, mat-forming, high shoot density.
Large areas of bare soil	Vigorous growth, rhizomes or stolons, preferably resembling natural plant assemblages. Ability to trap sediment.
Biodiversity concerns	Must resemble natural plant assemblages. Sometimes rare species may be used or species that make up the habitat of rare species.
Isolation	Large-seeded species, emulating natural plant assemblages.
Local economic benefits	Species that are known and desired by the local community and that can be harvested sustainably.

plant species, since these typically have high dispersal capabilities and do not play a large role in contributing to biomass or vegetation structure. The choice of species is dependent on many factors, including:

- **The natural habitat of the species.** Species should be selected that are naturally adapted to the conditions of the wetland in question. The following factors should be considered:
  - **The bioregion in which the wetland is located**. The broad-scale distribution of wetland species is dependent on climate, catchment and wetland geology, and water availability. South Africa has been subdivided into several 'wetland ecoregions' by the Department of Water Affairs and Forestry. A list of wetland species is provided for each wetland ecoregion later in the chapter.
  - **The type of wetland.** Wetlands are usually differentiated on the basis of their hydrogeomorphic setting, which describes the pattern of water flow into and through the wetland as well as its geomorphic setting. The hydrology of a site can be determined by flooding of rivers, by seasonal changes in ground or surface water level or by groundwater seepage. All of these situations create different conditions that plants have to adapt to. Some plants that cannot deal with complete inundation do very well in systems where water is flowing and the soil is aerated, such as inslope seepages.
  - The wetness zone within the wetland (i.e. permanent, seasonal, temporary). Flooding of soil is stressful for plants since roots need oxygen. Therefore plants have fairly narrow ranges of tolerance with respect to duration of inundation. A wetland soil can be saturated for the entire year, almost all of the year or for only a few months or even weeks.
  - **The nutrient status and substrate in the wetland.** The substrate (sand, clay or peat) will have an important impact on the drainage characteristics and nutrient status in a wetland. Sandy soils generally have a poor nutrient status and they are quickly drained. Clay can retain moisture very well, but here the aeration is poor and when the soil dries out it often shrinks and cracks. Peaty soils are mostly permanently flooded and when they are drained their internal structure is severely damaged. The most ideal substrate for plant growth is a humus-rich loam (a mixture of sand and clay).
- **Aims of rehabilitation.** The plant must have growth characteristics that are suited to the rehabilitation objectives.
  - A robust, vigorous aerial portion, extensive rooting system and/or a rapid growth rate are generally the most useful characteristics for plants that are to be used in bio-engineering.
  - If biodiversity and wetland integrity

are stated aims then a number of naturally co-existing species should be selected.

  - If biological filtering and/or water quality enhancement are the stated aims then plants that can cope with high concentrations of nutrients and/or detrimental solutes should be selected.
  - If sustainable harvesting by local communities is the stated aim than those species that are useful for those communities should be selected.

- **Availability of plant material**, given that the majority of wetland plant species are not commercially available. In many cases, grown plants like transplants are preferable because they can establish more quickly. This is especially the case in bio-engineering, when plants have to establish quickly before storm events occur that are too severe for juvenile plants
- **Origin of plant material.** Plants should preferably be indigenous and have been sourced close to the rehabilitation site. If exotic, they should not be invasive as their introduction may result in serious secondary impacts. Evidence to date suggests that vetiver grass (*Vetiveria zizanoides*, an exotic species with tremendous erosion control properties) is not invasive. However, if biodiversity conservation is a priority for the particular wetland then both exotic species and indigenous species with invasive potential (e.g. *Stenotaphrum secundatum*) should be avoided.

There is ongoing debate about *Vetiveria zizanoides* and there may be better locally available indigenous species for any particular application. Suitable locally indigenous species should be sought before resorting to exotics like *V. zizanoides*.

Suitable plants for revegetation can be selected from the total species pool of ecologically important wetland species (mostly perennial species that tend to make up a large fraction of the biomass in a natural wetland) presented in Appendix 6.1. In total, 350 plant species are mentioned, but each of them is only suitable for particular wetland type/s or particular region/s. Many factors need to be considered before a species or group of species can be selected. Thus, the procedure to select appropriate species or combination of species may be lengthy. The location of the wetland and the habitat type are the data requirements that initially inform this selection.

An alternative approach is to look at what is growing in a nearby intact portion of wetland that is of a similar type to that being rehabilitated and to identify those species that appear to have potential application to the site in question. One would then refer to the appendix for supplementary information.

Table 6.2 presents the definition of different wetland types while Figure 6.1 indicates the approximate distribution of wetland bioregions as defined in this report (after DWAF, 2003). A CD in the back cover of this report contains the database WET-Plant, which provides information on wetland plants and the type of wetlands in which they can be used. Ecoregion and wetland type are the first data requirements when querying the plants in the WETplant database. Further selection can be made by providing more information about the location and habitat conditions. The habitat needs to be described in detail, especially with respect to hydroperiod (temporary, seasonal or permanent), whether water is flowing or not, and substrate characteristics (clay, loam, sand or peat). Some regions also have very localized wetland flora that cannot be used just anywhere, such as Pondoland, the Lebombo Mountains, Table Mountain, the Kogelberg, the Cedarberg or the Agulhas Plain. Information about the distribution of species on this level is also indicated in the database.In Appendix 6.1 the species are presented in alphabetical

Vetiver grass

Vetiver grass (*Vetiveria zizanoides*) is originally from South India but it has been spread worldwide because of its aromatic oils. Later on, it was discovered that the grass also has very strong erosion control properties. Most specimens worldwide that are bred specifically for erosion control are descendants from a single strain of Vetiver grass, namely the Sunshine or Monte variety, which has all the same genotype. The grass is only propagated vegetatively but in a few cases it has been known to produce seed.

Properties of vetiver grass, in that it grows roots up to 3 meters deep in just a few years and can grow in almost any habitat, make it extremely suitable for erosion control. It is often planted in hedges and in rows along contours.

Even though vetiver is fast growing in a vertical direction it does not spread easily and it has been observed to remain confined to the hedge in which it was planted for more than 50 years. Research has shown that vetiver is able to produce fertile seeds in laboratory conditions but not under field conditions.

References on vetiver grass (*Vetiveria zizanoides*)

1. Comparisons between *V. zizanioides* and *V. nigritiana* (correspondence between D. Grimshaw, U. Lavania and M. Dafforn) online [www.vetiver.com/TVN_Vziz_v_Vnig.htm]]
2. Karyotypics of vetiver [http://prvn.rdpb.go.th/files/icv/CP-5-11.DOC?PHPSESSID=fc0d92fdbfcced381928a4c229caf526]
3. http://indaba.iusn.org/archives/aliens-1/2003-09/00004551.htm
4. Stop the White List [wwwjlhutsonseeds.net/WhiteList.htm]
5. Truong, P. 2000. The Vetiver Grass System: Potential Applications for Soil and Water Conservation in Northern California. [www.vetiver.com/USA_Yolo%20Agric.htm]
6. www.weeds.crc.org.au/cropweeds/crop_weeds_v.html
7. Klein, H. 2002. Weeds, alien plants and invasive plants. PPRI Leaflet Series: Weeds Biocontrol, No 1.1. ARC-Plant Protection Research Institute, Pretoria. pp.1-4 [www.arc.agric.za/institutes/ppri/main/divisions/weedsdiv/alienplants/indigenous.htm]

order and their growth form and functional types are provided. Plant traits that may be important for bio-engineering can therefore be interrogated.

Given this background it should be evident that the first thing to do after deciding that revegetation needs to take place in a wetland is to identify the wetland type and the wetland bioregion in which the wetland is located. These two factors will lead to a list of useful plant species. The hydrological regime of the site, the aims of wetland rehabilitation, the intended method of planting and more detailed environmental information about the site will further reduce the number of species in the list so that a final choice of appropriate species can be made.

Once a selection of plant species has been made, it is necessary to become more informed about these plants, their presence in nearby wetlands, their availability on commercial markets, and the variability among different strains. Attempts should be made to use plant material of a local strain. Some species have local or regional subspecies and in these cases the genetic make-up of the race that is used for rehabilitation is particularly important (examples include *Mentha longifolia* or *Laurembergia repens*).

If a combination of species is chosen, it is important to consider species that are compatible. Naturally, some species co-occur with each other, whereas other species compete with each other. Since competition causes a decrease in the performance of the plants and eventually leads to the exclusion of one of the species involved, it is best in rehabilitation to use combinations of species that co-occur naturally in nearby wetlands. There are also species that can establish only when another 'nurse' plant is already present, as it provides a microhabitat that is conducive for germination. The domain of ecology that deals with possible species combinations and exclusions in natural ecosystems is known as ecological assembly rules, which are dealt with in more detail in Section 6.4.

Table 6.2 Definition of wetland types (simplified from Ewart-Smith *et al.*, 2006). Habitat variations are mostly with respect to hydroperiod and substrate

Valley bottom wetland	A wetland where flow is dissipated across the valley floor soil levels.There is no channel in this situation since all water is flowing through or over the soil. There are often permanent zones present.
Lacustrine wetland	Wetland on the edge of a permanent water body such as a river or a lake. Within a floodplain the oxbow lakes also belong to this type.
Floodplain	A floodplain surrounding a river. Not often inundated but it can contain habitats such as oxbows and depressions that contain different species.
Seepage	An area with subsurface flow on a mountain slope, a basin or at the base of a mountain. The soil is moist but rarely permanently wet.
Pan	Isolated depression where water only enters through precipitation in the catchment. Fluctuating water table is because of seasonal differences in rainfall and evaporation.
Saltpan	Isolated depression that dries out completely in the dry season and leaves a saltcrust.

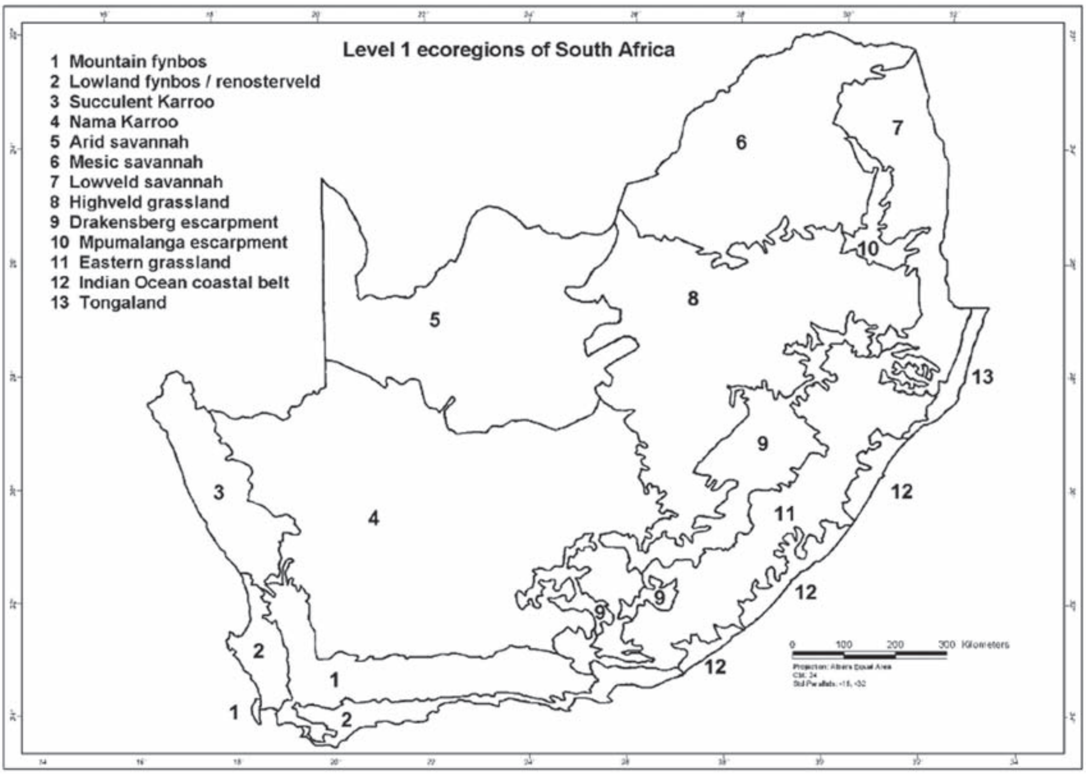


Figure 6.1: Wetland regions of South Africa (modified from DWAF 2001)

6.3 Planting practices

6.3.1 Preparation of the planting area

Before embarking on planting, it is important that the area is adequately prepared for planting. If good topsoil exists then no specific preparation is likely to be required. However, in areas where loss of topsoil has taken place, fertilizer application may be required. Where it is suspected that the soil may be poor it is useful to undertake testing of the soil nutrient status and liming requirements. To do this it is necessary to submit surface soil samples to a soil fertility laboratory (the provincial Departments of Agriculture or fertilizer companies have the facilities to do this).

If lime and fertilizers are to be used these must be incorporated into the soil at least two months before planting, except for nitrogen fertilizer that should be applied at the time of planting. Where typical signs of soil dispersivity are present (see Chapter 28), soil analysis should also be carried out for the quantity of gypsum to be added.

In some cases, especially in urban environments, soil transplantation may be necessary. This is not a measure that should be considered lightly since it will cause severe damage at the donor site and it is very costly and labour-intensive. This intensive rehabilitation method can be considered in an urban environment where the donor site is going to be unavoidably lost due to development, and where wetland soils are absent or seriously degraded at the receptor site. Soil degradation may take place after agriculture or mining has taken place or where soils have previously been built on (Bradshaw, 1997). In South Africa, there is not much experience with these intensive methods, except for the rehabilitation of Moddervlei in Cape Town (Gibbs, 2005), which was quite successful. The advantages are clear: the new soil will provide a seedbank and a whole array of soil organisms that promote soil development and plant growth within a wetland environment.

When dealing with soil transplantation, the distinction must be made between subgrade soil and topsoils. The *subgrade* refers to the underlying soil layer and it is this layer that is subjected to landscaping and sloping; the topsoil is deposited over the subgrade after landscaping has taken place. Depending on the wetland, the subgrade should have hydraulic properties that either prevent water seepage to deeper layers or allow groundwater exchange. Interactions between surface and groundwater at the site where rehabilitation is taking place, i.e. whether there is groundwater recharge from or groundwater discharge to the wetland, will determine the type of subgrade material to use. In the case of groundwater discharge one wants to promote as much water exchange as possible between groundwater and the wetland. Therefore, in this situation one would choose subgrade material with a high hydraulic conductivity, such as sandy material. However, where one is confronted with a groundwater discharge situation, one would want to minimize loss of surface water to groundwater and subgrade material with low hydraulic properties (e.g. clay) would be chosen. Sufficient subgrade material must be used to create the desired topography to achieve the objectives of rehabilitation.

The topsoil is generally 15 to 30 cm deep and provides the rooting medium for wetland plants. Only tree species and a few herbaceous species will grow roots that grow deeper than that. The topsoil has to be suitable for the desired vegetation and reflect the natural substrate found in similar hydrological conditions.

There are three main methods for establishing plants in a wetland: seeding; cuttings (plant parts that can grow a new plant or clone), and transplants (establishing whole plants). Thatching is a method of seeding that can be used with grasses or sedges that uses ripened seeds as they are still attached to the stems, which are cut from the plants. Stems with mature inflorescences should be collected and deposited on the rehabilitation site. Another planting method is hydro-seeding which will be discussed in more detail in Section 6.7.

Substantial woody cuttings or batons from some tree species will take root if driven into the soil or if laid partially buried on the soil surface and anchored with wires fixed to duckbill anchors driven into the soil below (Figure 6.2). Whole branches with off shoots anchored this way can protect the soil surface from flowing water and help to trap debris and sediment. Also layers of live brush wood that may take root if anchored down by batons and branches as above. Even if the brush does not root it will protect the soil below from erosion.

Planting methods are dependent on the species that are selected. There are wetland species that naturally only reproduce clonally and that can rarely be grown from seed. On the other hand, there are species that can only be reproduced from seed since they do not have the means for clonal reproduction. Transplanting whole plants is often a very expensive and laborious exercise, but can be worth the effort if the transplants are from close by (a donor site within the same wetland) or if it involves large species that give the wetland its characteristic vegetation structure (for example trees and shrubs). The planting methods are also dependent on the availability of seed, cuttings or transplants. The best way to ensure that plant material is available for rehabilitation sites is to establish small-scale regional nurseries.

For seeding the soil needs to be prepared to optimise germination. Such preparation is undertaken by hand hoeing. The soil in the seedbed should be loosened but firmed to facilitate good contact between the seeds and the soil. It should also be moist and as weed-free as possible.

Should the area be invaded by weeds prior to planting, these must be hand pulled, hoed, or killed with an appropriate herbicide before applying fertiliser. This operation should be repeated prior to planting to reduce the competition with newly established seedlings. Care must, however, be taken not to indiscriminately clear weeds, as the weeds may be performing a very useful function in covering and binding the soil and, in the case of poor soil, enhancing the quality of the soil by contributing soil organic matter. In these cases, the weeds would need to be cleared in a phased manner as the desired plants become progressively better established.

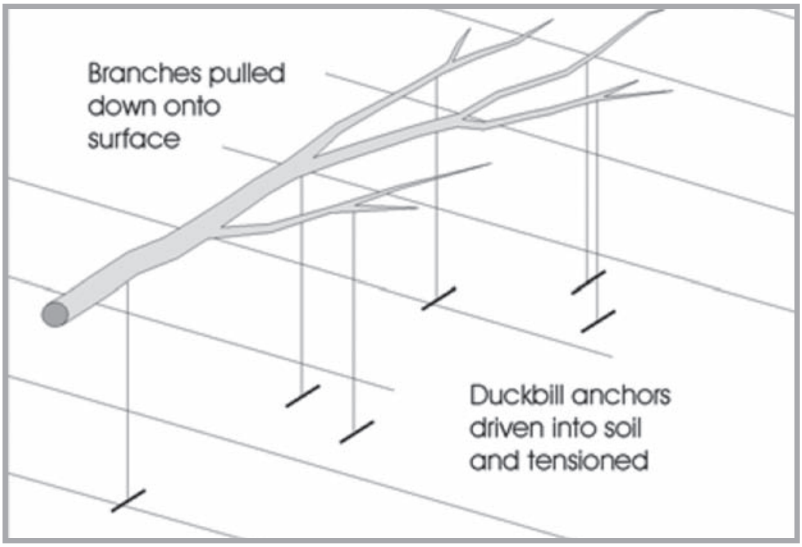


Figure 6.2: Whole branch woody cuttings or batons can be anchored to the soil to root and sprout.

Mature plants of certain wetland plant species are very well adapted to growing in flowing water. However, vegetation that has very recently been planted is generally susceptible to being washed away until it has become well established, particularly in areas where flow is permanent and/or at high velocity. In many situations it is possible to address this problem through the temporary diversion of flow. Earth-filled fibre bags provide a useful means of creating a small temporary dam above the area to be planted. A pipe inserted above the dam wall may also be required to carry water from the dam to beyond the planted area, with the size and/or number of pipes being dependent upon the rate of inflow of water into the dam. The diversion should be maintained for about two to four months depending on the speed with which the planted vegetation becomes established.

Even after a few months, the plants will not be fully established and additional measures may be employed to assist in overcoming the erosive effect of flowing water:

1. Fibre mats may be placed on the soil surface to protect the soil (see Section 6.7). By the time these mats have decomposed the vegetation would generally have established its own good cover. Avoid 3D 'tangle' type mats and fibre mats with a scrim section. These are very unfriendly to small reptiles that get partway through the opening and are then trapped because their backward facing scales hook on the threads of the mat. Galvanised mesh will corrode away in couple of years in an acidic wetland. Avoid the use of PVC coated mesh unless a permanent anchor is required.
2. Introduction of well established plants in an existing growth medium to the site, which would give the plants a head-start and allow them to more rapidly establish good cover.
3. Planting can be done into holes punched in sisal bags filled with soil and buried, or into ecologs (Figure 6.3).

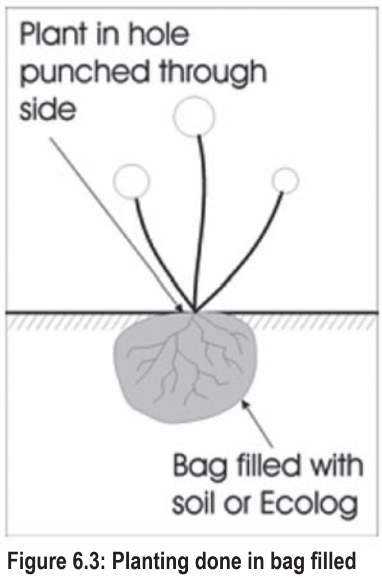


Figure 6.3: Planting done in bag filled with soil or in an ecolog

6.3.2 Selecting the best type of planting material

Having identified the possible species that can be used for wetland revegetation, together with their establishment characteristics, the types of planting material required need to be screened (Table 6.3). Examine the strengths and weaknesses of each of these in relation to the circumstances of the particular project. In many cases it is useful to use a combination of types of material (such as planting rows of whole plants to establish vegetated sills as quickly as possible, with seeding between the planted rows).

6.3.3 Collection of plant material

Where the collection of material involves disturbance of a 'donor site' this must be done with caution. Harvest about 0,5 m^2 for every 10 m^2 (or 5% of total area). Locate harvesting sites in a mosaic or chess board pattern. Do not take material from within stream channels, in flow concentration zones or in any other areas susceptible to erosion. One should think of donor wetlands in the same way as one thinks of living people donating organs; take only organs that will not permanently harm them. An exception to this would be

Table 6.3: Types of plant material available for wetland rehabilitation

Types of planting material	Strengths	Weaknesses
Natural, unassisted regeneration (vegetation that establishes without any planting or seeding by humans).	No costs involved. Nature does all the work!	Can only be used when the site has been stabilised by other means and is not reliant on the function of the vegetation. Natural regeneration can, depending on several factors, take a couple of growing seasons to establish fully.
Transplanted whole plants together with well established roots in a growing medium. The plants can be either grown in nurseries from seed or sourced directly from "donor sites" within intact wetlands. Large clumps can eventually be broken into smaller clumps.	This is the most reliable revegetation technique. Seed bank material from the donor wetland is also introduced with the transplants.	Costs may be high (higher transport and purchase costs if material is bought from commercial growers), and the wetland from where the material is harvested can be harmed.
Vegetative material includes runners (both stolons, which are stems that creep above ground and develop roots from their nodes, or rhizomes, which are underground stems with rooted nodes), woody plant cuttings, tillers (basic plants originating from lateral bud on the mother plant) and daughter plantlets produced by some sedges on the ends of the stem.	Costs lower than whole plants. Suitable for establishing large areas. Sourcing plantlets and stolons, batons or livebrush would generally have little impact on the donor site. Whole branch woody cuttings (batons) and livebrush layering are also useful materials.	The particular plants required may be difficult to obtain from nurseries, and if sourced from donor sites in the wild, may impact upon the donor wetland.
Commercially available seed (in some cases, seed may also be collected on a small scale from nearby plants).	Seed has been tested and germinates reliably. Effective means of establishing cover over wide areas, particularly when sites are naturally drier.	Ecotypes are unlikely to be indigenous to the area. Limited choice of species for which seed is readily available.
Thatching involves the cutting and collection of stems and mature inflorescenses of grasses or sedges when they are in the seeding stage. This material is used as the source of seed with which to establish the desired vegetation cover.	The grass residues (the culm and other cut matter) form a mulch that protects the soil from raindrop impacts and enhances the quality of the soil and therefore aids in the establishment of the seed. Particularly valuable in poor soils with little organic material	Harvesting must be well timed – if it is too early, the seeds will not yet be ripe, and if too late, most of the seeds would have already fallen. Seed predation may be high. Germination is often uncertain.

wetland areas that are to be unavoidably destroyed by a future development (e.g. a road or a deep storage dam). Plants taken from these donor wetlands would effectively save these plants from destruction by providing them with a 'new home'. Provided that these soon-to-be-destroyed wetlands are in the same bioclimatic region as the wetland being rehabilitated, the rehabilitated wetland will contribute in some way to off-site mitigation of the impacts on the donor wetland.

In the case that seed is collected from a donor site, the damage to the donor site is much more limited. In some cases the seeds have still to be extracted from the fruits, which requires some processing, in addition to which the seed may have dormancy mechanisms that need to be broken, for example through chilling. An alternative is to use a plant hormone to artificially break dormancy. Irrespective of the method used, dormancy needs to be broken before the seed is broadcast. The lack of detailed knowledge of seed biology that is required for each species before sowing takes place, is one of the disadvantages of using seed that is not obtained commercially for revegetation.

Where there is a very limited supply of planting material it is recommended that available material be multiplied in a nursery, which reduces the reliance on taking vegetative material from wetlands. As such, nurseries provide opportunities for enterprise development and job creation. It is important to emphasize, however, that nurseries have to be well planned and managed. The young plants grown in the nursery must be protected from wind and harsh sunlight that will dry them out, and from pests and diseases. It is important therefore that if a nursery is to be developed, the specific expertise required must be secured. The added advantage of local nurseries is that knowledge about local species and how to breed them is built up and that the available plants are from a suitable local race. These plans are already in place for urban wetlands in Cape Town. In some cases it has been possible for a rehabilitation programme like Working for Wetlands to forge a partnership with commercial nurseries.

If possible establish a local nursery a year before the rehabilitation work starts. Harvest or otherwise acquire as much plant material as possible, separate it out, and build up stock in the nursery for later planting.

6.3.4 Planting of material

Seeds, seedbank material and thatch have similar requirements and should not be used in areas subject to continuous flows, as the planting material is likely to be washed away unless particular precautions have been taken (see the preceding section on establishing plants in areas with flowing water).

If using **seedbank material** it is sufficient to use just a few 10 litre buckets full of sediment containing seedbank material, which will typically revegetate a large area of between 150 and 300 m^2 (Brock and Casanova, 2000).

- The material should be placed in lines 0.50 m wide, and between 1 and 10 meters apart depending on the application. The lines should be on the contours of the eventual slope. If the slope is steep, the rows should be closer.
- The seed bank and the germinating material should be protected against herbivores.

If seeding directly, the land must first be prepared and fertilised. The **seed** can then be either broadcast (spread) manually, which is preferred, or a cyclone seeder or fertilizer spreader can be used. It can also be planted in rows with a precision planter (a tractor drawn implement used in agriculture to establish pastures). The same rules apply to the rows as described in the previous paragraph on the use of seedbank material. The seeding rate (how much seed used expressed in kg/ha) varies according to the method and the type of seed being used. A good rule of thumb is to use 1.5 to 2 times the amount of seed used for row planting (precision planting) when broadcasting. The amount of seed to be used must also be modified for areas that are not irrigated or do not have a regular supply of moisture. An increase of 20% in seeding rate is recommended for most dryland (non-irrigated) establishment.

For large areas hydroseeding with the seed in a stabilised mulch can be considered. Commercial operations such as Hydromulch can do the work quite economically.

The seed should be planted no deeper than 2.5 times the width of the seed but never left lying on the surface of the soil. The more sandy a soil, the deeper the seed should be planted and the more rich in clay a soil is, the shallower the seed should be sown (within the above limits). When broadcasting seed it is necessary to lightly cover the seed with soil. This is best done by raking.

Once the seed has been planted the area must be rolled to ensure the seed has good contact with the soil. This can be done in large areas with a Cambridge roller or with a partly filled plastic water drum in smaller areas.

If **thatch** is to be used, the plant material must be harvested once the seed has fully developed, usually in the late growing season, using sickles or similar implements to cut the seed heads and their stalks. The material may be spread evenly over the area to be planted although it may be easily blown or washed away. Thus, it is generally preferable to lay the thatch in bands across the direction of overland water flow and to keep the thatch in place using a cover of biodegradable mesh or brush cuttings pegged to the ground. Avoid sowing or thatching in areas where runoff concentrates. If any grazing animals have access to the site it should be fenced off until the plants are established, unless the brush cover is able to prevent grazing. Avoid scrim type mesh that can trap small reptiles.

Working with **whole plants** requires a systematic approach:

- The timing of transplanting is best done shortly before or at the beginning of the growing season.
- For whole plants ensure that the plants are dug up with as much of their roots intact and such that the soil around the roots is not disturbed. The plants should be planted with their roots in as much of the medium as possible from which they were removed. This type of vegetative matter is as reliable as nursery grown container stock. It is possible to use bare root plants (plants which are removed from their growth medium and have exposed roots) that are, although less hardy, cheaper to transport because of their lower mass. However, the plants should be replanted as quickly as possible following removal. If they need to be stored then they must be kept in the shade in damp sacks or newspaper.
- Trim the leaves back to about 10 to 15 cm in length, so as to reduce water losses through transpiration.
- Large clumps of plants can be carefully separated into smaller clumps or into several individual stems with attached roots (known as slips).
- When planting the material, dig a hole deep enough to ensure that the roots do not bend upwards, which may result in 'J-rooting'. The soils around the newly placed plant should be firmly compacted.
- Should it be required, such as in high-energy environments, the plants should be secured using a coarse mesh (steel wire or plastic) and/or a fine biodegradable mat. The mesh or mat is placed over the vegetation securing it until it can fully establish. The plants must be able to grow unhindered through

the mesh or matting. Avoid scrim type or 3D 'tangle' mats. Individual plants can be secured with duckbill anchors. Mats can be staked down or held down with timber batons tied down using duckbill anchors.
- The spacing between plantings will vary according to their type (woody stemmed or herbaceous), but as a general rule it should mimic that found under natural conditions.

Planting material for transplants can originate from a commercial nursery or taken from a donor site within the same wetland. If a donor site is used there must be sufficient sites where it is safe to remove plants without seriously damaging the wetland. If there are not enough donor sites available, plants from a nursery are required, but here it is important to consider the genetic origin of the plants used since local strains are preferable. It is therefore best to use small regional nurseries that breed plants from the region, instead of large commercial nurseries that are likely to obtain stock from large regional suppliers. (See note in Section 6.3.3 about establishing a special purpose nursery a year before the project starts.)

Vegetative material such as rhizomes and stolons should be planted to a depth of about 50 mm. The soil around the propagule must be lightly compacted to ensure good contact between the soil and plant matter. If possible, leave about 25 to 50 mm of herbage above the ground level.

Cuttings can be made especially from woody species and can be made from the stem or the roots. A cutting should include at least one node since this is where the tissues are located from which new growth takes place. This also applies to rhizomes and stolons. Cuttings should be made from healthy and vigorously growing plants and should preferably be treated with dilute disinfectant to prevent the spread of plant diseases. It should be noted that not all species are suitable for

6.3.5 Watering and aftercare

Vegetation planted for rehabilitation requires a lot of attention after it has been planted, especially in the first few months of establishment. The area where the seeds or plants have been planted must be kept moist through emergence and the first weeks thereafter, which may necessitate watering or irrigation.

If required, nitrogen fertilizer should be applied just prior to irrigation.The amount of watering required is determined by the specific planting material used, the specific characteristics of the site and the rainfall conditions following planting. It is generally wisest to plant at the onset of the wet season so that watering requirements are minimal. The drier the site is naturally and the quicker it drains, the greater will be the general requirement for watering. Seasonally and temporarily saturated areas are likely to require watering, whereas permanently saturated areas are unlikely to require watering. Gully slopes and sandy soils are especially prone to drying out due to their quick drainage. A guideline for watering in areas that tend to drain quickly is to provide water at least twice a week. When watering, only wet the soil as deep as the plant rooting depth, and spray the water on at a rate that will be low enough not to cause runoff.

The volume of water required can be large and the watering times long as illustrated in this example. To increase the moisture content of 0.25 m depth of soil by 10% will require 25 l/m^2 at an infiltration rate of 8 mm/hr, and this will take 3 hours to apply. Irrigation needs to be applied rationally – measure the precipitation rate of the sprinklers (use a jam tin under the spray and measure the depth of water accumulated after an hour). Make sure this irrigation rate is lower than the infiltration capacity of the soil. Spray for as long as it takes to achieve the desired result. If necessary, dig up a sod to check the water penetration depth each time the site is irrigated until you understand the system.

Where plants have died or not emerged, fill in the gaps with new plants. This is particularly important in the case of vegetation sills established across the flow of water, as these gaps may serve as points of weakness where flow is concentrated.

Following the initial establishment period, the vegetation may require further aftercare, particularly if a very dry spell or major storm event is experienced during the period after establishment. Therefore it is crucial to follow up and check on the condition of the vegetation and assess the particular aftercare requirements.

6.4 Revegetation for biodiversity purposes, livelihoods and for biological filters

6.4.1 Revegetation with biodiversity concerns

Biodiversity concerns in a wetland require extra attention and it is often more costly and more laborious to restore a wetland's biodiversity than it is to stop erosion or keep the area wet (Perrow & Davy, 2002; Lockwood & Pimm, 1999). This is why the suggestions described below need only to be applied when there is a real concern for biodiversity in the area, for example in national parks, biosphere reserves and areas with a high degree of endemism. The nature conservation authority operating in the area needs to be consulted and involved in the rehabilitation process and may be able to supply additional funding, manpower and information for the rehabilitation measures.

The most important quality of vegetation when a site is revegetated for biodiversity purposes is whether the endpoint vegetation is natural. Often the assembly of natural communities is affected by chance (stochastic factors), which plants arrive first and the order in which they arrive and establish. The sequential arrival and establishment of plants at a site following a disturbance and the modification of the environment by this process such as an increase in soil organic matter, is known as succession. Succession leads to a gradual change in species composition and vegetation structure that is increasingly stable over time, until after many years a community is established that is stable. This stable community at the end of a successional process is known as the 'climax', whereas the early stage is known as the pioneer stage. Plants that colonise a site early in the successional process are known as 'pioneer' species, while those that dominate the late stages are known as 'climax' species.

Successional pathways may lead to alternative states in the climax vegetation (Didham & Watts, 2005). For example, if common reed arrives first in a wetland it will be able to expand throughout the entire wetland and form a stable community, whereas if some sedges arrive first they will result in an entirely different community where common reed cannot establish any more, since its seedlings cannot compete with the established sedges. This situation is especially the case in wetlands where one very successful species is present that can colonize a site quickly, decreasing the chances of other species establishing. Successful species that colonise a site very quickly typically establish through asexual reproduction, such as the production of horizontal stems or rootstocks from the parent plant from which erect stems are produced. Such species are known as clonal species as a single individual (or clone) may occupy large areas (hundreds to thousands of square meters).

When different successional pathways are possible, revegetation measures will aim towards the desired state as it is defined in the rehabilitation plan. Revegetation will give the species that are planted a decided advantage so that other species that might compete with them will not invade. The desired state may be defined in the rehabilitation plan for the following reasons:

- A certain rare vegetation type is desired. In this case the species that form the matrix of this vegetation type should be planted in combination with some pioneer species if the successional pathway is known. If a very specific species assemblage is aimed for it is not always necessary to actively plant or seed all of these. Natural recruitment can usually supplement the planted vegetation. In some cases, a particularly rare species that might find a suitable habitat in the wetland but that may not easily disperse into the wetland, may be planted alongside dominant matrix species.
- The desired state is defined by the habitat requirements of fauna in the wetland, for example birds that nest in reedbeds or frogs that inhabit arum lilies. Often the structure of the vegetation is more important in this case than the actual species composition.

In most cases when biodiversity is the only concern for revegetation, it is possible to use seeds, which is cheaper than transplants, but this also depends on the availability of seeds. The use of seeding is likely to produce results only if there are no invaders to be expected or only annuals that will not pose a real threat in the long term. The advantage of seeding is that a seed mix can be created by mixing various collected seeds and this seed mix can be used for seeding large areas of the wetland in a relatively cheap and easy manner.

As mentioned before, it can be more complicated if various species in the seed mix require specific germination cues like a chilling effect. The local conditions will act as a filter with respect to which plants germinate and grow competitively, and in this way the wetland will basically 'design itself' (Mitsch & Wilson, 1996). For a large wetland where natural processes create heterogeneity in neutral conditions this is a very attractive solution, but there is obviously going to be a waste of seeds because not all seeds will grow into mature plants. That is why it is not an attractive option when dealing with rare plants or rare vegetation types.

In a small wetland where conditions can be manipulated to some extent, seeds of rare plants can be used in a seed mix, but the seeds present in the mix should consist of species that co-occur naturally with the rare species. Reference sites (comparable sites where the rare species occurs naturally) play a very important role when dealing with the restoration of populations of rare species. These sites not only provide information about the communities in which the rare species occur, but also about their ecology, the processes required for germination and disturbances that play a role for these species.

There are some general rules about which species can row together and which cannot. Even though the research into **ecological assembly rules** is still going on, it is possible to state a few general rules that need to be taken into account when selecting plants for revegetation (Weiher & Keddy, 1999). The most important is the rule of niche separation. Plants that grow together occupy a different niche within the same ecosystem. This niche may be defined in space or in time. One species may be a shallow rooter and the other a deep rooter, or one may have large leaves overtopping other plants and the other small ones that can still capture sufficient light in the understorey. When it comes to the structure and functional type of the plants, plants that grow together should be dissimilar. This should be kept in mind when selecting plants from Appendix 6.2.

6.4.2 Revegetation for sustainable harvesting

When wetland rehabilitation takes place with the economic needs of a local community in mind it is important to keep the community actively involved in the rehabilitation process, so that their demands and desires are well-known. A meeting between the stakeholders, community leaders, farmers, cattle grazers, sangoma's and wetland workers will facilitate this. Many wetland workers are probably from the same community that benefits from the revegetation so it should not be difficult to convene such a meeting.

When planting the desired species it should be kept in mind that it must be possible to harvest the species sustainably. The ideal planting density depends on the species: most sedges and grasses can have high densities in a wetland, whereas most herbs (like medicinal plants) would be more sparsely dispersed over the wetland. Depending on the needs of the community, the size of the wetland, the planting density and the availability of alternative resources, a decision can be made whether it is feasible to plant the species in the wetland for sustainable use. This is an issue that needs to be discussed in a local stakeholder meeting.

6.4.3 Revegetation for biological filters

One of the many services that wetlands provide is the filtering of chemicals from the water to improve water quality. Several attributes of wetlands play a role in the processing of nutrients in inflowing water. Firstly, wetlands slow down flows so that suspended solids settle. Secondly, they form an environment in which reduction dominates and oxidization is suppressed. Thirdly, there are large numbers of micro-organisms in the soil in the wetland and because of anaerobic conditions they tend to be different species from the ones that occur elsewhere in the soil. But plants themselves also play a role in this filtering capacity by taking up nutrients and minerals. In an environment where polluted water is to be expected, a selection of plants that can deal with high nutrient loads or the presence of specific toxicants is beneficial for the downstream environment and its water users.

Artificial wetlands are often especially created for the purpose of biological filtration but natural wetlands that are to be restored can also fulfil the same functions. Different plant species can cope with different forms of pollution and it is useful to bear the properties of plants and their ability to deal with nutrient loads and other pollution when selecting species for wetland revegetation. Species that are useful in this respect are free-floating species as they are easily removed and after removal their progeny can steadily remove more nutrients. Table 6.4 shows a number of species and the pollutants with which they can deal. Whereas most plants can deal with organic waste and most types of wetlands will be effective for sewage treatment, the selection of plants for treatment of toxic mine sludge is more critical, because accumulation of heavy metals is not something that all plants can cope with equally. Some species are known as hyperaccumulators, which means that they do not only remove a constant new supply of solutes but also gradually deplete the total supply of heavy metals present at the site, which is useful in the case of a site that was previously heavily polluted. The heavy metals will not be removed completely but they will be accumulated in the plant tissues so that they can be removed relatively easy. Only a few hyperaccumulators are known from South Africa, but there may be more species that have this characteristic.

One of the plants with the most useful properties in this respect is the water hyacinth (*Eichhornia crassipes*), which is

Table 6.4 Properties of wetland plants as biological filters

Species	Typical features of the plant
Emergent species	
Typha capensis	Removes heavy metals, particularly nickel, copper, lead, zinc and cadmium. Also ameliorates heavy nutrient loading.
Phragmites australis	Removes iron, lead, zinc, cadmium and copper. Also heavy nutrient loading.
Burnatia enneandra	Suitable for heavy nutrient loading
Limnophyton obtusifolium	As above
Heteranthera callifolia	As above
Schoenoplectus brachyceras	As above
Schoenoplectus paludicola	As above
Schoenoplectus decipiens	As above
Eleocharis dulcis	As above
Eleocharis limosa	As above
Cyperus fastigiatus	As above
Cyperus marginatus	As above
Cyperus papyrus	As above
Flood-tolerant plants	
Bolboschoenus maritimus	Salt-tolerant, accumulates minerals
Eleocharis dregeana	Suitable for heavy nutrient loading
Fimbristylis complanata	As above
Fimbristylis dichotoma	As above
Panicum subalbidum	As above
Panicum repens	As above
Bacopa monnieri	Accumulates large quantities of heavy metals, hyperaccumulator
Submerged plants	
Ceratophyllum demersum	Accumulates large quantities of heavy metals, hyperaccumulator
Najas graminea	Suitable for heavy nutrient loading
Najas horrida	As above
Potamogeton thunbergii	As above
Potamogeton crispus	As above
Potamogeton pusillus	As above
Nymphoides thunbergiana	As above
Nymphoides indica	As above
Nymphaea nouchali	As above
Free-floating plants	
Ceratopsis cornuta	Easily removed
Spirodela polyrrhiza	Easily removed
Lemna gibba	Easily removed
Lemna minor	Easily removed
Lemna aequinoctialis	Easily removed

a declared weed in South Africa and is not allowed to be deliberately planted in a wetland.

The ultimate fate of the pollutants trapped by the plants must be understood. There is no point in using hyper accumulator plants to concentrate heavy metals and then burning or composting the harvested plant material where it will release the contaminants back into the environment.

Similarly the fate of nutrients must be understood. Phosphate is a persistent nutrient and very little is accumulated in the emergent parts of plants so harvesting will have little impact on the total phosphate balance. Some is absorbed onto soil particles but recent work indicates quite rapid saturation of this sink (5 years or so). Most phosphate is stored in organic detritus and is loosely attached to sediment. It is easily remobilised by physical wash out or change in water chemistry.

6.5 Bio-engineering and its potential benefits

Vegetation can be used alone or with engineering structures

Bio-engineering is the use of vegetation for controlling runoff, stabilising erosion and trapping sediment. Vegetation may be used alone or supported by engineering structures or soft applications (such as fibre mats to enhance the likelihood of establishment. Furthermore, vegetation may be used to augment hard engineering structures, where the vegetation plays a significant role in the long-term success of the structure.

The difference between hard, structural options and soft, bioengineering options, is that hard interventions allow immediate deactivation of the erosion problem, normally reducing the velocities of flow leaving the intervention. This is done by planning the intervention to either flood out the erosional headcut or the intervention itself is placed in the headcut to nullify its effects. Bioengineering methods focus more on giving the natural environment a helping hand in achieving a balance where the erosion processes are slowed down enough to allow deposition to occur. These options then reduce velocities over time and give vegetation an opportunity to establish.

Bio-engineering is, where applicable, preferable to other forms of engineering and has several advantages.

- It tends to have a low impact during implementation, generally requiring low levels of site disturbance unless re-sloping is required.
- Unlike rigid structures (such as rock-packed gabions), plants can suffer a great deal of damage from flooding and yet recover rapidly and continue with their intended function provided that they are not washed away (Hayes *et al*., 2000).
- Plants are generally speaking more aesthetically pleasing than hard structures.
- In the long-term plants require low levels of maintenance, and once they have become well established the intervention generally becomes self-maintaining.

Vegetation in a wetland has a very important influence on the runoff characteristics of a wetland, and rates of sediment deposition and erosion within the wetland. Plants do this in five principal ways.

1. The cover provided by the vegetation (aerial parts and litter cover) intercepts rain drops and reduce their energy of impact on the soil surface. Vegetation cover thus reduces:
   - sealing of the soil surface, which in turn increases infiltration and reduces the amount of runoff and
   - the extent to which soil particles are dislodged and removed.
2. Vegetation cover also protects the soil

surface against scour by surface flow, which further reduces loss to erosion.
3. The aerial components, particularly when they are tall and robust, offer frictional resistance to surface water flow, which slows down the flow and therefore diminishes its erosive powers and promotes the deposition of sediment.
4. The rooting systems of the wetland plants anchor the soil, thereby increasing the sheer strength of the soil material and reducing the soil's propensity to erode.
5. Certain plants also possess a certain capacity to spread rapidly and to grow through recently deposited sediment.

It is these five features that make plants very useful in stabilising erosion in wetlands. The extent to which a particular plant possesses these features depends on the physical and biological characteristics of the individual plant. For example, some plants (e.g. tall robust reeds) offer much more frictional resistance to water flow than short growing lawn grass, the strength of which is its ability to rapidly spread laterally and cover newly deposited sediment.

6.6 Plants used in bio-engineering

Bio-engineering can be used for a wide range of rehabilitation problems, each of which has particular requirements in terms of the characteristics of the plants used (Table 6.5).

Gully head erosion may potentially be very effectively controlled by the binding effect of suitable plants. Where the erosion hazard of the gully head is moderate (e.g. the gully head is shallow [<500 mm] or is already moderately sloped) then all that may be required is the establishment of deep rooted plants (e.g. Vetiver zizanoides) in lines across the direction of water flow to give the soil in the headcut area additional strength. However, refer to the cautionary note in Section 6.2.

Where the erosion hazard is somewhat greater but still not so severe as to require major structural intervention then a potential solution for stabilizing the gully head would be to slope the area in order to form a **vegetated chute**. By providing greater horizontal distance for its vertical

Table 6.5: The role of vegetation for different wetland rehabilitation problems

Problem	Techniques to be used	Role of the plant	Characteristics required
Stabilisation of gully head erosion	Vegetated chutes and vegetated rip rap chutes	To provide a high level of cover over the soil surface. Should not produce too much turbulence and scour.	Should generally tolerate permanent wetness, have an extensive, strong rooting system and the ability to recover rapidly from damage.
Stabilization of gully floors	Vegetated sills	The plant is required to reduce erosion within the gully by slowing runoff and binding sediment.	Adapted to extremes of wetting and drying, hardiness and the ability to recover quickly from being covered in sediment.
Structure augmentation	Soil stabilisation through re-vegetation of engineering structures	Provide cover for exposed soils, assist in runoff control and improving the aesthetics of structural rehabilitation.	Rapid growth (quick spreading with the ability to recover from sedimentation), dense and robust aerial portions and a strong rooting system.
Reduction in hydraulic efficiency of gullies and drains	Vegetated sills and root plugs	Slow runoff moving through the channel, dissipate energy, trap sediment, and increase the extent to which water spills out of the channel.	Tolerance of long periods of water logging, high roughness, rapid growth and spreading ability.

drop (i.e. making the slope more gentle) as well as spreading the flow over a wider cross-sectional area, the runoff velocity and its attendant erosive energy would be reduced. A slope of 1:7 is the maximum slope that can be considered. Manning's formula is useful in determining the width (for capacity) and slope (for maximum velocity). In many cases the vegetation will require, at least initially, a supporting application (see Section 6.7).

The most suitable plant for **vegetated chutes** would have a creeping growth habit that provides a high level of cover. Buchanan (2000) found that in seasonally or permanently wet areas, a trailing sedge such as Isolepus prolifera proved highly effective in stabilising highly erodible soils. Under drier conditions, a species such as Hemarthria altissima may prove very suitable. It is important to add, however, that the head of a gully is often very susceptible to erosion. Thus, in this location vegetation usually requires supporting applications (see Section 6.7 and 6.8).

The principle in **gully bed stabilisation** and **drain rehabilitation** is to form bands of robust, tall vegetation within the channel (e.g. 500 mm wide at 5 m intervals). The frictional resistance offered by these bands of vegetation would slow down the runoff. This would have the dual benefit of increasing the frequency with which the channel overspills and of promoting sediment deposition in the channel. In the long term, the deposition of sediment in the channel would further reduce the capacity of the channel, particularly as the vegetation in the bands spread into more of the channel, further increasing the extent of overspill.

Because of the nature of erosional processes within gullies, the **banks of gullies** and **streams** are often too steep for the establishment of vegetation. The solution may be to cut away some of the bank to create a more gentle slope, which can then be revegetated. In particularly unstable situations, structures (e.g. rock-filled gabion mattresses) will be required to give added support to the vegetation (see Chapter 7).

The choice of plant to use for these areas is important as they may not be as wet as other areas within the wetland and the role of the plants would be to rapidly establish a high degree of surface cover while anchoring the soil with its roots. It is a good idea to plant creeping plants in the topsoil along the edge of the gully, allowing the plant to spread over the gully sides.

Where woody stemmed species can be used (those areas where fire is excluded and trees naturally occur within wetlands), they can be very effective in stabilising banks, particularly those with steep sides, as their rooting system is able to penetrate the soil profile far more deeply than most herbaceous species. This could circumvent the need to slope the banks to an appropriate angle. It must be borne in mind, however, that woody-stemmed species take more time to become fully effective than herbaceous species do. In the case of rapidly eroding banks Rutherford et al. (2000) recommends the use of quicker growing "sacrificial" trees (planted adjacent to the banks) whose purpose it is to slow down the bank erosion until the larger growing, deep rooted species (planted a few metres back from the bank) have the chance to establish.

Careful thought should be given to planting trees. The root network of many tree species is not dense enough to hold the soil so the trees need to work in conjunction with a herbaceous or grassy under storey, but the shade from the trees can inhibit the growth of this under storey. A second round of planting may be required once the tree canopy starts to shade out the under storey vegetation.

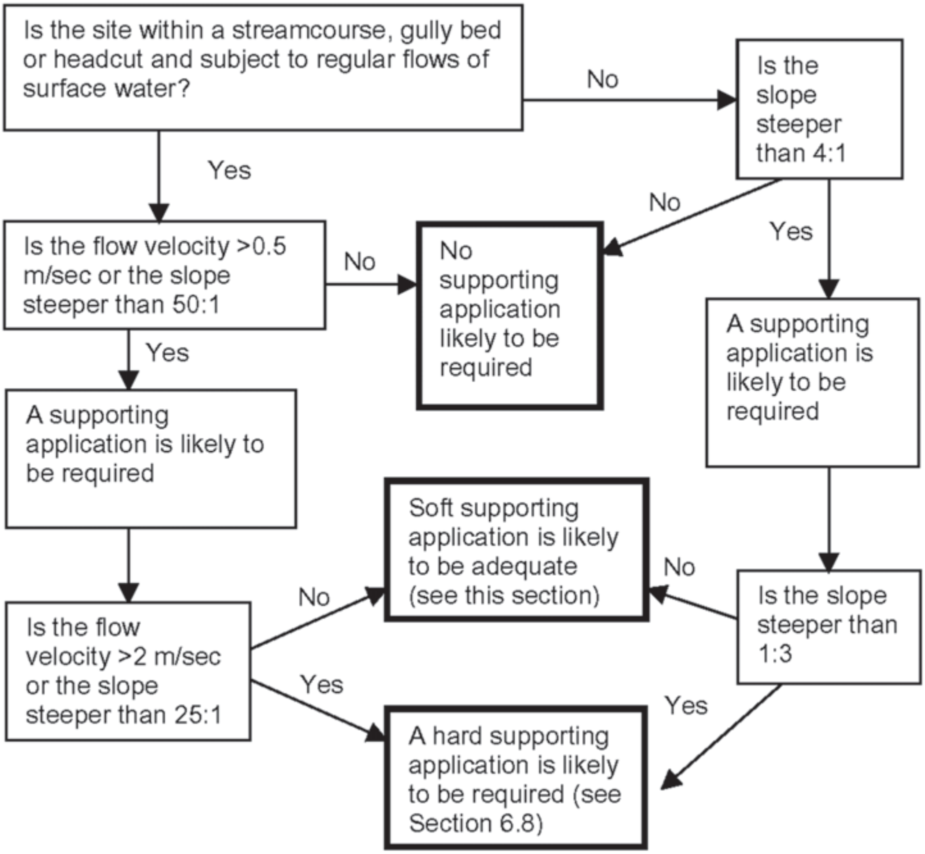


Figure 6.4: Decision tree to assist in determining whether vegetation requires supporting applications (slope is given as horizontal:vertical)

Note: the decision tree must be interpreted with caution and is intended as only a very general guide. It does not account for some important features (e.g. soil erodibility) that would have a bearing on the support likely to be required

6.7 Structures supporting vegetation

When planting vegetation it is important to consider whether it will require additional support and whether this should be hard or soft (Figure 6.4).

6.7.1 An overview of the different applications

Table 6.6 provides an overview of the different applications available for supporting vegetation. These products are discussed in detail later in the section. The products have been divided up into main groups: those that are laid flat onto the soil surface and those that are vertical. The horizontal group includes hydroseeding, nets, mats and mattresses. These products progress from a layer of seeds and mulch, to nets with open areas exposing the soil surface area, to mats that cover the entire surface area, to mattresses that can be used in higher velocity conditions and can be incorporated into the soil. The vertical group includes the fibre rolls, fibre bags and sediment fences. These products are used to trap soil and sediment behind them and allow vegetation to grow in the deposited soil. These products reduce current velocity by blocking flowing water, thereby promoting sediment deposition.

Table 6.6: Suitability of different supporting applications for addressing different erosion problems

	Supporting applications					
Erosion problems	Brush mattress Live cuttings	Brush mattress	Brush mattress Wire and pegs	Vegetative bundles	Brush fences Live cuttings	Brush fences
Temporary erosion control	√	√	√	√	√	√
Sheet and rill erosion	√	√	√	√	√	√
Dissipating wave action	√	√	√	√	√	√
Stream channel		√	√	√	√	√
Gully erosion		√	√	√	√	
Gully head erosion			√			

Table 6.6 (continued): Suitability of different supporting applications for addressing different erosion problems

Applications	Hydro seeding	Nets	Mats	Mattresses	Fibre Rolls	Fibre Bags	Sediment fences
Temporary erosion control	√	√	√		√		√
Sheet and rill erosion	√	√	√	√	√	√	√
Dissipating wave action		√	√	√	√	√	
Stream channel		√		√	√	√	
Gully erosion		√	√	√	√	√	√
Gully head erosion				√		√	

Note: geocells represent a further application supporting vegetation but are dealt with in Section 28.5 as they are also used in civil engineering applications.

When deciding amongst different applications for areas subject to streamflow, their resistance to flow is a key consideration. Unfortunately it is not a simple matter as their ability to resist flow depends upon both the velocity and the duration of flow. For example, a particular application may be able to withstand a given flow velocity that continues for a period of a few hours, but the same application may fail to survive a much lower flow velocity that persists for months. Nevertheless, a broad grouping of the applications in terms of their ability to resist flow is provided in Table 6.7, which serves as a general guide.

Table 6.7: General resilience to flow of different applications

Resilience to flow	Type of applications
Very low	Hydroseeding
Low	Brush mattress, sediment fences
Intermediate	Brush mattress well anchored, vegetative bundles, brush fences, nets, sediment fences (with a spillway notch and re-enforcement as per ARC design)
High	Fibre mats and matresses, fibre rolls and bags (all must be well anchored into firm substrate)

Note that except in the case of well designed structures or in slopes anchored by deep rooted trees a soil slope will not have long term stability at a gradient steeper than the natural angle of repose of the material.

Typical angles are:

Clay 18^{o} = 3:1 H:V
Loam 25^{o} = 2:1 H:V
Sand 30^{o} = 1.7:1 H:V

Vertical banks may be stable up to a height of about 1.5 m because of cohesion (stickiness) of the soil but this is soon overcome by water pressure in the cracks or other mechanisms.

As a rule do not try to stabilise slopes steeper than 3:1 H:V by surface treatment alone.

6.7.2 Brush mattresses

Brush mattresses (Figure 6.5) are live cuttings or branches that have been layered on the ground, with or without a layer of soil over them (African Gabions, 2004). A brush mattress forms a living ground cover that protects the underlying soil from erosion (Hollis and Leech, 1997).

There are different types of brush mattresses:

1. Cuttings mattress – live cuttings are used with a soil cover.
2. Brush mattress – branches and brush are used over a gentle slope.
3. Brush mattress – branches and brush with pegs and wire are used on steeper slopes.

Brush mattress systems are used to stabilise soil, reduce angles of slope and reduce the length of slopes. The soil is stabilized by providing a surface covering. The mattresses trap sediment that helps with the growth of the cuttings and forms a seed source for other species.

The use of brush mattresses requires that areas be sloped, allowing slight depressions in the slope where branches or brush will be packed to form a type of mattress or mat. Depending on the steepness of the slope wire or wire netting can be used to keep the layers of vegetation in place.

Figure 6.5: Photograph of pegged brush mattress. (African Gabions, 2004)

The following are key elements for the installation of brush mattresses or matting:

- The proposed site should be pegged out with pegs and twine in a grid of 1 m x 1 m for purposes of securing the mattresses in place.
- Slope the site or excavate the proposed site to a depth of 200 mm. (Hollis and Leech, 1997)
- Pegs should be knocked into the soil to a depth of at least 300 mm and a further 300 mm should be exposed above the soil. Live stakes can be used as pegs (African Gabions, 2004)
- Cut branches between 10 and 25 mm in diameter into lengths of between 1 m and 3 m and place these on the site between the pegs
- Arrange the branches in a crisscrossed fashion in order to allow for a uniform mattress African Gabions, 2004).
- The branches are then pushed down and wire is used to secure the mattress in place by looping the wire around the pegs tightly to ensure that the brush branches are kept compact.
- Cover the mattress with the excavated soil for live cuttings to a depth of approximately 200 mm leaving some branches exposed (Hollis and Leech, 1997).
- Water the mattress regularly to allow the cuttings to sprout.

As an alternative to all or some of the stakes use duckbill anchors (Rope construction 011-493-7956; www.ropecon.co.za) to tie down transverse branches. Avoid horizontal wiring in wetland applications, it is unsightly and the sharp points of partially corroded wires can be dangerous to animals walking or burrowing.

6.7.3 Vegetative bundles or live fascines

Vegetative bundles are cigar shaped bundles of live cuttings approximately 2 m long (Figure 6.6) that are tied and placed in trenches (Figure 6.7), staked and partially covered with soil.

Vegetative bundles are used mostly on contours starting at the bottom of the slope and working upwards (Hollis and Leech, 1997). Once placed in contact with the soil, the stems root and send up new shoots to create thickets that catch transported soil and sediment. Vegetative bundles provide erosion and sedimentation control by reducing the speed of runoff, trapping soil and sediment. The trapped soil and sediments allow for vegetation to develop. The excavations for the vegetative bundles increase the infiltration of water, which helps the initial establishment of the cuttings. The sloped areas with vegetative bundles reduce the effective slope length, which effectively reduces the erosion potential of the site.

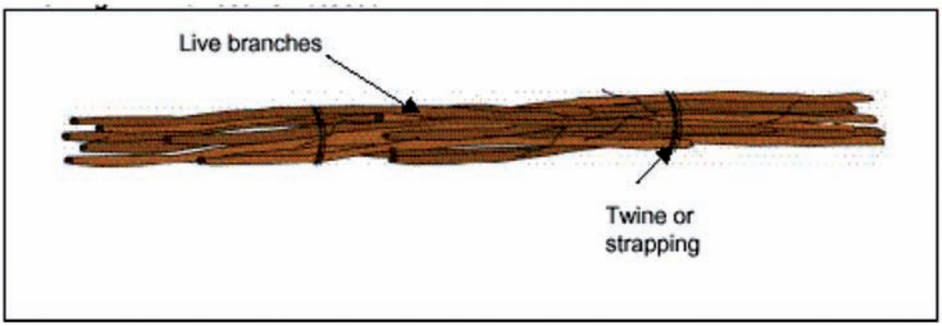


Figure 6.6: Vegetative bundle tied every 250 mm apart

The following are the key elements for the installation of vegetative bundles:

- The proposed site should be pegged out along the contour with pegs and twine, starting at the bottom of the slope and working upwards.
- Dig a shallow trench 200 mm deep and 400 mm wide along the contour for the length of the proposed site.
- The vegetative bundles should be placed perpendicularly to the flow of the water.
- Using twine tie live cuttings together to make bundles of approximately 200 mm to 300 mm in diameter (Figure 6.3).
- Tie the bundles 2 or 3 times along their length (Figure 6.3)
- Place the bundles in the trench working from one side to the other (Figure 6.2).
- Ensure that the bundles are snugly fitted together when placed next to each other in the trench.
- Knock in stakes every meter immediately on the down slope side of the bundle, either perpendicular to the slope or vertical.
- Ensure that the stake is a minimum of 300 mm in the soil with the top of the stake a further 100 mm above the bundle.
- Fill in the trench with soil and compact the soil to ensure that the fill material is not washed away.

6.7.4 Brush fences

Brush fences are called by different names in different parts of the world including cuttings fences, branch fences or vegetative fences. Brush fences are created by using a wire fence with vegetation laced through the spaces in the fence (African Gabions, 2004). The fences can be laced with live cuttings or cut brush or branches to create a barrier to slow down water and reduce the angle of the slope. The brush fence can effectively reduce run off and trap sediment by slowing down water that is flowing off the slope.

The following points are the key elements for installation of brush fences (African Gabions, 2004).

- The proposed site should be pegged out with pegs and twine.
- Dig a trench 6m long per section to a depth of 600 mm and width of 400 mm.
- The trench should be oriented along the contour (perpendicular to the flow of water).
- 1.2 meter long standards or droppers must be placed at each end and at the center of the 6 m long excavation.
- The standards must be driven 600 mm into the soil in the bottom of the trench such that the tops of the standards should be level with the surrounding soil.

Figure 6.7: Installing live vegetative bundles on a slope with coir netting (African Gabions, 2004).

- Place wire mesh between the standards at each end in the trench. Pig fencing, chicken mesh or rectangular netting wire can be used, whatever is available. Pull the wire tight and secure to the 3 standards.
- If live cuttings are being used, space twenty cuttings along the length of the trench (they should be approximately 300 mm apart). The open space between them will allow for the expected growth. Half the cutting should be buried in the soil.
- If brush or branches are being used, lace these to the fence as tightly as possible next to each other.
- Fill in the trench with soil and compact the soil to ensure that the fill material is not washed away.

Alternatively avoid the wire and construct woven or brush fences using robust stakes driven into the ground with the gaps filled by brush bundles or woven in green laths (Figure 6.8).

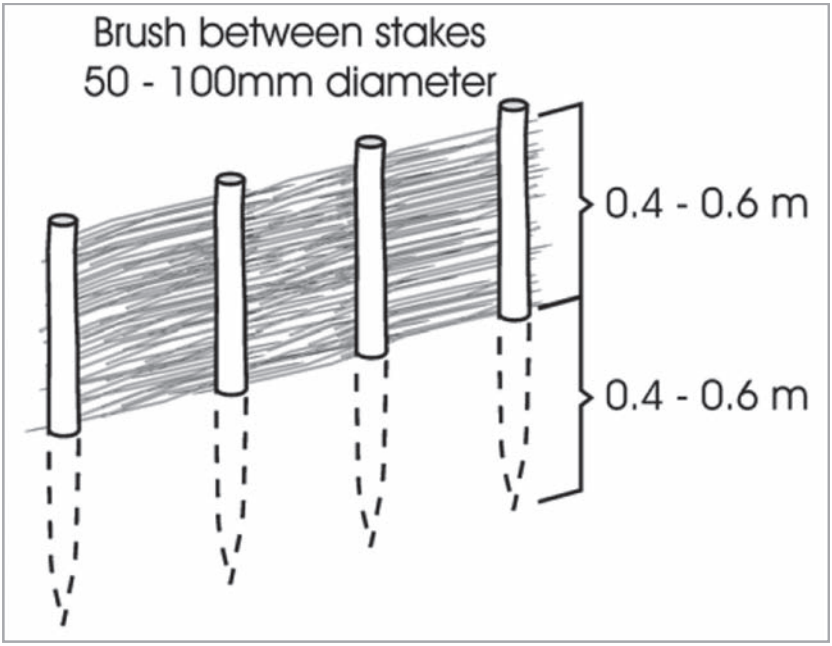


Figure 6.8: Woven brush fence without wire. Tree trunks can be anchored under triangular frames using poles of 100 to 150 mm in diameter driven into the ground at a depth of 1 m (Figure 6.9).

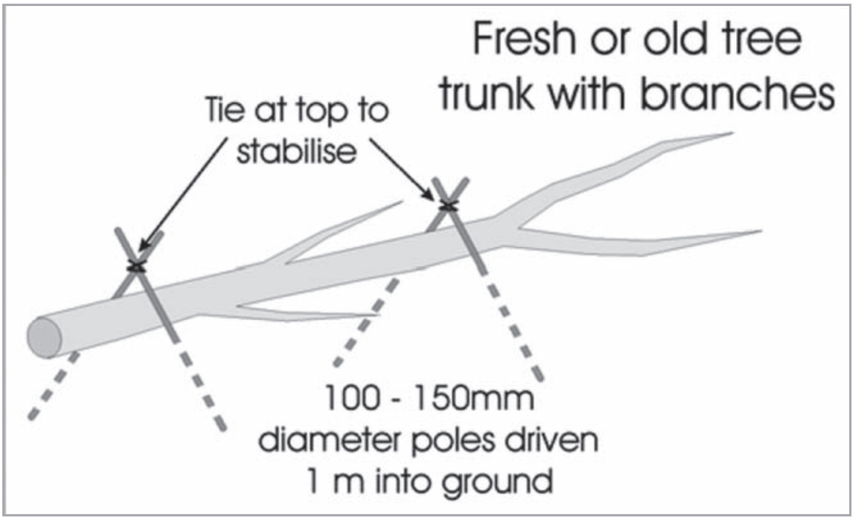


Figure 6.9: Tree trunks anchored by triangular frames

6.7.5 Hydroseeding

Hydroseeding is the mixing of a slurry of water, fertilizer, seeds and a binding agent that is sprayed onto soil surfaces to protect the soil from erosion processes. A binding agent is used to keep all the material being sprayed together such that once it has landed on the soil surface the binding agent keeps the slurry attached to the soil surface. The seeds germinate with the benefit of the moisture and fertilizer. The vegetation then stabilizes the soil.

Hydroseeding is intended for use when either the area is too large, inaccessible or unsuitable for conventional seeding and when results are required fast (www.finncorp.com). Hydroseeding is done with large trucks or trailers that can carry large volumes of the slurry. There are many different types of mixes that can be used in hydroseeding an area. Hydro-mulching can also be done on potential erosion sites. The site is seeded and then a mixture of mulch is sprayed over the seeded area (Erosion Control, 2005 - www.dietzhydroseeding.com; for a local contact www.hydromulch.co.za). The mulch acts as a protective layer to the seeds, which allows for an increased percentage of seed germination compared to seeding without mulching by reducing soil moisture loss and providing initial soil protection till the seeds have germinated (Hayes et al., 2000).The mulch generally used is made of bales of dry grass or any biomass that is shredded and sprayed over a distance onto the site (www.haybuster.com). Mulches can also be distributed over a site by blowing dry shredded biomass out instead of mixing and spraying it.

6.7.6 Fibre netting

Use netting carefully Fibre netting is generally made from biodegradable fibres or plastic netting to improve the integrity of the fibres. The mat is a continuous layer covering the exposed soil such that up to 60% of the underlying soil is exposed (Figure 6.10). Netting works very well where the soil is sufficiently nutrient rich to establish a layer of vegetation. The netting also absorbs moisture and provides a good environment for seed germination and plant growth. The mesh also provides an environment where sediment and seeds can be deposited.

The sloped or worked area can be seeded and then the fibre netting is placed over the seeded area (www.bmpstore.com). Water flowing over the mat has its velocity reduced because of the roughness of the fibre netting. With the reduction in velocity, sediment is deposited in the netting and this improves the likelihood of vegetation establishment. Biodegradable fibre nets generally have a lifespan between 8 and 18 months depending on the surrounding environmental conditions (African Gabions, 2004). The recommended slope on which fibre nets should be used is a maximum of 1:2 (horizontal : vertical), depending on the environmental conditions of the site. Select the type of net or mat carefully and use with circumspection. They can trap small reptiles by hooking on their scales and burrowing animals by blocking burrow exits.

Figure 6.10: Different fibre netting types and densities (www.erosionblankets.com)

6.7.7 Fibre mats

Fibre mats are similar to fibre netting, generally being made from biodegradable fibres although most of them on the market have plastic netting to keep the fibres in place (Figure 6.11). Fibre mats are used mainly in applications where underlying soil needs to be protected from erosion processes by the overlying mat. The mat also absorbs moisture and provides a good environment for seed germination and plant growth. The sloped or worked area can be seeded and then the fibre mat placed over the seeded area (www.nagreen.com). Water flowing over the mat has its velocity reduced because of the roughness of the fibre mat. With the reduction in velocity, sediment is deposited in the mat and this improves the vegetation's opportunity to establish (www.profileproducts.com). These fibre mats have a 24-36 month life span depending on the surrounding environmental conditions (African Gabions, 2004). The recommended slopes that fibre mats should be used on is a maximum of 1:2 (horizontal : vertical), depending on the environmental conditions of the site. Fibre mats can be used for numerous applications (Figure 6.12) but should not be used beyond their capabilities. Mats and nets must be well anchored to prevent flow between the mat and the soil surface where it can still cause erosion.

Figure 6.11: Different types of fibre mats available (www.erosionblankets.com)

Figure 6.12: Fibre mats covering compacted soil berms in a seepage wetland that previously had been drained

6.7.8 Mattresses

Fibre mattresses consist of either synthetic or natural fibres. The main function of the mattresses is to allow water to permeate through the mattress whilst keeping the in situ soil in position and allowing sediment to be trapped by the mattress (Hayes et al., 2000). As with fibre netting, caution must be used as animals can become trapped within them.

Mattresses, mats and nets differ - mattresses are developed to be incorporated into the soil while mats cover the soil surface. Mattresses consist of layers of either synthetic or natural fibres that look like inside layers of mattress springs. There are many different kinds of mattresses available on the market: Mac Mat and Mac Mat R from African Gabions and Pyramat from Contech are a few examples. Refer to Figure 6.13 for an example of a well vegetated mattress. Figures 6.14 and 6.15 illustrate installation and final rehabilitation of a steep slope with a mattress.

Figure 6.13: A mattress that has vegetation growing hrough the product

Figures 6.14 and 6.15: Mattress being installed on bank and after establishment of vegetation (African Gabions, 2004)

Figure 6.16: Fibre rolls

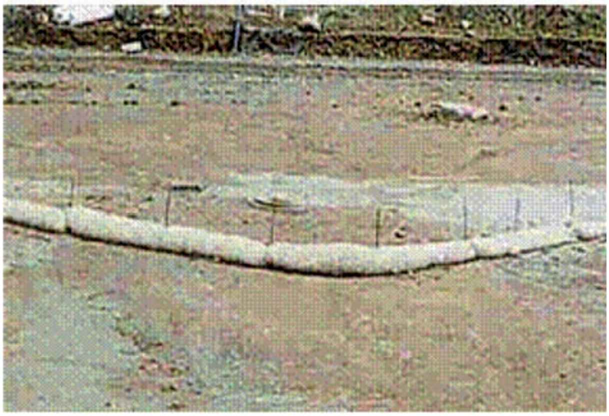


Figure 6.17: Fibre rolls pegged in position on bare soil (www.beltonindustries.com)

6.7.9 Fibre rolls

Fibre rolls are rolls of natural fibre that have been rolled into units of various sizes (Figure 6.16). A thin plastic netting sleeve keeps the fibre in position. Coir is the most commonly used fibre in South Africa for this method. Fibre rolls are used perpendicularly across erosion sites (Figure 6.17). They break the water's velocity moving down the erosion scar and allow sediment to be trapped behind the product. Fibre rolls in general have an 18-24 month life span depending on the surrounding environmental conditions. (African Gabions, 2004). The recommended slopes that fibre rolls should be used on depends on the local conditions of the site (see Section 6.7.1 for information on suitable slopes)

6.7.10 Fibre bags

Description and types of fibre bags

Fibre bags are also known as fibre logs, fibre sheaths or ecologs. The difference between fibre rolls and fibre bags is that fibre bags are hollow whilst the fibre rolls are fibre filled. Fibre rolls are available in units up to 10 meters in length whilst the bags are available in units from 2 to 6 meters long.

There are three different types of fibre bags available for soil conservation purposes. Each one of the fibre bags listed below has different uses, depending on the environmental factors at the designated site.

- Biodegradable fibre bagsBiodegradable fibre bags are economical, durable and biodegradable, providing structural stability and resistance to forces of water action until vegetation is naturally established.
- Fibre bags with plastic sheaths. These fibre bags are the most common fibre bags in South Africa. They perform the same function as the biodegradable fibre bags except they are made from less durable fibres and therefore need the plastic netting sheaths to improve their structural integrity.
- Fibre bags with wire sheaths.These fibre bags have plastic sheaths over the fibre bag with a wire sheath over it to improve the structural integrity of the product (Figure 6.18). These fibre bags can be used for applications in higher velocities than the unprotected fibre bags.

Fibre bags can be used in low velocity interventions over large surface areas due to their cost effectiveness. Figures 6.19 and 6.20 show the use of fibre bags in a sloped erosion gully placed in perpendicular fashion across it, and the recovery of the site after 6 months of natural establishment of vegetation.

Figure 6.18: Fibre bag with wire sheath. Vegetation can be seen emerging from the top soil in the bag.

Figure 6.19: Fibre bags placed in sloped area of gulley at the London rehabilitation project in Mpumalanga

Figure 6.20: The London rehabilitation site 6 months after installing the bags

The fibre bag is basically an empty sock that needs to be filled with a type of material to give the sock both volume and mass depending on the application for which it is being used.

- In situ soil material
  This works very well as fill material. During the sloping or excavating process topsoil can be used to fill the fibre bag. The top soil contains seeds and/or plant material that could resprout vegetatively from the immediate area of the intervention, which allows recruitment from a local plant or seed source since resprouting or germination takes place through the fibre bag. This method works very well in wetland rehabilitation projects due to the high moisture content in the fibre bag.
- Imported soil material
  The soil being used for the fill material in this case would need to have vegetation inserted into the fibre bag that could short vegetatively or it would require pre-mixing the soil with seeds that are acceptable to use on the site.
- Imported crushed rock or inadequate size gabion rock
  The excess from building hard interventions can be used as fill for fibre bags. These fibre bags do not have plant material growing in them but in the sediment that is trapped behind the intervention. Over time the fibre will decompose and sediment will fill the rock cavities and allow vegetation to spread. Mix soil with the crushed rock to create an erosion resistant growing medium. The bags will degrade in the sun so an erosion resistant medium held together by stones or roots is essential.
- Vegetative fill material
  Any grass or biomass can be used as fill material. Thatching grass is most commonly used. Using grass that is laden with seed allows for seed germination in the bag rather than in the sediment behind the bag. Filling can be done off site and the filled fibre bags can be placed in position without having to fill each bag on site. The benefit of this is that the local impact on site is kept to a minimum, which is particularly important in the case of small problems such as shallow gully head erosion or shallow drains in permanently wet areas.
- Log chips
  Log chips are a waste product at most sawmills in South Africa. These chips can be used as fill material in similar applications as the vegetative fill material.

6.7.11 Sediment fences

Sediment fences are used most commonly in dry land applications. They can be used in certain types of gully erosion, sheet erosion, rill erosion and for temporary sediment management during construction. There are very many different types of sediment fences on the market overseas, but this is not the case in South Africa. The sediment fence is a fence that has either a semi-permeable or non-permeable membrane attached to vertical poles such that sediment is trapped upslope of the fence.

The fences can only be used where the water levels are relatively low and slow. The nature of the fence does not allow for treatment of high velocity or high energy problems, since the membranes can easily tear or the poles used to keep up the fence can be forced over. Geotextiles, plastics and mats can be used to create sediment fences.

Sediment fences are placed perpendicular to the direction of water flow. They can range in height, although the higher the fence the greater will be its risk of being washed away. However the number of fences required will be inversely related to their height. For sheet and rill erosion the fences need be no more than 200 mm high, but the number of fences required may be very high to treat a single slope. In dealing with a particular erosion problem one therefore needs to trade-off height against the number of fences. Fences can make small waterfalls which can exacerbate erosion downstream. The toe of the fence must be well buried and enclosed to ensure that it is not undercut.

Sediment fences work very well in providing temporary stability until vegetation has taken hold. They are not a solution on their own.

Low impact installation aesthetics, cost-effectivenessFence failure

6.7.12 Negative and positive aspects of the applications

Negative aspects of hydroseeding

- Use of vehicular equipment
  Specialized vehicular equipment is required to do hydroseeding, making projects that require hydroseeding very expensive. Furthermore, wetland sites are difficult to access in a vehicle because of the their saturated soils, making them unsuitable for conventional hydroseeding. Hand seeding is thus generally likely to be a better option in these situations.
- Application and post-application issues
  Flooding or high rainfall events before the seeds have germinated can wash away the seed mixtures from the site (Hayes et al., 2000). Poor seed to soil contact is achieved if the site is not correctly prepared, which results in poor seed germination. Large amounts of water are used during the application, which is often difficult to deliver to a site in sufficient quantities. Needs moisture after germination or the sprouting seeds will die.

Positive aspects of hydroseeding

It is a very easy way of applying seeds to a large area, but good access to the site is required. Despite the high cost, if an area is sufficiently large it can be seeded very cost effectively since the cost per unit area declines as the area treated in a single application increases. The equipment does not have to go onto site and this reduces the environmental impacts on the site during implementation (www.usgenviroshield.com). A single hydro-seeding event application includes mixing seeds, fertilizer, water, binding agent and mulch, which would have to be applied separately if done manually.

Negative aspects of fibre nets, fibre mats, mattresses, fibre rolls and fibre bags

These products are generally not suited to sites with high velocity flows. These products are not fire resistant and can easily burn, allowing the exposed scarified soil to erode. If the anchoring system fails the entire intervention can be lifted and torn, resulting in the whole intervention being lost.

Fibre bags have wire sheaths that strengthen the integrity of the fibre bag. The wire sheath has a high value in some communities such that bags are ripped out of the ground and the wire removed and used for fencing. Mesh can trap small animals, and partially corroded steel wite is harardous.

Incorrectly filled fibre rolls and bags slump and create flow concentration zones that can result in increased likelihood of erosion. Some of the products have plastic sheaths to strengthen the product, these sheaths can be ripped to pieces when animals walk over them. The plastic sheeting also gets stuck to the hooves of animals and the sheath gets ripped when the animal moves off. This can result in the products failing to achieve the rehabilitation goal.

Positive aspects of fibre nets, fibre mats, mattresses, fibre rolls and fibre bags

The application of these products has a much lower impact on the site than hard interventions. They blend in with the surrounding environment and are aesthetically pleasing. These products are a tool that is in the process of establishing vegetation in the application, and not the end result in their own right is the case for solutions designed by civil engineers. More importantly, these products are relatively cost effective when compared to many civil engineering interventions.

Negative aspects of sediment fences

Sediment fences are short-term solutions that need lots of maintenance. When water flows over the fence it scours the toe of the fence and if this is not monitored and maintained, it can result in the fence failing. The sediment fences are exposed to sunlight, which decreases the lifespan of the fence and can result in failure. Each sediment fence can hold large amounts of sediment depending on its height, but failure of the fence results in gully erosion that will propagate upstream.

Positive aspects of sediment fences

The use of sediment fences has a much lower impact on the site than civil engineering interventions. Sediment fences are a phase in the process of establishing vegetation, and not the end result. Sediment fences are quick and easy to install, which makes them cost effective. Motorised applications for installation of sediment fencing are available making it possible to work on large areas very cost effectively.

6.7.13 Installation of the applications

Hydroseeding

The hydroseeding techniques discussed below are general applications as each site would have to be evaluated according to local environmental conditions. It is recommended that professional hydroseeding operators be used for hydroseeding projects due to the high level of expertise required in choosing the right type of product for the site. Different sites have different climatic conditions, soil types and levels of existing erosion. All these considerations have to be taken into account when mixing the product. Different seed types and/or fertilizer mixtures will be useful for different areas.

Key aspects of hydroseeding include:

- The area of the proposed project has to be carefully measured to work out volumes for the hydroseeding.
- Areas where sloping and soil preparation are required must be done before hydroseeding begins.
- An appropriate slurry mixture has to be developed for the specific site based on soils, rainfall, wind and water erosion, and the slope being sprayed (www.earthsavers.com). Development of the mixture need to consider types of:
  - seeds to be used
  - soluble and/or slow release fertilizer (www.ewing1.com)
  - binding agent since the greater the amount of mulch and seeds being used, the stronger the binding agent will have to be.
- Premixes are available from companies for sites that have similar environmental conditions and slopes.

Installation of netting, mats and mattresses

The following are key elements for installation of netting, mats and mattresses:

- To ensure the lifespan of the product during storage, it is important to keep it dry and out of direct sunlight.
- The proposed site should be marked out with pegs and twine.
- Prepare the site for the planned intervention, including sloping the area to the required slope, removing vegetation and topsoil where necessary and storing these.
- All vegetation removed during the sloping process must be kept to one side for later use with occasional watering as necessary.
- Only once the site has been prepared do the next installation steps follow.
- Scarify the surface of the soil to a minimum depth of 150 mm (African Gabions, 2004).
- Dig a trench of 300 mm x 300 mm at the top of the slope to anchor the product.
- Place the edge of the product into the trench so that it covers the bottom of the trench, making sure that it has good contact with the underlying soil and leaving about 500 mm of material above the trench
- Staple the material to the bottom of the trench, fill in the trench with soil and compact the soil to ensure that the fill material is not washed away.
- The material can be rolled out from the top to the bottom of the slope, or along the contour depending on the width and length of slope to be covered. Long, narrow slopes can best be

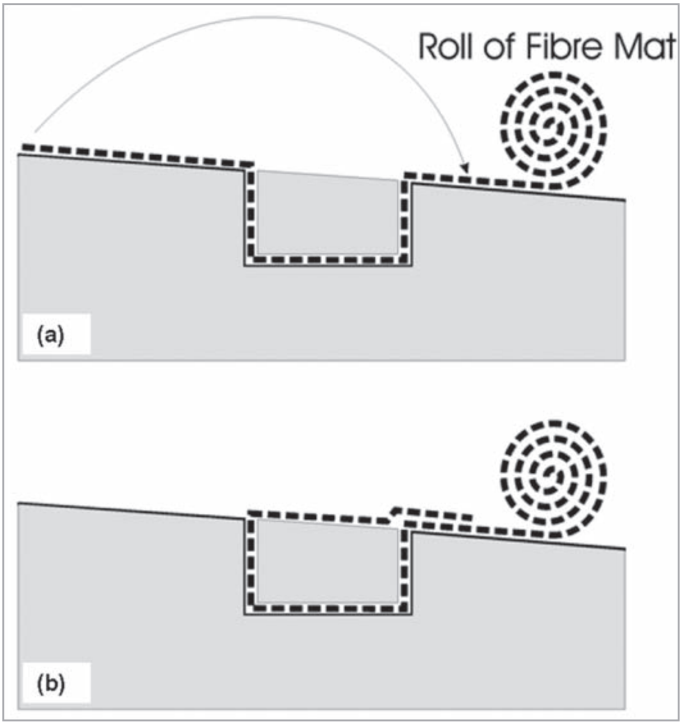


Figure 6.21: Anchoring the material at the top of the slope in a trench filled with soil and firmly compacted (a) and folded over from the upper side over the compacted spoil (b). The overlapping layers must be securely pegged at the top of the slope

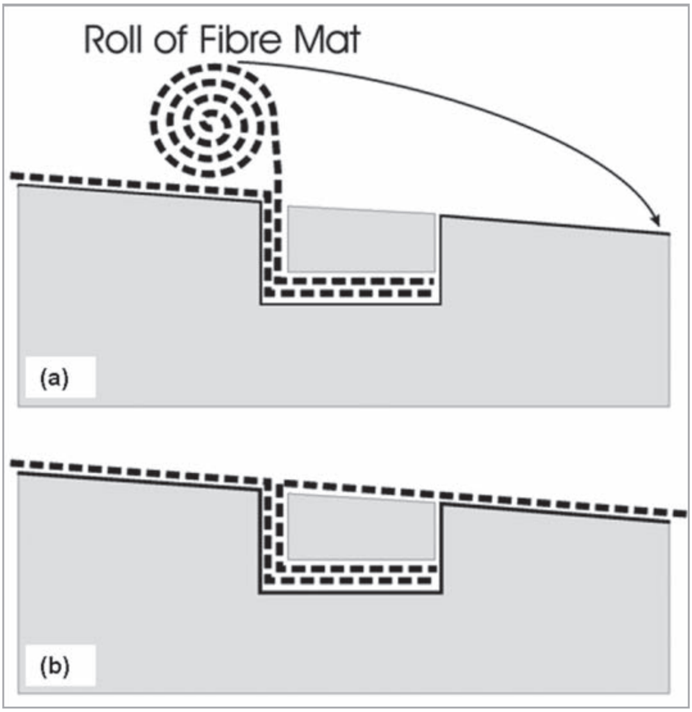


Figure 6.22: Anchoring material at a join on a slope. The ends of both rolls **of fibre mat are buried in a trench from the top of the slope (a) and the new roll of fibre mat is then rolled over the fill and down the slope (b).**

treated by rolling the material down the slope, whereas short slopes are best treated by rolling the material along the contour. Anchor the material at the top of the slope in a soil filled trench (Figure 6.21).

- Where a join takes place in flat areas or on a very gentle slope (<5%), the material on the upslope side is lifted at its lower end and the next piece is placed underneath creating a 150 mm overlap. This overlap area must be pegged/stapled to secure the two layers. Where joins are on slopes greater than 5% it is necessary to anchor using trenches to secure the material in place (Figure 6.22).
- If more than one piece of product is required in a single trench, such as for the very large areas they will have to be placed such that they overlap by 150 mm to ensure that no soil is left exposed.
- The product should be pegged to the ground with staples a maximum of 500 mm apart, depending on the slope and the environmental conditions of the site. The steeper the slope the greater the number of staples that should be used. The density of staples is provided by the supplier of material (www.nagreen.com).
- The following revegatation methods can be used
  1. Seeding the area before the product is placed in position.
  2. Placing the product and then planting vegetation through the mat into the scarified top soil. Plugs, slips, sprigs and seedlings can be used in these situations. Tufts of vegetation from the slope are commonly used as the material is from the site and readily available.
  3. Mattresses can be placed in position and seed spread across the surface of the product. The seeds will fall through the mattress. A 15 mm layer of soil is then spread across the surface of the mattress, some of which will settle into the mattress.
- The area must be watered once the site has been revegatated and done on a regular basis to ensure the vegetation if given ample opportunity to grow.
- Monitoring of the intervention should be in done in accordance with the best management practices being implemented. If any maintenance is required it should be done regularly to ensure the integrity of the intervention.

Installation of fibre rolls and bags

Always, due to their weight, install dry fibre rolls as wet fibre rolls are more difficult to handle and can slow down operation time (www.coirproduct.com).

- The denser the fibre roll the longer the application will last. On some sites longer lasting applications will be required where vegetation has more difficulty establishing (www.coirproduct.com).
- For all applications it is critical that the products are placed parallel to the contour or perpendicular to the expected flow of water.
- In order to fill each bag with material, open the mouth of the bag and place fill material into it. Using a pick handle, force the material to the back of the bag. Do this until the bag is completely full and has expanded to its maximum volume. Half full bags do not have the same height and therefore do not trap as much sediment as a full bag.
- Place the bags in position so that they fit snugly against the surrounding soil, ensuring that no water can erode underneath them and so that they are closely abutted to one another. This is very important and if not done correctly will result in erosion at this point in the intervention.
- Dig small trenches that are deep enough to contain the bottom half of the product, approximately 200 mm.

- Commence the installation of the product from the bottom to the top of the site.
- The products must be keyed in well to the banks of the erosion problem such that water flows over the product and not around it, which may lead to erosion and product failure. It is important that water must be able to flow over the product and not around it. For more information see www.earth-savers.com.
- Wooden stakes, broom sticks, metal pins or duckbill anchors (www.ropecon.co.za) can be used to secure the products. If hard fill material is used in the fibre bag, make pilot holes with a metal rod through the fibre bag and then use the wooden stakes or broom sticks. In gully floor applications soil anchors should be used in conjunction with the pegs. This gives the fibre bags a more secure anchor in situations where high velocities are expected during high rainfall events. The anchors are placed on the upstream and downstream side of the product and tied together with wire. Depending on the soil structure anchors should penetrate the soil to a minimum depth of 500 mm below the surface. (www.cocoterra.de.)
- Drive the stakes through the products leaving no more than 50 mm of the stake exposed. Stakes should be placed every 1.5 meter of the length of the roll. On very steep or erosive slopes, additional stakes may be placed on the downslope side of the roll. The use of staples, stakes and pegs as soil anchors is discussed later in this section.
- Products used on the edge of water bodies must be placed so that 50 mm of the roll extends above the surface of the water (www.kristar.com).
- At the edge of water bodies drive stakes 300 mm apart in parallel to the product. Place the product in position and using coir lacing or wire, lace the parallel stakes together keeping the product in position (Figure 6.23; www.kristar.com). Wave action on the edge of water bodies will dislodge items and if the product is

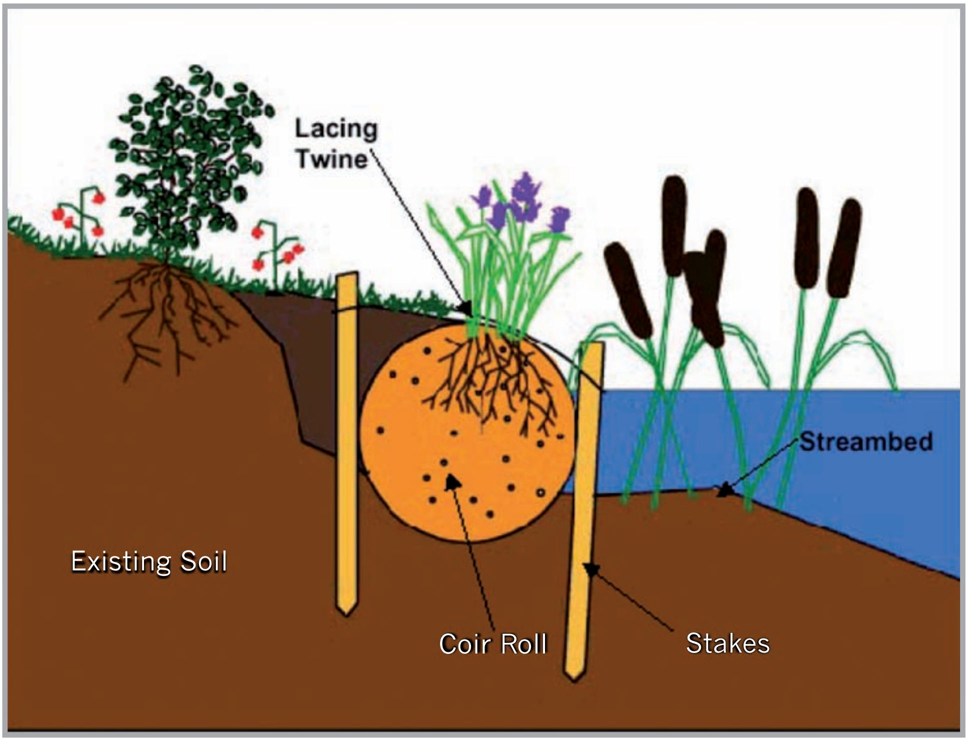


Figure 6.23: Pegging of circular products at the edge of water bodies (African Gabions, 2004)

not correctly anchored the wave action will lift and drop the product until it dislodges, causing the product to fail.

- The vegetation removed during the sloping can be used to plant in the product or in the soil behind the product. According to African Gabions (2004), it is recommended that 2 plants be planted every 300 mm along the length of the product.
- In sites where there is gully erosion, the products should be used in conjunction with sloping of the problem. Once the sloping has been completed, the products should be placed into position so that no soil surface area is exposed. Where the water enters the gully head erosion it is very important to fit the product as tightly as possible against the soil surface. The pegging of these products is very important, since if any of the products should move, gully head erosion may continue. This will concentrate water flow and undermine the products.

Figure 6.24 shows how gully erosion of 1 m deep and 2 m wide that was deactivated using fibre bags with wire sheathing.

Installation of sediment fences

- Sediment fences need to have poles placed a maximum distance apart of 1 m such that the larger the velocity the closer together the poles need to be inserted. The poles are driven into the ground, wooden stakes are used more commonly. The size of the stake depends on the height of the fence.
- Once the poles have been put in place, a small trench needs to be excavated to secure the membrane into the soil on the upslope side of the poles.
- The membrane is placed into the pit and compacted, and it is then attached to the poles with wire or cable ties.

The different products discussed in the above sections require different methods in order to secure them. The applications themselves have been split into two groups, namely the horizontal applications that are applied to the soil surface, which require staples, and the vertical applications that require stakes. Those applications that require staples are fibre mats, fibre netting and mattresses, while those that require stakes are fibre rolls and fibre bags.

Figure 6.24: Fibre bags used to deactivate gully head erosion. Note the very small step height and downstream impact protection.

Staples

To achieve optimal results for the erosion control installations, proper staples (Figure 6.25) must be used. These will be provided by the supplier of the mattresses as they depend on the application and on local conditions, particularly slope and velocity of water flow. The website www.nagreen.com can also be consulted.

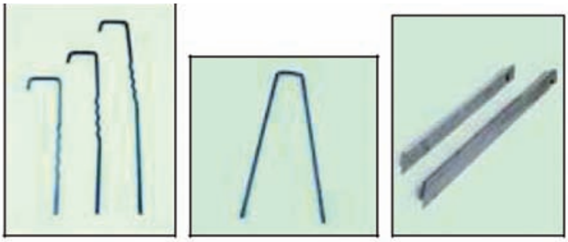


Figure 6.25: Different types of staples available on the market. Scale 1:20 (www.jmdcompany.com)

Different types of stapling methods can be used to effectively secure the mats, nets and mattresses in place. Steel staples, steel pegs or wooden stakes can be used to secure the applications. According to African Gabions (2004) the pegs should be a minimum of 200 mm long and 4 mm wide. This minimum length is very similar to all the other types of staples available on the market. The type of staple is not as important as meeting the requirements of the density and pattern of arrangement. There are currently staple guns on the market specifically developed for securing these applications. They are relatively expensive but if large projects are being undertaken their use could save time on securing the applications and therefore save money (www.kristar.com).

Stakes and Pegs

Fibre rolls and fibre bags must be pegged into position to secure them in the required positions. If these applications are not pegged into position correctly they can be moved out of position, which can result in the application failing.

There are many different kinds of pegs that can be used in pegging down applications, including steel pegs, plastic pegs and wooden stakes. They all serve a common purpose, but cost effectiveness and durability should be the final factors in deciding upon which to use. In certain areas of South Africa broom handles can be acquired and used as pegging material.

According to African Gabions (2004) the pegs should be a minimum length of 0.8 m long and 40 mm wide. The peg can be driven in on the vertical or perpendicular to the slope, although on steeper slopes the peg should be driven in at an angle between perpendicular to the slope and vertical. This decreases the possibility of the product moving when water backs up against it.

Where applications need to be anchored to soil that is not firm on the surface, as is typically found in permanent wetland areas, then soil anchors such as duckbills should be used. These are driven with a steel rod deep into the soil (usually at least 500 mm below the surface) to firmer layers below and are connected to the application with well-tensioned wire. See www.ropecon.co.za for further details.

6.8 Civil engineering applications in support of vegetation

Where a hard structure is considered necessary to support the vegetation because slope or velocity of runoff expected are excessive (see Section 6.7, Figure 6.4), it is preferable to use a rock-filled gabion structure within which soil can be included and plants could establish. As the plants became progressively better established, this would allow the plants to take over the function of holding the intervention together. However, under certain circumstances (See Section 4) rock-filled structures may be unsuitable, requiring that concrete structures be used.

Channel plugs may consist of vegetation used in conjunction with gabion rolls, rock-filled gabion mattresses and other supporting structures. These may be partly filled with rock and soil with either herbaceous or suitable woody plants in them, depending on the particular circumstances. These structures can also be used for both bank and gully head stabilisation. Where it is anticipated that the soil will be lost from the structure, a fibre mat may be placed beneath the lid of the gabion.

Where structural support is required for vegetated chutes, the drop can be shaped into a milder slope (1:5 to 1:10, vertical to horizontal) and packed with rip rap, which is then planted with suitable vegetation and covered with a biodegradable net or wire mesh that is pegged down securely over the vegetation to allow it to establish without being uprooted by early rains.

In contrast to the above approach where vegetation is assisted by structures, the approach of **conventional engineering being assisted by the use of vegetation** can be considered. Vegetation must always be used in all wetland rehabilitation structures as the re-vegetation and natural stabilisation of the problem is the eventual desired result. Very few engineering measures will last forever and are designed to allow nature the opportunity to stabilize itself.

Vegetation fulfills the following roles when used in conjunction with conventional engineering techniques.

- Provides additional stability through the control of runoff.
- Assists in the capture and retention of sediment
- Adds to the sheer strength of gabion structures through the reinforcing effect of its extensive root network
- Mitigates against some of the negative impacts of rehabilitation structures by beautifying the site (aesthetics).

Vegetation is particularly useful in the following situations:

1. Erosion structures built of soil. In the creation of earthen dams or earth plugs in drains it is imperative to establish vegetation over the structure to protect it against rain drops, wave action on the up stream side of the dam and against other forms of erosion (e.g. resulting from livestock traffic). It may be difficult to establish wetland vegetation on the dam wall, as it may be too dry for hydrophytes (contact your local extension officer of the Department of Agriculture to find out which is the best dryland species to use). A suitable non-invasive prostrate (creeping) species that gives good cover and has extensive roots should be chosen. The spillway should also be vegetated.

2. Sediment retention structures require vegetation to be established in areas where deposition is expected. The plants will trap the sediment and bind it, stopping it from being eroded during the next storm event. This vegetation may also extend considerably the effect of an erosion-control structure when it is established in sediment deposited

behind the structure. This aspect is well illustrated in the Hofmeyer district of the Karroo. Vegetation in the form of Common reed (*Phragmites australis*), was planted in the sediment that had built up behind a structure built by the Department of Agriculture in 1976. After a period of years the deposition had extended the effect of the structure an extra 10 km upstream and well above the elevation of the structure's spillway, through the forced deposition of sediment and its subsequent colonisation by reeds.

3. Gabion structures. The wire baskets holding gabion structures together will eventually rust over time. By the time they do so, if vegetation is well established over the structure then the roots of the plants and the sediment that has been trapped will often have taken over the function of holding the structure together. However, if any steps imposed by a gabion structure on the slope of the land exceed more than about 0.5-1.0 m vertical, then the roots may lack the strength to prevent the structure collapsing. Thus, it is recommended that gabion weir structures be stepped on their downstream side, with vertical steps not exceeding 0.5 m. In order to promote colonisation of gabions by vegetation it is recommended that the void spaces between the rocks in the gabion be filled with soil. This is difficult to do once the gabions have been completely filled. Fill the voids with soil as filling proceeds – even 200 mm of voids will be difficult to fill from the top. In addition, rhizomes of appropriate deep, strong rooting plants such as *Phragmites australis* and palmiet can also be inserted into the voids.
4. Any rigid structures having a significant aesthetic impact, particularly when the wetland is in a largely natural, undisturbed area. Vegetation that can be established in and around these structures would assist in reducing this particular impact.
5. Vegetation used as 'vegetated sills' upstream of hard structures dissipate the energy of runoff upstream of the structure and thus produce a measure of additional protection to them as well as assisting in the establishment of vegetation on the structures.

CHAPTER 7: GULLY BANK PROTECTION

An actively eroding stream or gully coursing in a meandering fashion through a wetland area will rapidly destroy it through undercutting of its banks. If the objective is not to lift the streambed to its original level, but merely to curb any further destruction, the following methods are recommended, and are given in ascending order of catchment size with an increasing energy environment. These methods therefore mainly deal with the protection and stabilisation of the banks of gullies.

7.1 Sloping and vegetating minor gully banks

Where the gully is no more than approximately 1.0 m deep, and the catchment area small (recommended 10 ha), the topsoil of the site immediately adjoining the channel is removed and stockpiled in a safe place nearby. The subsoil thus laid bare is excavated at a slope equivalent or more gentle than 1:3 (vertical: horizontal) and deposited in the gully. This deposit is carefully compacted while in a moist state. The best moisture content can be estimated by squeezing a ball of soil in the hand. The moisture content is about correct when the ball just holds together when the fist is released, and lies intact on the palm of the hand with a sheen of moisture on the surface which disappears fairly quickly.

The topsoil is now returned to the sloped area, and spread as evenly as possible over it. Vegetation suitable to the site is planted (Figure 7.1). The additional advantage to this idea is that, as the channel cross section is made shallower and wider and established to vegetation, so the chances of floodwaters overflowing into the adjacent flood area will be that much greater. The new shape will cause a reduction in velocity with a resultant increase in flow depth. Note that the base of the modified channel should be planted to strong, hydrophitic plants while the outer edges will require plants more suited to drier regimes. It must be emphasised that the stockpiling of the topsoil and its replacement is vital, especially where very erodible subsoil is present. Failure to do this will be tantamount to a waste of money and effort.

The method for determining the side slopes (and therefore the new width and depth of the watercourse) to which the gully walls should be sloped is an exercise using Mannings Equation that is discussed in detail in Chapter 17. The critical design velocity would depend on the soil type and can be obtained from the same chapter. The explanation of how to build to a specified slope is given in Chapter 29 (Section 29.6).

7.2 Protection of substantial gully bank sidewalls

Protection for gullies with larger catchment areas, and for side slopes that, for some reason or other, need to be cut steeper than the recommended 1:3, require a stronger protective lining (see Figure 7.2). With large catchments floodwater generally flows more rapidly, and in cutting gully banks to a steeper slope than the natural angle of repose for the specific material, the slopes will be more vulnerable to erosive action. The chances for a good stand of vegetation in the higher energy situations that now arise will become more problematic

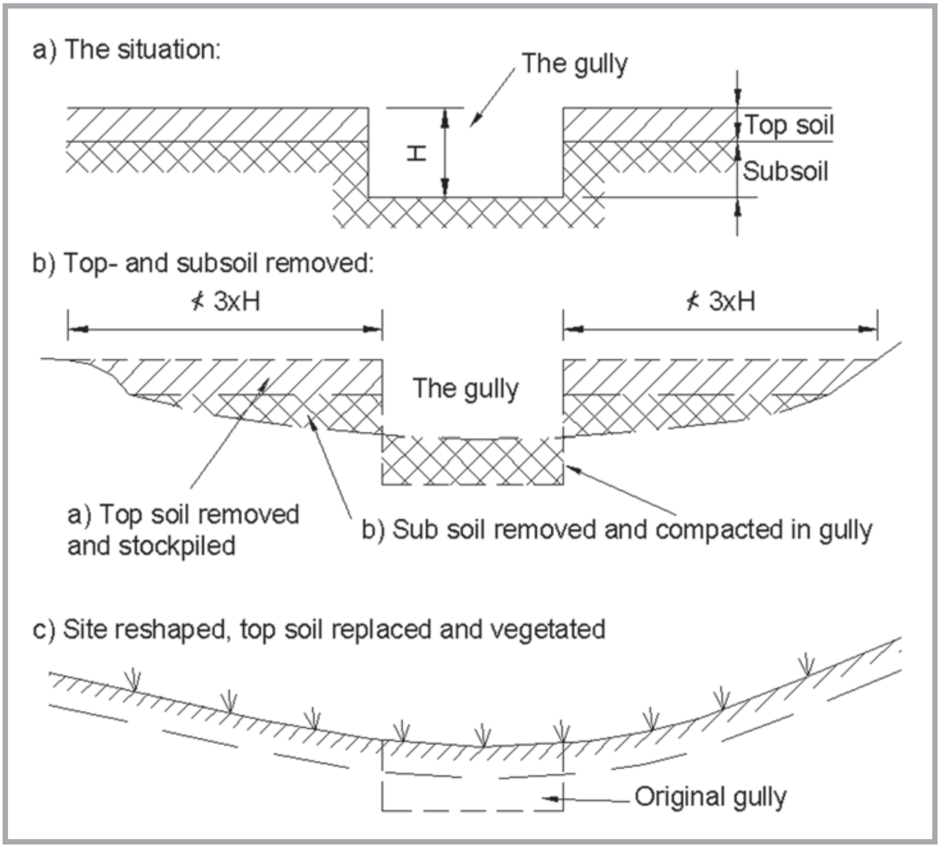


Figure 7.1: Sloping stream banks and gully sides, simultaneously in-filling a portion of the gully with excavated soil

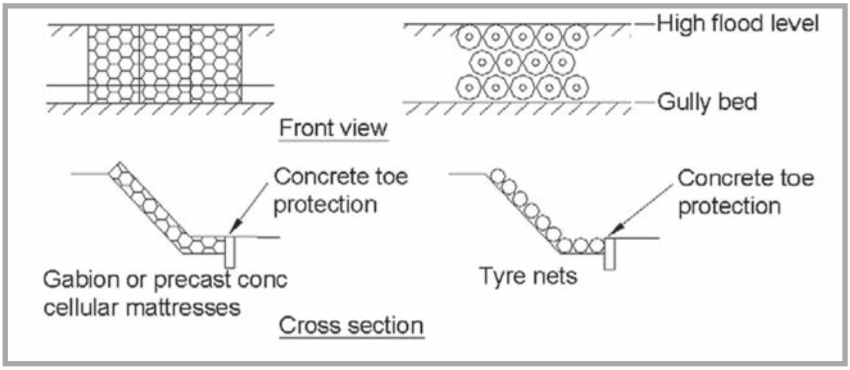


Figure 7.2: Sloping and protecting steep gully banks with a permanent lining

Suitable protection will now only be afforded using one of the following techniques:

- **Old motor vehicle tyres:** The same sloping process is followed as for sub-chapter 7.1, but now a design velocity of 2/0 m/sec. may be used. It should be borne in mind, however, that where velocities exceed 3-4 m/s, heavy damage can be caused to any slab of material not strong and heavy enough to withstand the shear forces that can develop. As a rule anything with an expected velocity V > 3 m/s should be considered a Level 3 structure – see Chapter 16.The tyres are either bolted or wired together using galvanised material. Iron anchor rods (e.g. iron fencing standards) driven through the mattress and well into the soil profile every 3-5 metres will give added stability to the structure in withstanding the velocity of storm runoff. Soil is poured and firmly compacted into the holes in and between the tyres, and vegetation established. If the gully bed is very erodible it may be advisable to, in addition, build a series of small weirs (500 mm in height), down the channel, in order to reduce the velocity of the floodwaters. See Chapter 21 for detail on these structures.

One problem with this technique is that of fire. If the tyres ignite during a rangeland fire they could catch alight, the fire not only destroying the tyres but the surrounding vegetation as well. There is the added danger of the soil organic matter being so destroyed that the site becomes an extreme erosion hazard. Another problem arises if the joins between adjacent tyres should break and the tyres wash downstream, causing a littering problem. If this option is to be attempted, it must be done with great care. This is without a doubt a poorer option, especially in large catchment areas.

- **Gabion mattresses:** The gully wall is sloped to the required angle - preferably not steeper than the angle of repose of the soil unless closely spaced anchors are used. (maximum slope 1:1.5 (H:V), but refer to suppliers for slopes steeper than 1:2 (H:V)). A geotextile filter fabric is laid down the slope, and the gabion mattress constructed on top of it. The filter is required to stop the gradual scouring of soil out from underneath the mattress, while also allowing the pressure of subsurface water to escape through the material. Where an erodible streambed is encountered the mattresses may be continued right across the bed. Pioneer vegetation should establish between the rocks once sediment has been lodged in the interstices. The design may call for soil to be imported and mixed in with the rocks, but this will only be an option where the velocity of flow is below 2 m/s. Vegetation that is tolerant to flooding and robust enough to withstand moderate velocities should be chosen to establish in and around these structures (see Chapter 6).

  While great care may be taken in laying, wiring and filling the gabions, the fact remains that the wire will rust through in time, especially if the runoff is corrosive, such that the rocks may be plucked out and rolled downstream by floodwaters. For this reason, where reliance is placed on gabion mattresses and baskets in streambeds, the design velocity should not exceed 3 m/s (see Chapter 17). If this is done there will be less chance of the rock fill being washed away once the baskets have broken open. Vegetation that binds the rocks together will be an added benefit.

- **Pre-cast concrete cellular mattresses:** These are solidly made concrete interlocking blocks that are joined together with cable wire to form a flexible mattress that is even more durable and resistant to high velocities. Exactly the same methodology regarding a filter fabric is followed as for the gabion mattresses, but now higher velocities may now be used in the design. The gaps in the concrete blocks allow vegetation to grow through, and in time cover the concrete. Where calculated velocities exceed about 4 m/s careful design is required. Shear forces at bends in the stream may be double that along straight reaches, stagnation pressures can lift blocks, hydraulic jumps can flap the panels, plunging flow can move individual blocks and cause serious damage to the subgrade. For V > 3 m/s subgrade erosion is a significant cause of failure. The block panels remain in place but voids form under the filter fabric.

The trade names of materials are Armorflex from Concol Technicrete (see www.technicrete.co.za) and Terrafix from Infraset (see www.infraset.com). See chapter 28 for details. The downside to the use of this material is cost, but then it would only be used under conditions of high flow velocities.

- **River jacks** placed along the outside line of a stream bank (as shown in Figure 7.3) tend to cause a reduction in the rate of flow of floodwaters. Sediment suspended in the flood automatically settles out around the jacks. Suitable vegetation is once again needed to stabilise the sediment.

  While the illustration in Figure 7.3 shows the river jack made out of creosoted wooden poles, the national Department of Agriculture engineers have had great success with specially crafted concrete poles. Some of their work in the Karroo has been so successful that they are no longer visible – buried 3 metres deep in the sediment trapped by them and masked by river reed.

- **River walls** constructed of gabions are passive structures that protect the riverbank from high-energy river flow. Their design is illustrated in Figure 7.4, and may resist velocities as high as 6 m/sec.
- Sugar farmers along the KZN coast have had considerable success with the planting of **indigenous riverine trees** that have the growth ability to cover the soil surface with buttress roots (see Chapter 6 for more information).

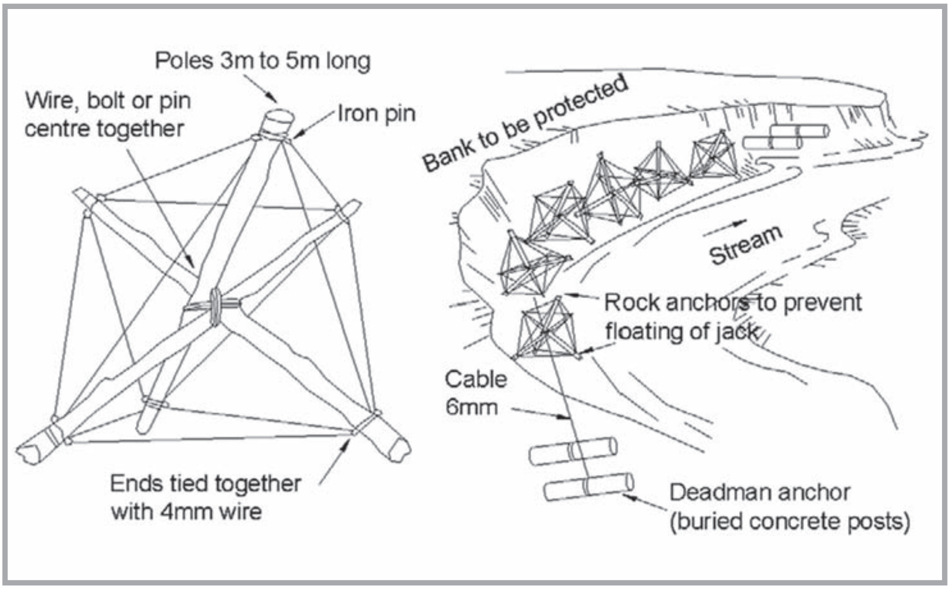


Figure 7.3: Using river jacks to stabilize stream bank erosion

- **Groynes** have a particular application in wide rivers with swiftly-flowing floodwaters (Figure 7.5). Their function is to guide the water away from the riverbank under threat, and to keep the flood flow in the middle of the river channel. The correct placement of these structures is critical if they are not to create even more problems, and their application is best left to experienced river engineers. They are, generally constructed of gabion baskets tied on to gabion mattresses. For construction techniques using gabions see Chapter 21.

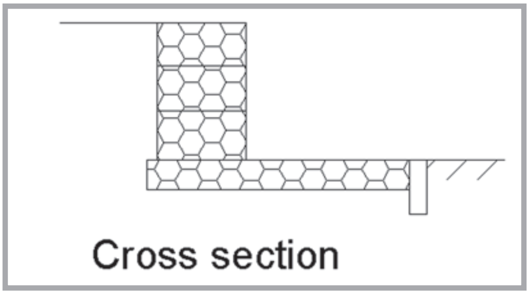


Figure 7.4: Protecting stream bank with a wall of gabion baskets on a mattress

- The velocity of flood peaks may also be reduced by spacing relatively low **weirs** across the channel in order to create sections of zero gradient. As explained in Chapters 8 and 9, in trapping sediment the conditions for promoting vegetation growth will be improved and velocities will be automatically reduced.

- **Structures using vegetation**: Tree trunks long enough to extend across the gulley can also make very effective weirs if the ends are buried in the banks on either side (Figure 7.6).
- Brush layering anchored by tree trunks can also be very effective (Figure 7.7).
- Tree root boles can be used on concave banks to enhance bank stability (Figure 7.8). In this case the trunks are buried and the root boles extend into the gully.

Figure 7.5: A system of gabion river groynes protecting a stream bank

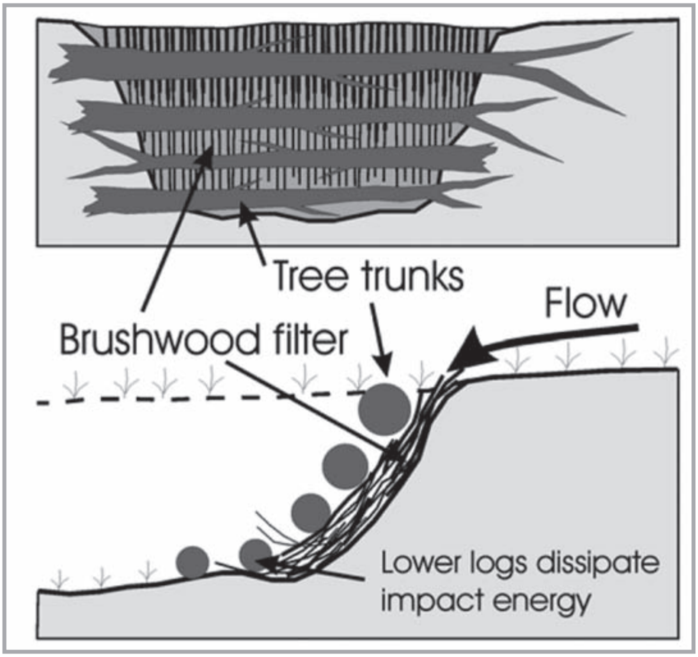


Figure 7.6: Tree trunks, with brushwood, make an effective weir.

Top diagram a cross-sectional view, lower diagram a longitudinal view.

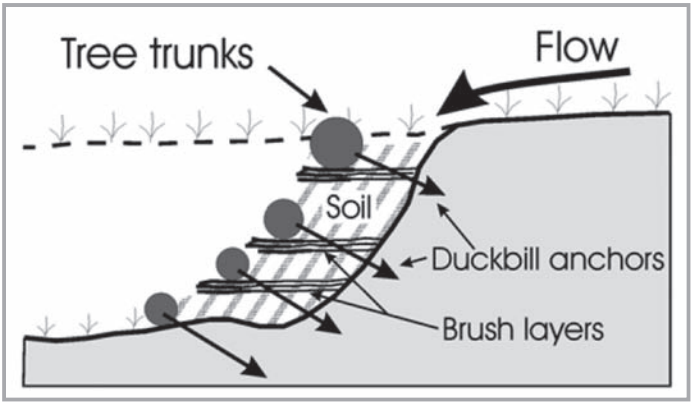


Figure 7.7: Brush layering anchored by tree trunks can also be very effective

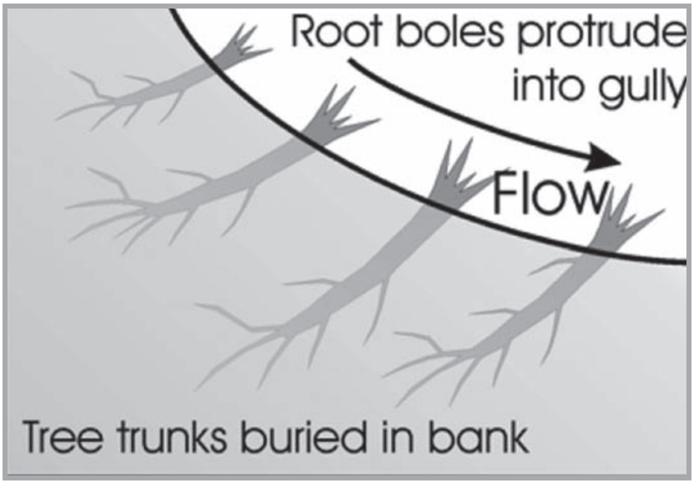


Figure 7.8: Root boles used to enhance bank stability

CHAPTER 8: EXCAVATED DRAINAGE DITCHES, CAMBERED BEDS AND MINOR GULLIES

The drainage channels and gullies discussed in this chapter are relatively small and nor do they have large catchments. As a result, the structures required to rehabilitate them are also fairly small. Consequently, all rehabilitation structures mentioned in this chapter fall under Level 1 category, which means they may be designed by a certified wetland worker (Chapter 16).

8.1 Drainage ditches

In this context drainage ditches are generally those channels that have been excavated in wetlands in order to drain them for agricultural purposes. They do not usually have large catchment areas, and the sediment load in the water they carry is generally at low concentrations. They are seldom more than 1.0 metre deep, and are also not usually actively eroding. Their only problem is that they are draining the water table in the wetland, and as a result the wetland has been losing, and will continue to lose, both surface and subsurface water, to the detriment of bio-diversity and functionality of the wetland. Where drainage ditches have been eroded to larger proportions they should naturally be treated as for major gullies (see Chapter 9).

If the ditches are really small, and the spoil from their original formation is still lying alongside them, the obvious method would be to fill them back in and to revegetate the surface (Figure 8.1). A portion of the work could be accomplished using a disc (preferable) or mouldboard plough, but the finishing touches will require hand labour. If the spoil has been lying there for a considerable time a large portion of it may have been lost through rainfall runoff action. Alternatively, there may still be sufficient material stockpiled to create a wide, shallow ditch that will channel the base flow but allow higher rates of flow to spill out into the adjacent wetland. The cost of importing soil from elsewhere in order to regain the original topographic terrain can be easily calculated and compared with the costs of the alternatives. The environmental costs to the donor area will then also have to be taken into account. Unfortunately these options, when using hand labour, can work out rather costly, and compaction when large amounts of soil is involved tend to be insufficient. On the other hand the land user/owner may be willing to assist by providing a couple of hours of his tractor and plough to carry out the initial, harder work as well as the compaction using the tractor wheels.

If the ditches are small and there is not much in the way of original wetland vegetation present in the channel, an option that may be considered is to simply establish plant species that will form dense clumps in time, across it. This would slow down velocity of runoff, trap sediment, and act to push the runoff back into the wetland. See Chapter 6 in this regard.

With larger ditches, the normal practice is to block them with soil ‘plugs’, spaced along the ditch so that the throwback of the lower one stretches back to, but does not quite reach, the upper one (Figure 8.2). Should the water that is trapped by the lower structure push back and lie against the adjacent one upstream, instability of the latter could be caused through saturation of the soil comprising the upper plug, and it could collapse. With a low height of structure and a flat slope in the wetland this could possibly not be a problem as long as it collapses only after vegetation has adequately colonised the site. The better alternative in most instances is to use concrete or rock-filled gabions in the construction, for both permanence and lower maintenance.

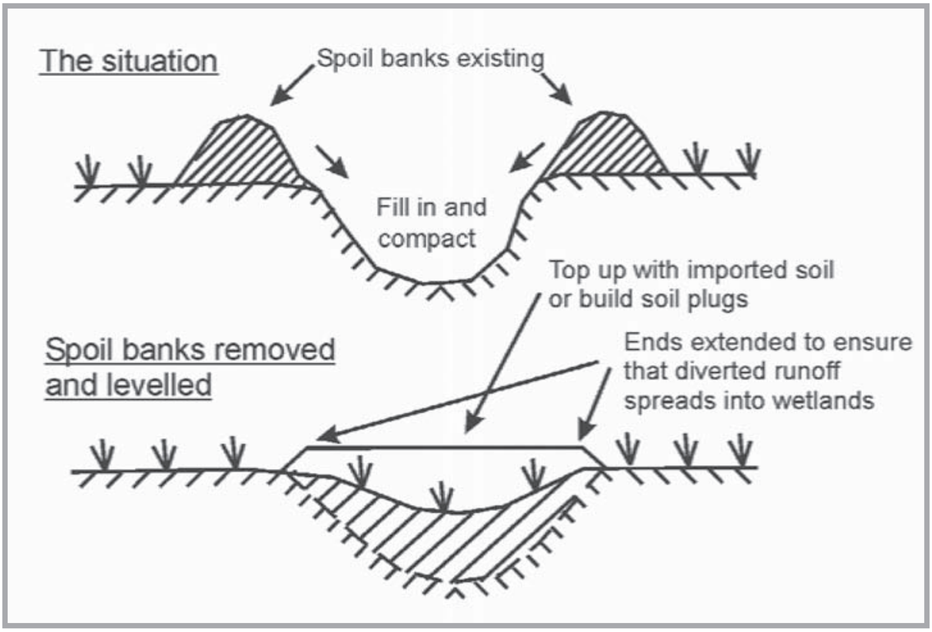


Figure 8.1: Cross-sections of filling-in drain with soil and/or imported material

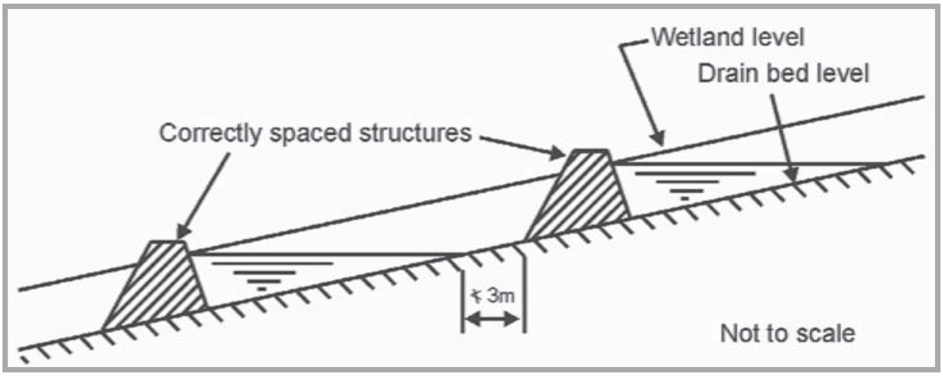
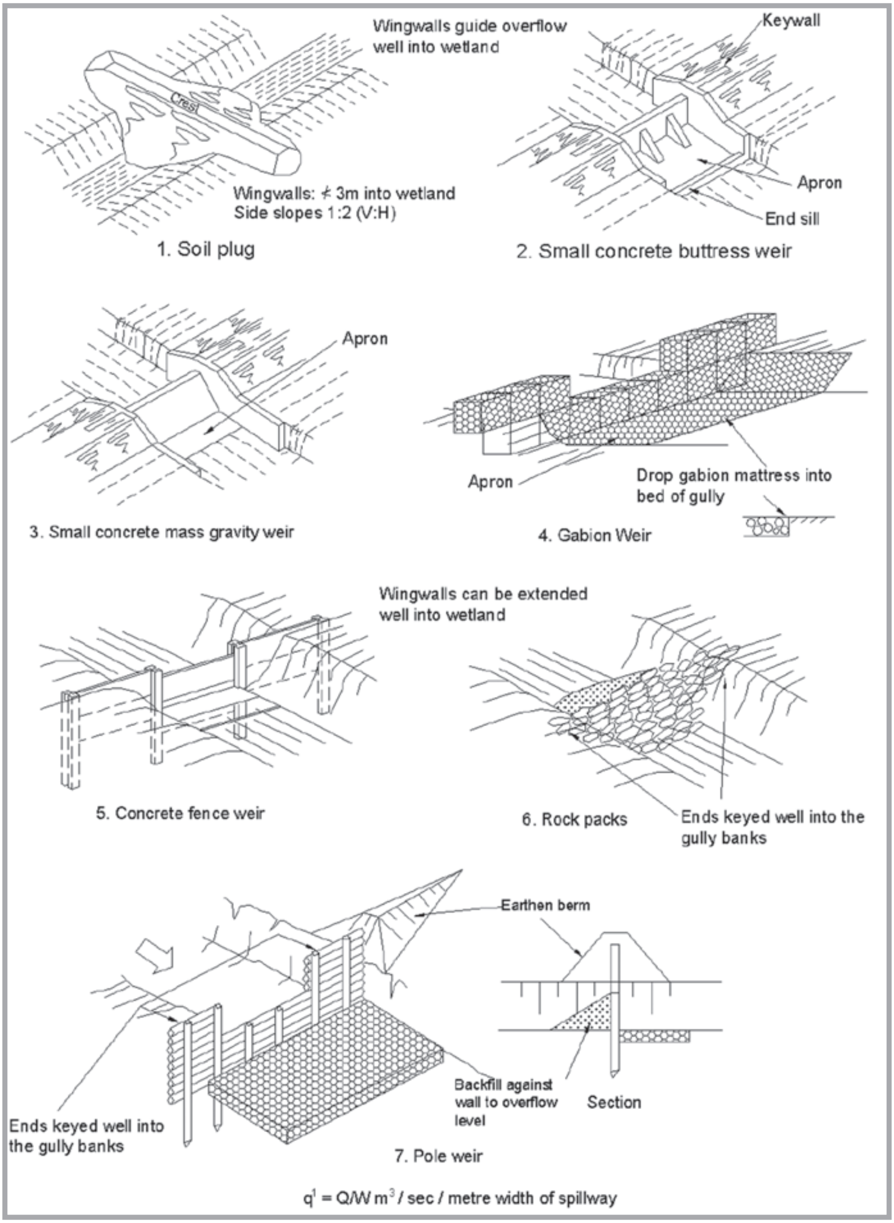


Figure 8.2: Side view showing spacing of structures for zero interference where only water will be stored

Soil plugs, correctly constructed, require first the removal of all sediment, vegetation and roots from the base area, the same in the borrow area, and then firm tamping to create a solid structure. This can be fairly expensive in terms of the cost of hand labour. They also, by their very nature, push all of the runoff into the wetland, often robbing lower plugs of much needed moisture. Smaller concrete or gabion weirs with a central overflow will allow some of the runoff to pass on to lower-lying structures and will provide a better spread of water. A range of structures suitable for blocking drains and minor gully is shown in Figure 8.3.

No matter how small the weir type structure is, and just as for the larger structures, they all need adequate toe protection. The roller of the hydraulic jump on the downstream side of the overpass spillway will cause a scour hole that may make the weir unstable.

The topsoil in wetlands often comprises peat, or what is termed, in soil classification, Organic A soil horizons. These soils comprise largely organic



[1] i.e. q = Q/W m^3/sec/metre width of spillway

Figure 8.3: Various types of structures that may be used to block drains and minor gullies with q[1] < 0.1 m^3/s/metre

materials that collapse on drying out, and are also not easily compacted during the construction process. Vertic A-horizons which are black and clayey, and charactrised by large cracks with very shiny faces along the cracks are also sometimes found in wetland situations, and these are very erodible. They are entirely unsuited as construction materials and should be disregarded for this purpose in favour of (imported) mineral soil plugs, or concrete, rock pack, or gabion structures. This is discussed in more detail in Chapters 19, 21 and 28.

The precautions that do need to be taken include:

- Soil plugs should have shallow side slopes (3:1 H:V or shallower) if domestic cattle graze the wetland.
- Compact the soil firmly during construction of soil plugs, with the soil at optimum moisture content – see Chapter 27.
- Establish suitable vegetation as soon as the weather allows for plant growth.
- Import mineral soil from elsewhere for soil plugs if the wetland comprises in any way deep organic material. A 2% organic matter content is probably the absolute upper limit for soil as a construction material. A lower content would be preferable.
- Keep grazing animals out of the recuperating area while restoration or rehabilitation is taking place.

8.2 Cambered beds

Cambered beds, aka. ridge and furrow, are a series of broad beds constructed at a gradient, with intervening ditches between them, built by farmers to promote drainage in wet areas. The beds themselves are raised above original ground level in order to shed excessive water, while the ditches in between intercept the water and carry it away to a disposal point. In this way crops that are not tolerant of poor drainage are grown on the beds. There are two basic methods of restoring wetlands that have been destroyed by this ridge and furrow method.

- **Total restoration of the ground surface:** Using the furrows as a starting point, plough clockwise around them to the middle of both adjacent beds, using a share-type (e.g. disc) plough. Repeating this a number of times, and preferably using as much speed as possible, the soil in the beds will be moved towards and into the furrows (Figure 8.4, option 1). The furrows will eventually be filled in and the beds broken down. The disadvantage to this method is that the rigorous earthwork would have destroyed any wetland plants that had colonised the area since the agricultural operations of the past. On the other hand, the subsequent planting up could then concentrate on suitable wetland species, possibly making for a swifter return to true wetland conditions. This technique does not lend itself to hand labour, but with mechanisation can be very cost-effective.

- **Tied ridges:** Tied ridges involves building cross berms or soil plugs in the ditches between the beds in order to dam up the water that flows away between them (Figure 8.4, option 2). If the abandonment of the land had allowed an appreciable amount of suitable wetland species to colonise the area, it would possibly be better to try and convert the land back to wetland with the minimum of disturbance to the vegetation present. In this instance the furrows could be blocked with soil plugs or other small structures. It has also been successfully done using a tractor pulling a dam scoop. Soil is scooped up behind the tractor as it travels in the furrow between the beds. At intervals of 10 to 20 metres the scoop is upended to drop the soil collected and the tractor carries on. In this instance the soil is dumped loose, and the driver must ensure that he has dumped extra soil to allow for settlement.

The downside of this option is that:

- The original natural flow pattern of the wetland has not necessarily been regained. The furrows may have been aligned at an angle to the slope of the land, making future maintenance potentially problematic.
- Any catchment water should be diverted away from the rehabilitating area, otherwise large scale damage to the ties could be caused during flooding.

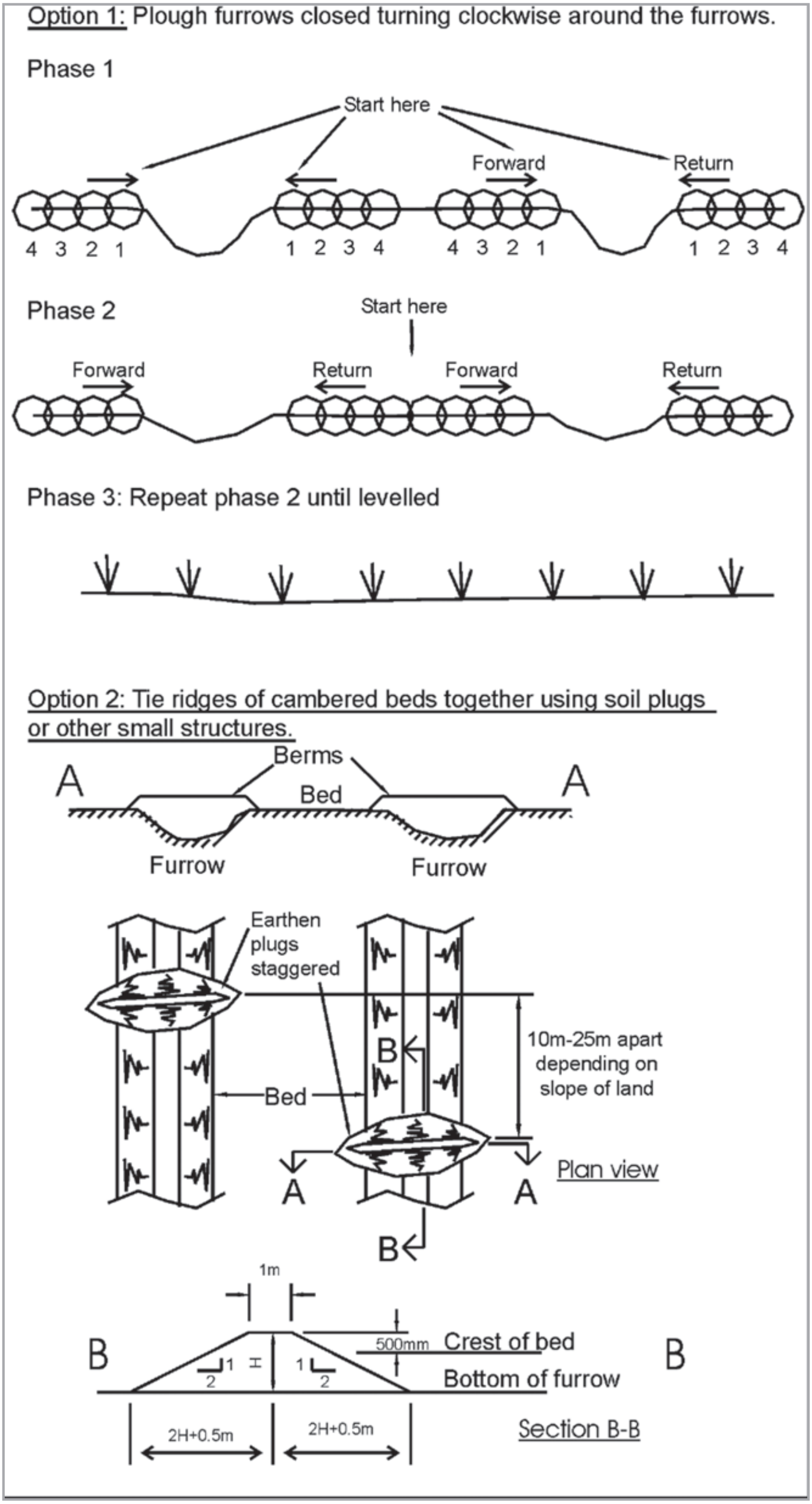


Figure 8.4: Remedial measures in a cambered bed situation.

8.3 Minor gullies

In this context, minor gullies are those that are not more than 1.5 m in depth, and have a maximum catchment area size of 5 ha. If the objectives do not require total restoration the first consideration would be to test the channel against Manning's Equation (see Chapter 17, where a critical design velocity is used to determine slope and roughness of the channel). The idea would be to determine whether bio-engineering alone or in combination with sloping of the banks plus partial in-filling of the channel would not possibly solve the problem in an easier and more cost-effective manner. If by planting suitable vegetation (with or without sloping the banks) stabilisation will be achieved. This will be the route to follow, as long as the set objectives allow for continued concentration of at least a part of the runoff in the wetland. If, by planting suitable vegetation, the velocity is reduced, flow depth will build up and flood peaks may spread out over the wetland. This consideration applies equally to drainage ditches and cambered beds.

When building earthen embankments or if using soil plugs to rehabilitate minor gullies, it is essential to slope the vertical sides of ditches and gullies, where the structures are to be built, to at least 1:1 but preferably to 1:2 h:v) (see Chapter 7 for sloping). The length of the sloped section must cover the entire base area of the structure. If this is not done a firm join will not be achieved between the vertical face and the compacted soil, and stored water WILL find its way through the embankment at the interface between the gully profile and the added soil. This could lead to failure of the structure through tunnel erosion at the point of seepage, especially if the soil is dispersive (see Chapter 28). Figure 8.5 has relevance.

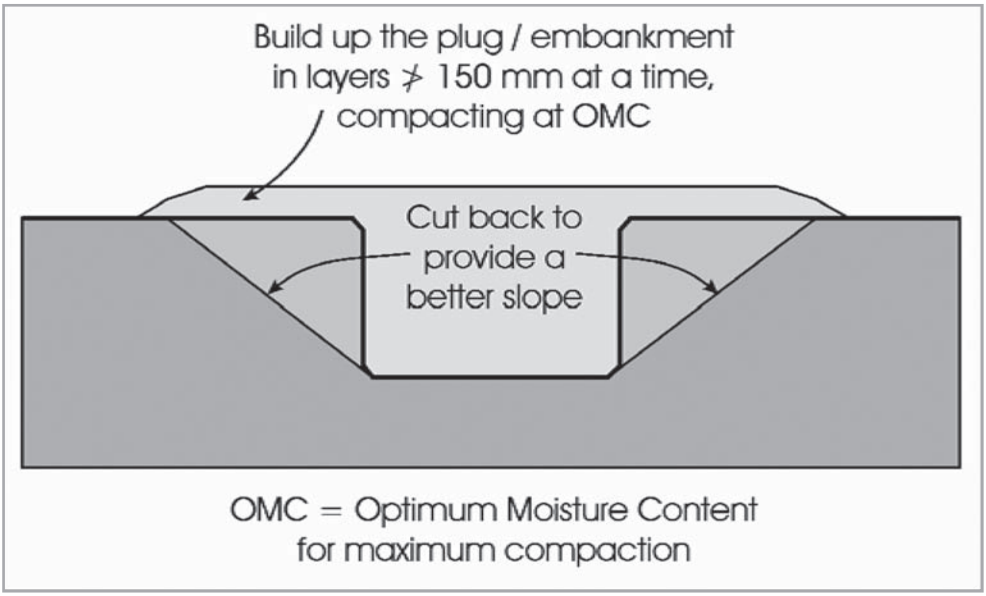


Figure 8.5: Sloping vertical banks before building plugs in order to guard against damaging seepage. (See Figure 28.3 for a description on how to judge optimum moisture content (OMC)).

The plug/embankment should be compacted in layers. The maximum thickness of soil that can be satisfactorily compacted by hand is 100 mm. For mechanical compaction the best layer thickness is 150 mm. Avoid using vibrating rollers in the proximity of saturated soils. Plate compactors are useless on clay soils. Hydraulic compaction (i.e. hoping the soil will compact itself if saturated) is also useless with clayey soils.If there is any doubt about the contact between the natural soil and the fill, form a sand drain over the downstream half of the area using a 150 mm thick blanket of clean sand (Figure 8.6).

If mechanical structures are deemed necessary, the sketches in Figure 8.3 should be considered. Note that only rock masonry and concrete structures may be considered as permanent. However, they will be no greater than 1.0 metre in height and in a relatively small catchment with low flood peaks. Their stability should therefore only be required for a short period of time before the vegetation that was planted as part of the rehabilitation takes over the task of stabilising the gully. More detail on these structures is given in Chapter 21.

It should be noted that it is sometimes feasible to plan these structures without building the overflow section right up to original ground level, but that the shoulders are at or above ground level. This is to ensure, for example, that the floodwaters only pass through the structures, and not around them, until vegetation has taken over and started to choke the channel. Choking of the spillway will then push runoff out into the wetland. In other instances, and depending upon the objectives, the spillway of the structures may be sited at original ground level if the objective is to push all flood water into the wetland. In this instance wing walls and/or spreader canals (Chapter 20) could then be excavated into the wetland to promote the diversion of the runoff well into the wetland, thus speeding up the process of restoring the natural vegetation through the wider distribution of extra moisture.

It should also be noted that in all cases the part of the shoulders that are termed keywalls are always dug well into the adjacent gully banks to ensure that water does not seep around the structures through the soil profile. Should this indeed happen, it is probable that subterranean erosion will cause their collapse. For this reason it is always advisable to fill in behind these structures with firmly compacted soils. The critical areas are the points where the key walls enter the gully banks. Fill the downstream side with clean sand to form a filter and trap any soil particles that are washed out of the leaky joint upstream (Figure 8.6).

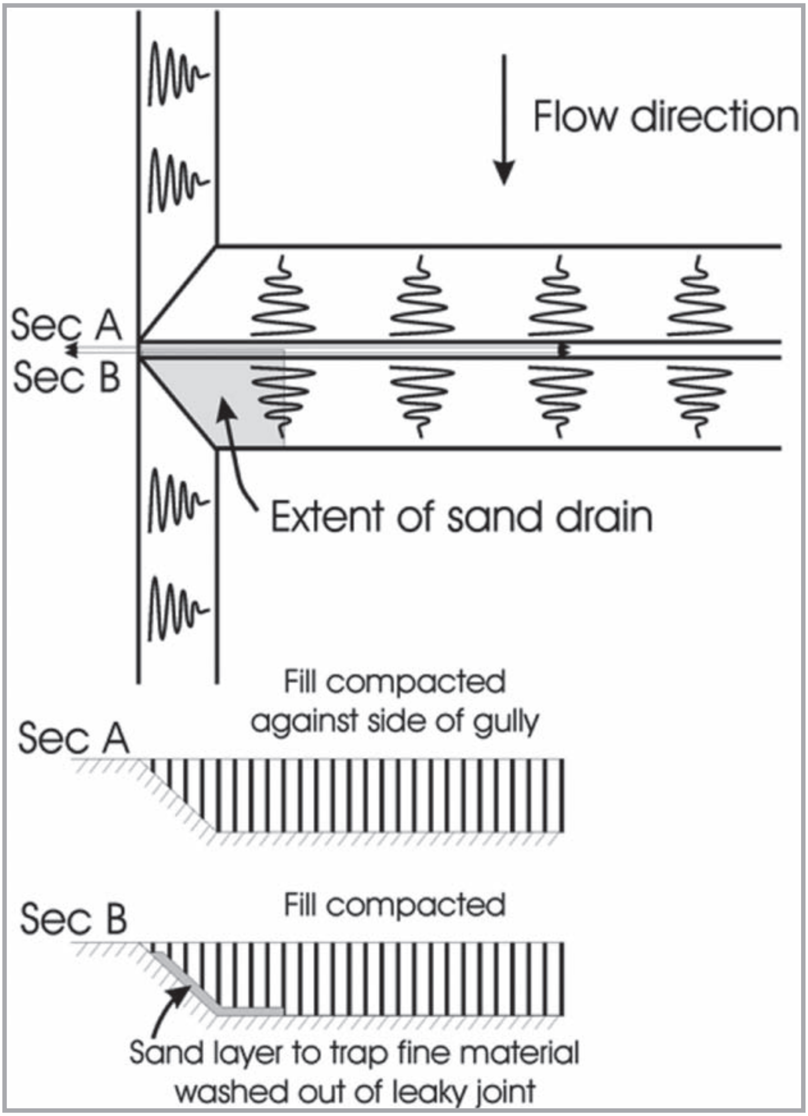


Figure 8.6: Use of a sand drain at the contact between the soil and the fill

CHAPTER 9:
STABILISING AND REHABILITATING MAJOR GULLIES

For the purposes of this manual, major gullies may be considered to be those exceeding 1.5 metres in depth and/or with catchment areas exceeding 25 ha in extent in natural catchments or 5 ha in urban catchments. There is therefore a considerable volume of floodwater that can be expected to flow through them at various times; velocities are high; there is generally a fairly large diversion of water away from the wetland and into the gully; and erosion in the gully may be excessive. Because of the larger catchment areas, there is usually a moderate to high sediment load in the floodwaters entering the gully as well. The structures that will be built in these gullies will need to be designed not only to reduce the velocity of the flood, but to push a portion (or all of the flood, depending upon the objective) into the wetland. It may also need to be able to pass a portion of the flood through or over them without causing damage. It may be required to apportion the basal flow as well – allowing some of the basal flow to continue down the gully while the rest is used to re-wet what was a permanently wet wetland. These considerations will all depend upon the set of objectives that have been decided upon for the rehabilitation work.

While these are typically the types of structures that are coded Levels 2 and 3, and which should therefore be designed by a person with more experience (as indicated in Chapter 16), these structures can also be used in Level 1 conditions. In using concrete and not earthwork for Level 1 structures for instance, although more costly, there will be less maintenance required. The designs in Chapters 21 and 22 and Appendix 3 will therefore apply equally to Levels 1 to 3. With larger floodwaters expected from Level 2 and 3 catchment sizes (500 ha plus) however, extra conditions may apply that are not necessarily catered for in this manual.

The structures may comprise: (see Chapters 19 to 22 for details on design of structures)

- **Earthen berms**, with or without pipe spillways (Figure 9.1). These structures are used to divert storm runoff water into the wetland. They would normally allow at least a portion of the base flow to continue down the gully. They would not normally be recommended in situations where large amounts of sediment occur in the floodwaters, or where the soil is unstable and erodible. One does not wish to divert sediment into an area where rehabilitation with vegetation is required, as it will tend to smother and kill off the plant growth.
- **Weirs** of concrete, rock masonry, or rock-filled gabion baskets (Figures. 9.2 and 9.3). These are typically used to stop head cuts eroding upstream. They are placed either at the face of the gully head, or lower downstream in order to flood back to the problem. In the latter case they are then also used to protect the gully banks where they are threatened, and/or to recharge the soil profile with moisture along the stretch of gully that is backfilled with runoff. The height of the structure and spillway may be lifted or lowered to either push all of the runoff into the wetland, or to allow only smaller amounts of the floodwaters to overflow, depending on the objective. They are the safer alternative to earthen embankments, especially where heavily sediment-laden runoff is found. As sediment builds up behind a structure, it will start interfering with the functioning of the spillway. Having a central, overflow

spillway, velocities are higher and this will tend to keep the spillway clear of sediment build-up. In fact, with judicious planting of suitable vegetation in the sediment deposited behind these structures, the effect of the structure can be extended well above and beyond its spillway elevation. The option shown in Figure 9.3 will not only decrease the height of freeboard, but the keywalls will assist in guiding overflow into the adjacent wetland.

- **Chutes** of sodded grass, concrete, concrete cellular mattresses, and gabion mattresses (Figure 9.4). These structures are generally used to stabilise head-cuts, and for use as spillways for earthen structures, discharging overflow directly back into the gully.
- **Energy dissipators** are structures designed to reduce runoff velocity at the lower end of chutes, weirs and culverts.

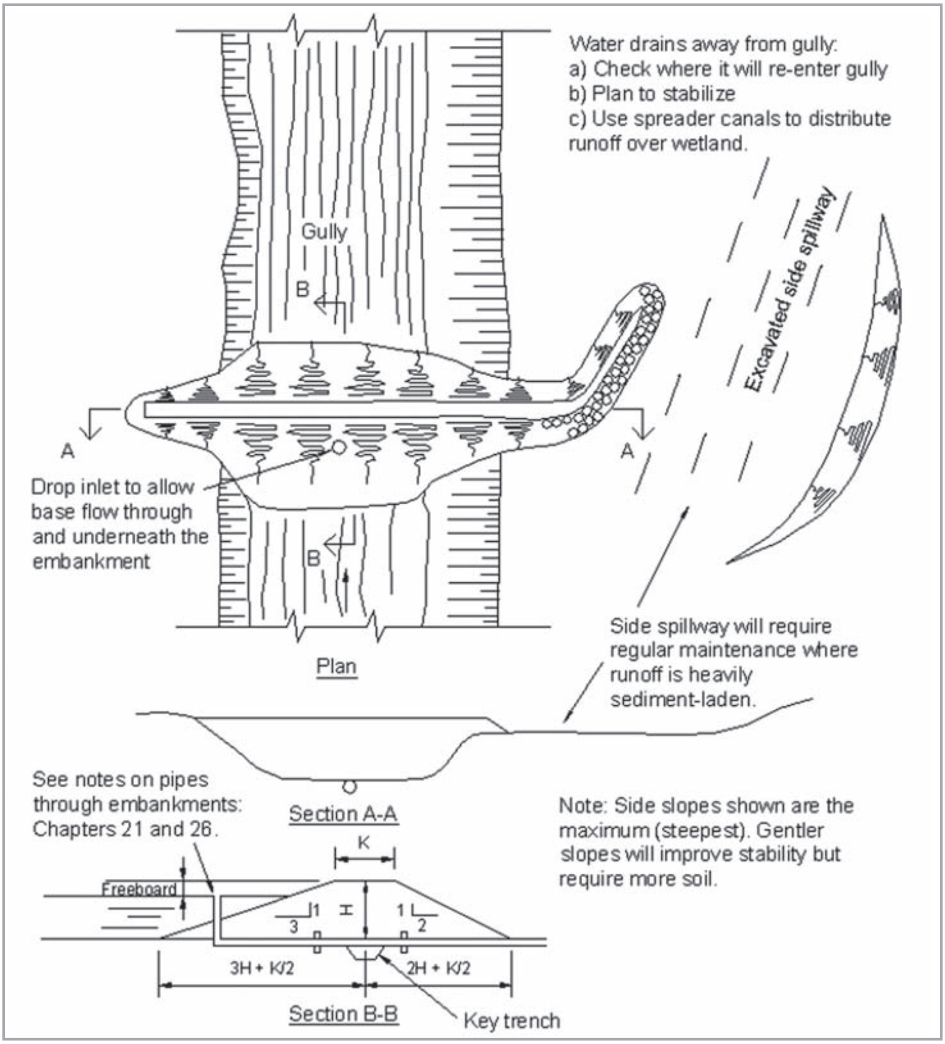


Figure 9.1: Earthen embankment as a diversion structure with both a pipe and a bypass spillway

It should be obvious from the above that the technique in placing larger structures is very similar to that when dealing with smaller gullies and drains. The structures themselves are larger; they have to withstand greater flood peaks, and are therefore of a more permanent nature, being designed for at least a 1 in 20 year flood event. Typical building is in concrete, and to a lesser extent, gabions.

The choice of structure type, its construction material and design are dependent firstly on the set objective of the project, secondly on the availability or otherwise of good, solid and strong foundations (i.e. solid rock), and thirdly on economics. It is also influenced by the size of the flood peak, and to a lesser extent on the availability of suitable local building material. Lack of rock formations can be solved by laying a specially designed raft of reinforced concrete.

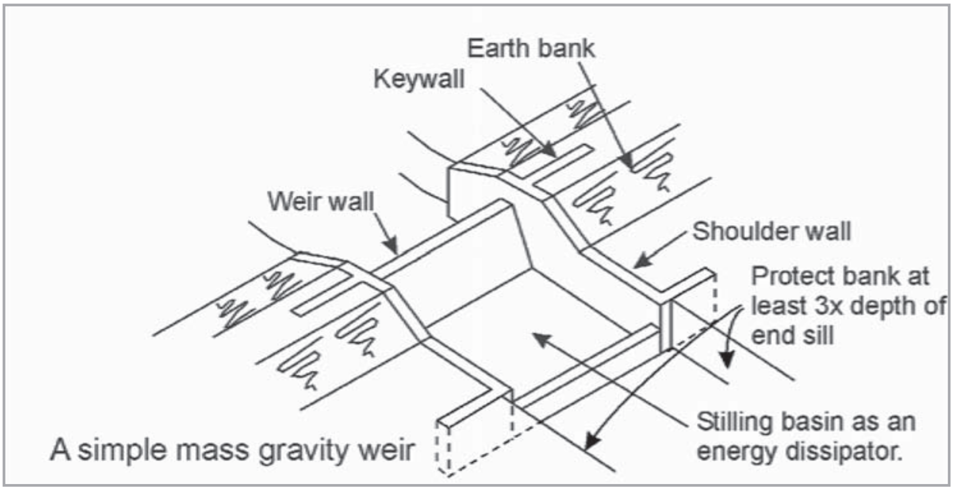


Figure 9.2: Isometric view of a weir with central overflow spillway

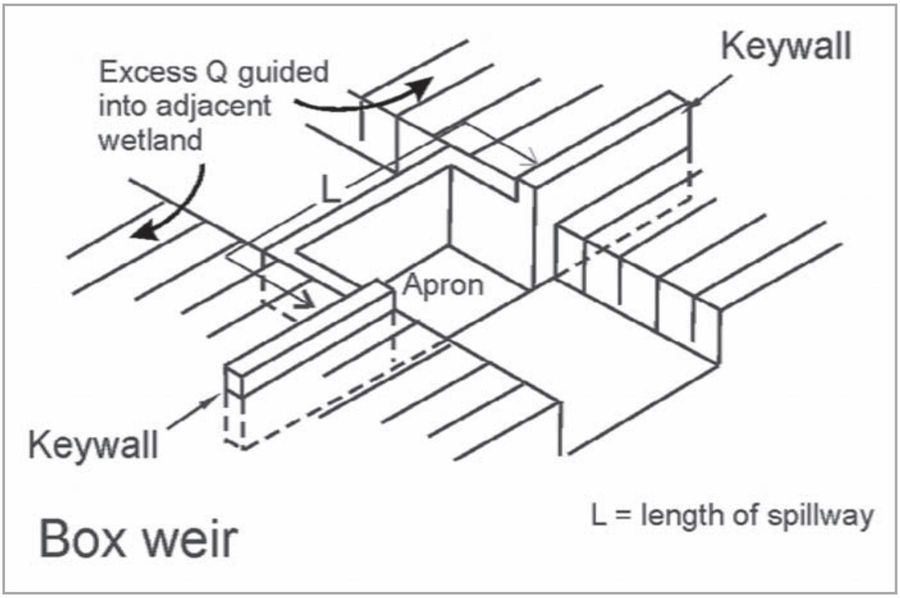


Figure 9.3: Box weir: A method of increasing the spillway length in order to reduce flow depth through the spillway

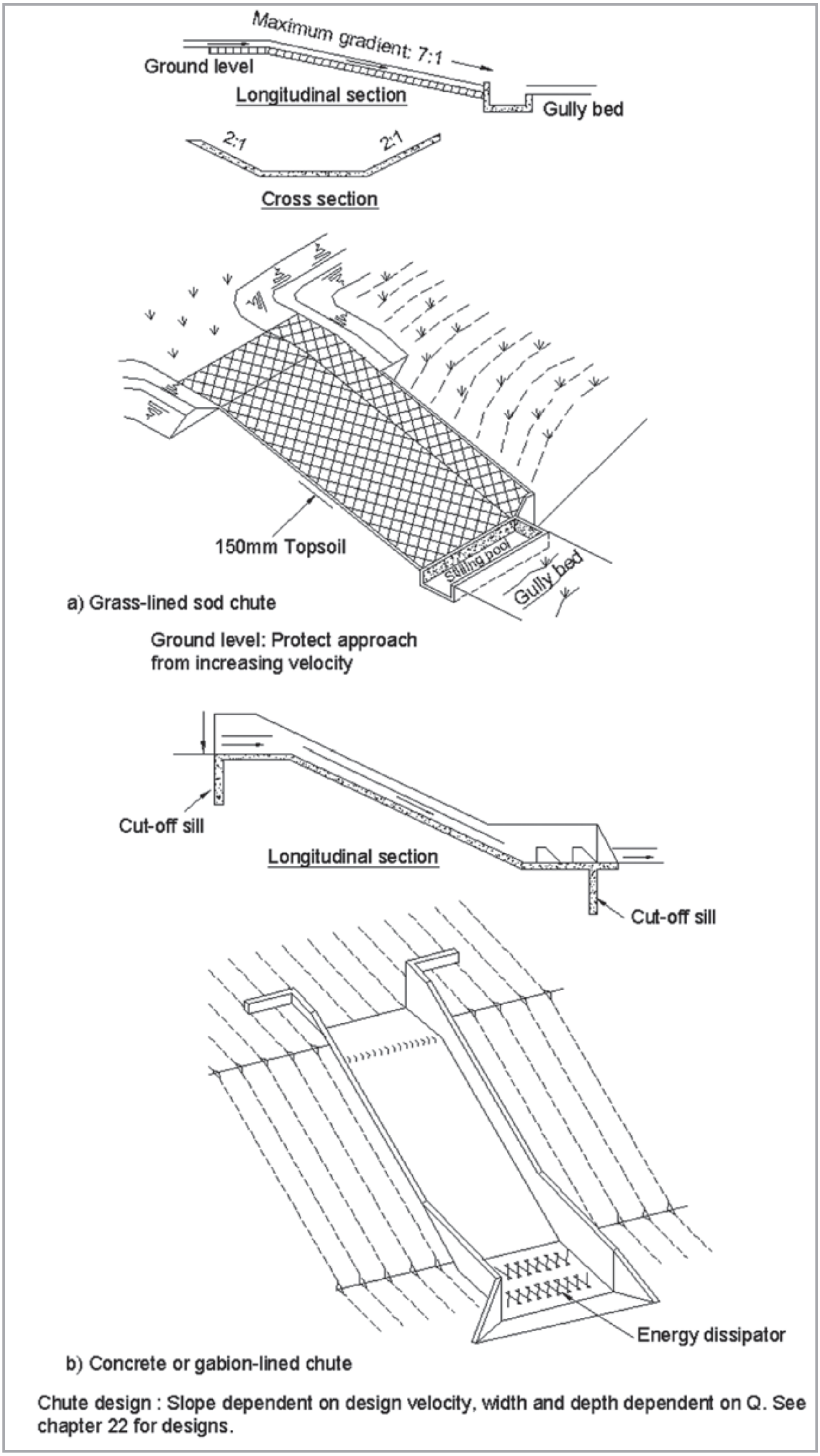


Figure 9.4: Isometric view of chutes (see Chapter 22 for designs)

CHAPTER 10:
REHABILITATION OF DEGRADED PEAT DEPOSITS

Peat deposits become degraded due to a number of factors. These include:

- the advance of erosion gullies into the peat deposit
- the presence of ditches that were dug in an effort to drain the deposit for agricultural and other purposes
- the active mining of the deposits
- the planting to timber.

The extremely valuable contribution that peat deposits make to the environment (especially in regard to the water conservation aspect) makes the rehabilitation thereof a very important conservation consideration. The various methods of rehabilitation relate fairly directly to the manner in which they have degraded, and these are discussed in that order below. The control of minor gullies and drainage ditches, as well as major erosion gullies, is dealt with in detail in chapters 8 and 9, and will therefore not be repeated here.It is important to remember that plugs may not be made of peat. Any structure built into a drain or gully must extend downward into mineral subsoil or onto rock, otherwise subsurface movement of water through the peat will undermine the structure. Similarly, it will not be satisfactory to key structures into peat banks. Mineral soil will have to be packed around any solid surfaces.

Peatlands that have been partially mined and then abandoned need stabilisation in order to reduce the excessive amount of moisture that escapes through seepage out of the cut face. If this is not done the peat gradually degrades as it dries out from the edges. Die-back of the vegetation on the surface occurs as a result of drought conditions in the profile, and further degradation occurs when (not if) the dry peat catches fire. Gully erosion of the cut face will also occur, especially if there is a gradient towards the workings. The purpose of rehabilitation is therefore to keep the water table in place and to ensure that erosion of the cut face does not occur.

Figure 10.1 illustrates the various actions that need to be instituted. The only foolproof method of stopping lateral movement of subsurface water is to install a waterproof membrane as close as possible to the cut face of the peat. A trench is dug into the undisturbed peat and parallel to the cut face, deep enough to penetrate the underlying clay. It should be excavated approximately 5 m from the cut face. A 500 or 750 micron polyethylene film is laid on the inward side of the trench, which is then filled with a mineral soil to hold the polyethylene film in place. A geosynthetic clay liner such as Bentofix or similar material could also be considered, or simply using bentorite in the backfill to create a waterproof plug. This material is either imported from outside the peat deposit, or excavated en situ in the mined section of the peat deposit. The area excavated could be fashioned into a wildlife pond (see Chapter 23 for details on this).

The cut face must now be protected. Slope it to a 1:3 grade, cover it with a 1m thick blanket of mineral soil, and stabilize the slope with suitable vegetation. This will be suitable as long as there is no indication that excessive amounts of runoff is concentrating on any part of the cut face. If this is not so and the face has been badly damaged in parts by gully erosion it will be necessary to stop this water from exiting in a random fashion.

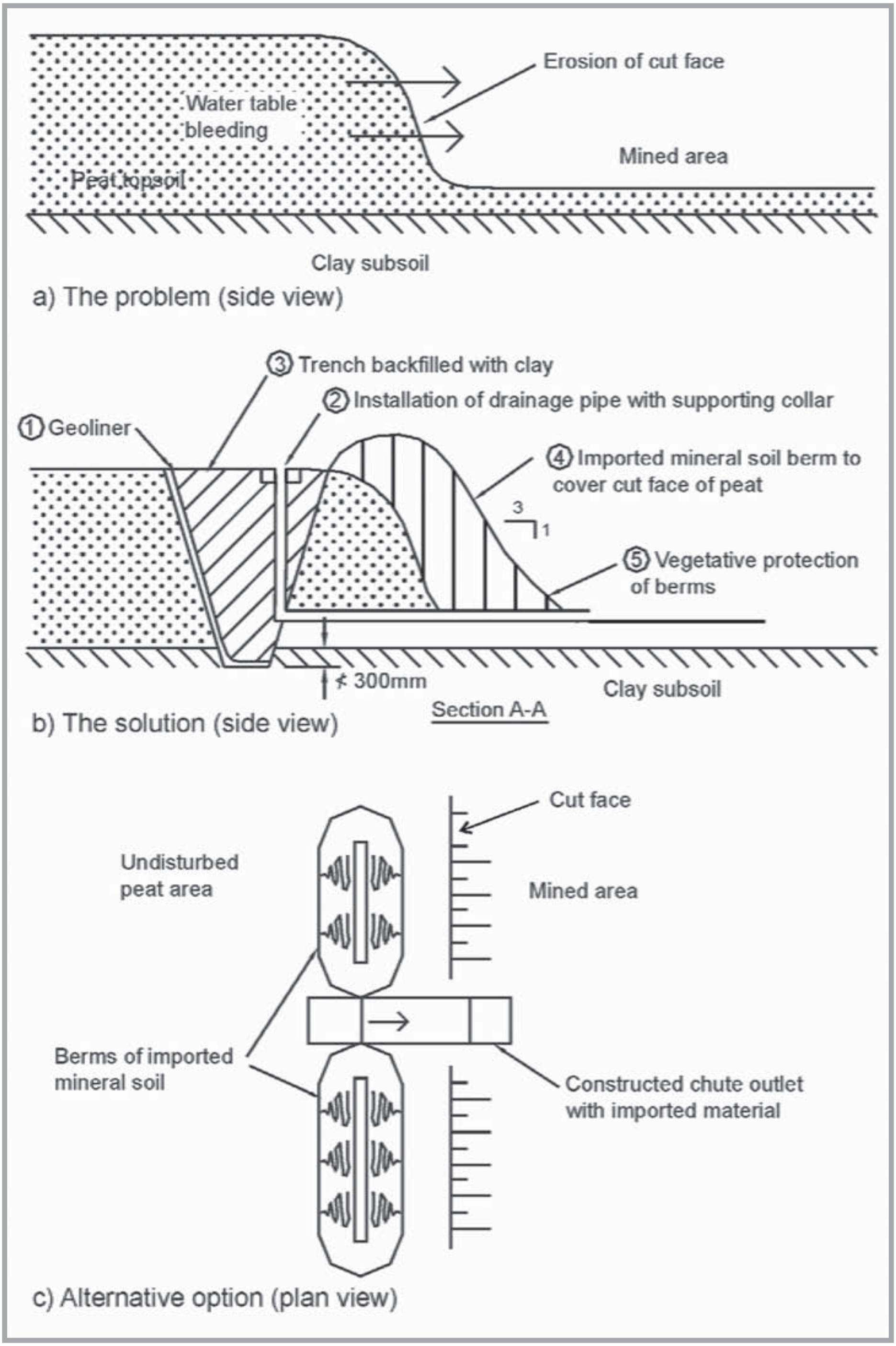


Figure 10.1: Stabilizing a cut face in a partially mined peat deposit

CHAPTER 11:
CHOOSING THE CORRECT TYPE OF STRUCTURE FOR THE SITUATION

There is a fairly wide range of types of structures (as well as construction materials with which they can be built) that may be chosen for a specific rehabilitation project, and a number of them could be suitable for a specific task. It is therefore necessary that the planner be aware of the advantages and disadvantages of each type of structure, and the different materials that can be used, before he or she starts working on a chosen design (Table 11.1).

Table 11.1: Typical solutions to erosion problems, with advantages and disadvantages of each

Solution	Advantages	Disadvantages
1. Fill in the ditch / minor gully with soil	1. Permanent solution 2. Rapid construction with machinery 3. Natural flow pattern is normally regained 4. Water table level rapidly lifted 5. Little / no maintenance needed	1. Expensive construction with hand labour, but cost-effective with selected machinery 2. Seldom compacted properly by hand labour, even with good supervision 3. Problem of sourcing suitable material and the rehabilitation that is required on the site where the soil is mined. 4. Extensive replanting is required when carried out with machinery
2. Plugs in gullies and drains: 2.1. Earthen	1. Labour-intensive construction 2. Less disturbance in wetland when built by hand	1. Damage by stock, runoff water and gravity, unless properly protected 2. High maintenance requirement 3. Seldom compacted properly 4. Base flow is automatically directed into the adjacent wetland unless special provisions are made to pipe it through the structure 5. Suitable soil for construction is sometimes lacking
2.2. Rock packs (Height of structure H < 1.2 m, Height (depth) of overflow h < 150 mm)	1. Labour-intensive construction 2. Vegetation may colonise the structure and mask it	1. Damage by stock, water and gravity 2. Difficult to repair properly 3. Pervious structure – little damming effect 4. Not easy to build properly 5. Difficult to key into banks 6. Fair disturbance in wetland 7. High maintenance requirement 8. Not recommended
2.3 Timber or concrete panel weirs (H < 1.0 m, h < 150 mm	1. Labour-intensive 2. Less damage in wetland 3. Cost effective when catchment area is small 4. Rapid construction	1. Damage by grazing animals 2. Degree of maintenance required 3. Only suitable in small gullies and drains, with low flood peaks 4. Visible while new, although they can be painted (brown not green)
2.4 Gabion Weirs H < 3 m	1. Labour-intensive construction 2. Semi-permanent structure 3. Relatively simple construction 4. Not easily damaged by animals 5. Low maintenance until rust starts; then high maintenance. PVC coated product where water corrosive 6. Vegetation masks and stabilises the structure	1. Special precautions to seal water off 2. Standard sizes make it difficult to fit 3. Corrosive water a problem 4. Moderate disturbance in the wetland during construction 5. Relatively expensive 6. Theft of wire casing a real problem

2.5. Concrete weirs	1. Labour-intensive construction 2. Permanent structure 3. Full control of water level 4. Relatively inexpensive 5. Can take any shape required 6. Low maintenance 7. Teaches a marketable skill	1. Semi-skilled labour is required 2. Mixing of concrete in the wetland is undesirable 3. Transporting mixed concrete into the wetland is problematic 4. Moderate local disturbance in wetland during construction 5. Visible while new – can be painted (brown not green)
3.Diversions: 3.1.Earthen	1. Labour-intensive construction, but heavy work 2. Easy construction with machinery 3. Basal flow and storm flow can be separated by installing a drop inlet, allowing the former to carry on down the channel while all (or part) of the latter is diverted into the adjacent wetland 4. Damaged by stock	1. Causes unnatural change in flow pattern 2. Liable to damage by animals 3. Dispersive soils, moisture content during compaction are problems 4. High maintenance in arid areas 5. Expensive if covered in gravel/ concrete 6. Construction with hand labour can be difficult and expensive – need to ensure bond with *en situ* soil 7. Return-to-stream could be a problem
3.2. Gabions	1. Labour-intensive construction 2. Not easily damaged by animals 3. Simple construction 4. Semi-permanent	1. Expensive 2. Theft of wire casing 3. Return-to-stream could be a problem
3.3 Concrete	1. Labour-intensive construction 2. Permanent 3. Low maintenance 4. Ease of construction 5. Teaches a marketable skill	1. Expensive 2. Return-to-stream could be a problem
4. Chutes 4.1 Grass or rock lined (V £ 2 m/sec)	1. Labour intensive construction 2. Relatively inexpensive on small catchments and in high rainfall areas.	1. Requires regular maintenance 2. Not suitable where base flow is present 3. Not suitable where soil is erodible 4. Not suitable in a cut-and-fill situation – must be in cut only 5. Not suitable in low rainfall areas
4.2. Gabion * V < 3 m/sec	1. Labour intensive construction. 2. Semi-permanent 3. Relatively low maintenance	1. Need to reduce velocity at outlet 2. Not suitable where soil is erodible 3. Separating base and storm flow is difficult 4. Not suitable where water is corrosive 5. Not suitable in a cut-and-fill situation 6. Rocks must be expertly and tightly packed to ensure they do not slide 7. Liable to under-cutting if counter-provision not catered for in design
4.3 Concrete *May be either solid steel re-inforced construction(V £10 m/s), or un-reinforced but using either geocell pockets (V £ 4 m/s), or Armorflex blocks (V £ 4 m/s)	1. Labour intensive construction 2. Permanent 3. Minimum maintenance 4. Relatively simple construction 5. Teaches a marketable skill	1. Need to reduce velocity at outlet 2. Not suitable in a cut-and-fill situation. 3. Need to provide drainage if of solid construction 4. Separating base and storm flow difficult 5. Relatively expensive 6. Liable to under-cutting if counter-provision not catered for in design

*Note: Chutes designed for V > 3 m/s must be considered Level 3 structures – see Chapter 16.

As a general rule the above maximum velocities are recommended for given applications. They may be given in the product literature for laboratory conditions but generally do not work in reality. Anything with V>4 m/s needs engineering design (level 3 structure-see chapter 16). Remember that the stagnation uplift pressure associated with V=4 m/s=0.8 m level of water is sufficient to lift 0,3 m of concrete.

CHAPTER 12:
FISHWAYS

Fishways, also known as fish ladders, are broadly defined as any natural or artificial device that enables fish and other aquatic organisms to overcome structures in streams and rivers that obstruct their natural migrations. Both the Environment Conservation Act (1989), and the National Water Act (1998), carry the stipulation that appropriate mitigation measures (such as fishways) are required wherever in-stream structures obstruct the natural migration of indigenous aquatic species. Although emphasis is on the effect of a barrier in rivers, the effect that even small barriers can have on smaller streams should not be discounted. Weirs, chutes and diversions that are built in wetlands in order to rehabilitate them, and where important biota migrate, should therefore also require a properly designed facility to allow them to pass either through, over, or around the structure, especially where rare and/or endangered species are found.

A recent Water Research Commission publication *Guidelines for the planning, design and operation of fishways in South Africa* (Bok A, Roussouw J and Rooseboom A; WRC Report No. 1270/2/04), provides the latest available local information on the subject. This section, as well as the design detail (dealt with later), is a summary of the bulletin mentioned, with occasional references to the situation as it will pertain to Working for Wetlands and its modus operandi. While the said bulletin covers a wide range of situations, only those pertinent to typical Working for Wetland situations are dealt with here.

There are three basic types of fishways considered by the authors to be suitable for South African conditions. They are illustrated in Figures 12.1-12.8 below.

Space does not allow of the detailed background to the information given here, but those interested may acquire a copy free of charge from the WRC office in Pretoria. It is suggested that at least the Technical Advisers of Working for Wetlands should acquire a copy for general use and understanding. What follows is the basics of investigations required for the collection of data that will be required for the choice of type of fishway, and the manner in which the dimensions of said structure may be developed.

Figure 12.1: Notched weir fishway under construction – Komatipoort

Figure 12.2: Notched weir fishway – Komatipoort

Figure 12.3: Pool and slot fishway – KNP

Figure 12.41: Bypass Rockramp fishway – KNP

Figure 12.5: Pool and weir fishway – Sabie River

Figure 12.6: Pre-barrage – Olifants River

Figure 12.7: Haga-Haga river pool and sloping weir fishway designed for small fish (<120 mm long)

Figure 12.8: Close up of sloping weir of the Nhlabane pool and weir fishway at low flows, looking upstream

12.1 Establishing the need for a fishway

The first step in investigating the potential barrier effect of a proposed rehabilitation structure is to study the feasibility of the proposed structure, the site characteristics, as well as the data available on the aquatic species present in the stream/gully under consideration. Tables 12.1 to 12.8 below indicate the procedures for accumulating data that will enable the correct design of the most suitable fishway for the specific site.

1. For a fishway to be effective, the timing of hydrological events (i.e. runoff events) needs to coincide with the migration urge. For upstream spawning this is critical; for dispersal of juveniles it is not so critical. If, therefore, and because of a degraded catchment the runoff events are very erratic and heavily sediment-laden, the chances are that a fishway would not be effective in a spawning scenario. Alternatively there may be no migratory species in the stream, or it may consist solely of eels that do not need a sophisticated fishway to move up- or downstream. The site-specific information necessary will have to be obtained from local experts – e.g. museums, academic institutions, or the provincial nature conservation authorities.
2. This question is only of importance to obstructions higher than 10 m where a fishway is required for biota migrating downstream and may be killed when attempting to negotiate a high waterfall out of the spillway.
3. There may be no (or minimal) suitable habitat present upstream; high dams (without fishways) or waterfalls are serious obstructions to fish movement.
4. The structure to be implemented may assist in keeping out undesirable alien biota from upstream areas, and this may be of greater environmental benefit than the building of a fishway.
5. The funds required to construct an effective fishway may be prohibitive, it may be impractical to build one on the site chosen for the obstruction, or more cost-effective mitigation measures may be available. The latter could include the construction of artificial spawning beds, the regular capture and transport of species, or the captive breeding and restocking of them.

Table 12.1: Questions for assessing the need for a fishway

Fishway not needed or not feasible	No	Will the structure block the natural migration of any species present in the stream? See point 1 above	Yes	Fishway needed : further evaluation required
	No	Will fish attempting downstream migration over the structure survive a passage through the spillway? See point 2 above	Yes	
	No	Are there accessible and biologically significant habitats upstream of the proposed structure? See point 3 above	Yes	
	Yes	Will alien fish benefit more from the fishway than indigenous species? See point 4 above	No	
	Yes	Are there other more cost-effective mitigation measures more suitable? See point 5 above	No	

12.2 The need for informed decisions regarding the building of a fishway

It is necessary to quantify the benefit that will be derived from the facility in order to make the best use of the funds available. The scoring system in Table 12.2 will assist in the decision-making process.

Table 12.2: Proposed scoring (ranking) scheme to determine the importance of providing a fishway

Criteria	Max. Score	Site Score	Explanation
Socio-economic value of migratory species present	12		Value for food, angling, eco-tourism
Conservation status of migrants present (number of Red Data or threatened species)	12		Taken on a provincial level (4); national level (8); global level (12)
Ecological value of migrants (importance of role in ecosystem functioning)	12		Value in natural food web, e.g. high in reserves
Importance of upstream habitat to migrants	12		Low (4), moderate (8) and high (12)
Proportion of catchment/upstream habitat obstructed	9		<25% (3), 25-50% (6), >50% (9).
Fish habitat integrity of river for migrants (i.e. PES/Management Class)	9		Poor, or Class E/F (3), moderate or Class C/D (6), good, Class A/B (9)
Percentage of stream flows that barrier structure blocks fish passage due to drown-out characteristics of site	8		20-40% (3); 40-60% (5), > 60% (8)
Feasibility of constructing a successful fishway (i. e. confidence of success)	8		Low (3), moderate (5), excellent (8)
Expense of fishway in relation to the ecological benefits	6		High (2), moderate (4), low (6)
Financial and other support from NGOs, government, special interest groups, etc.)	6		Low (2), moderate (4), high (6)
Presence of permanent/natural barriers downstream	6		None (6), rare (4), many (2)
TOTAL SCORE	100		

12.3 Biological data needed to assist in the design of a fishway

The successful design of a fishway is dependent largely on the hydraulic and physical characteristics that cater for all the migrants expected to use it. The biological information required regarding the species expected to use it is listed in Table 12.3 below.

1. Dimensions of the fishway should accommodate both the smallest and the largest fish/aquatic organism targeted. The former in regard to the maximum velocity of water flowing through the fishway, and the latter regarding the minimum volume of water, channel depth and passage width. More on this aspect will be discussed later. The authors are in the process of identifying various Regions in which the same species of migratory fish and other aquatic organisms occur. This will simplify data collection.
2. Observations as to where migrants accumulate in the stream bed, and which stream channels they prefer, will assist in deciding exactly where the entrance to the fishway should be located.
3. Reasons for migration (i.e. spawning or juvenile dispersion) will determine the ecological impact of possible delays at a barrier through lack of sufficient water.

Table 12.3: Biological information on migrants/ target species required

Step	Required Info. on Migratory Species	Action / Explanation
1	Species and size rangepresent at site, or which are thought to migrate within the stream reach	• Refer to Migratory Regions (see below) and existing databases to determine the migratory aquatic spp. expected at site. • Do field surveys of fish populations. • Use available knowledge to determine size range of migratory spp. at site. • See point 1 above.
2	Swimming ability	• Use available data on maximum swimming and jumping ability of the various target spp. See point 1 above.
3	Swimming behaviour and preferences	• Use available data to determine whether target spp. prefer to jump or swim within nappe between pools, or to climb on wetted perimeter (e.g. eels, prawns, etc.). • Observe behaviour at site. See point 2 above.
4	Timing of, and reasons for migration	• Find out months of year when migration occurs. Correlate with stream hydrology. See point 3 above.

12.4 Hydrological and Hydraulic considerations

The fishway should operate effectively over the 'normal' range of streamflows anticipated during the time period when the target species can be expected to undertake their migrations. The upstream (headwater) and downstream (tailwater) water levels at the barrier site over the range of flows during which migration takes place must be established to ensure that the correct type of fishway is constructed. Most important too is the correct design for the type of fish that will use it. The site-specific hydrologic and hydraulic factors required for a design are reviewed in Table 12.4 below. While this could be a problem for the Working for Wetland team, it should be noted that the Design section contains a General Purposes design for sites where very specific details are not available.

1. Tailwater is the height that water builds up on the downstream of a barrier during high flood events. It occurs when water flows away from the downstream side of the structure at a slower rate than it flows through the spillway. The percentages given are those of the times that the phenomenon will occur. If it will occur fewer than 20% of the time the score will be between 0 and 2.
2. While a number of species migrate upstream during high flows, there are some that do so at low flows. This shows how important a careful study of the aquatic biota is, before any designs are carried out.
3. In the context of the relatively small projects in small catchment areas with the expertise available to Working for Wetlands, this may not be feasible. However, if the structure is expected to have a serious impact on the movement of, for example red data species, it should be worthwhile calling in the services of a specialist on the subject.

Table 12.4: Site-specific hydrologic and hydraulic considerations

Requirement	Action / Explanation
Range of flows over which the fishway should function successfully	Undertake an hydrological analysis of the stream at the site to establish: • Mean monthly flows • Daily flows in critical months when migrations of target fish take place. See point 1 above.
Characteristic flow pattern at site	• Determine the characteristics of the flood hydrograph at site, particularly if spawning takes place during high flows. See point 1 below. • Determine characteristics of high and low flows • Determine flood levels to ensure the structure is protected from flood damage • Quantify the change in flow pattern at the site caused by the structure and water use. See point 2 above.
Headwater and tailwater levels	• Undertake hydaulic surveys to determine the head- and tailwater levels over which the fishway will be expected to operate. See point 2 above. • Ensure location and design of exit and entrance (for upstream-migrating fish) of fishway will accommodate the head- and tailwater pool level fluctuations at flows anticipated during the main migration periods.

12.5 Topographical considerations

The physical characteristics of the site could influence the choice of type of fishway that can be constructed, as well as its design. If suitable rock formation for foundation purposes is not available it could increase construction costs considerably. Similarly, if the stream/gully is deeply incised, costs and practicalities could totally preclude fishway types requiring large amounts of space and gently sloping gradients. The on-site information required is summarised in Table 12.5 below.

Table 12.5: The influence of topographic features on fishway design

Topographic Features	**Influence on Fishway Provision and Design**
Presence of rock formations on stream banks	• Rock formation on the riverbank for foundation purposes will reduce costs — however, reinforced concrete floor slabs can overcome the problem at relatively low cost • Rock formation present could be used as the floor of the fishway structure, saving costs • Suitable sloping rock could be used to form natural-type fishways such as rock-ramps
Presence of rock formations in the stream channel	• Location of the fishway entrance is determined by location of natural channels and pools in the streambed downstream of the structure • Construction of a series of low sills downstream of the barrier would facilitate entrance to the fishway. Rock foundations in this area will reduce costs • Low sills or streambed structural alterations could improve tailwater levels, thereby reducing the need for expensive, high-volume fishways
Sufficient space and suitable, gentle gradient on the stream bank.	• Bypass fishway channels with slopes < 1: 20 are often the preferred option, but only if space and gentle slopes allow this

12.6 Choosing the appropriate Fishway Type

There are three basic types of fishways recognized as suitable for South African conditions. The main advantages and disadvantages are highlighted in Table 12.6 below. Bearing in mind that fishways are principally utilized on rivers, and the structures built by Working for Wetlands are generally in minor drainage ways, only the most suitable designs for this situation are explained in Chapter 24.

Table 12.6: Advantages and disadvantages of the three most common fishway types (Refer to Figs 12.1 to 12.8 above)

POOL- AND-WEIR-TYPE	ADVANTAGES
	Effective at passing a large variety of fish species at relatively low flows.
	Can be modified (e.g. notched weirs, wide, sloping weirs) to operate effectively at very low flow rates – down to 4 litres per sec.
	Can be modified to accommodate climbing and crawling spp., as well as very small (<20 mm long) fish. This is achieved by incorporating wide, laterally-sloping weirs within the fishway to provide wide, gently sloping wetted perimeters that can be used for climbing.
	DISADVANTAGES
	Does not operate effectively over a wide range of headwater pool levels, unless special headwater inflow controls are provided.
	Cannot accommodate large discharges, as turbulence levels within pools increase rapidly as flows increase.
	Sediment tends to accumulate in the pools, unless submerged orifices are provided.
VERTICAL SLOT TYPE	ADVANTAGES
	Can operate very effectively over a wide range of headwater pool levels.
	Passes small fish if gently sloped (gradient <1 : 15).
	Can easily accommodate large discharges, as velocity and turbulence do not increase noticeably with increased flows or water depth.
	Slot extends to bottom of the weir, so sediment does not accumulate in the pools.
	DISADVANTAGES
	Does not appear to allow the passage of climbing and crawling species unless the floors are roughened.
	Requires large discharges (>5 litres per sec.) to operate effectively for large spp. due to the large slot required. A slot 185 mm wide on a 1: 12 grade requires 120 l/s to operate effectively.
	Due to the large minimum size of pools and lengths of structures, this type can be relatively expensive when only small fish are targeted.
NATURAL BY-PASS CANALS AND ROCK RAMPS	ADVANTAGES
	Is often the first choice. Should mimic hydraulics in natural rapids and thus provide for a wide variety of spp. and size classes.
	Do not require much maintenance. Are largely self-cleaning.
	Can be aesthetically pleasing and provide 'riffle' pool habitat.
	Can easily be combined with end sill pools to facilitate migrations at high flows.
	DISADVANTAGES
	Feasibility depends almost entirely on the suitability of the topography.
	Requires a relatively large amount of space on the streambank due to gentle slopes of 1 : 20 required.
	May not operate at very low flows (< 5 l/s) where losses are high.

The design and construction procedures of fishways are detailed in Chapter 24.

SECTION 2:
THE DESIGN PROCESS

The concepts of discharge, spillways and wet and dry freeboard have been discussed previously. It is now time to use these concepts in designing the various types of structures that can be used in wetland rehabilitation. The following norms are recommended for all structures built to hold back and to pass, via spillways of whatever kind, runoff water. In order to save space and overcome duplication, some of the sketches that would normally accompany the explanations given are produced in Appendix 3 along with the examples of the designs. Only those needed to clarify certain aspects will be given here.

The design is a compilation of calculations to determine the sizes of all the components of the structure envisaged. In choosing a design, the type and quality of the material to be used must be determined. The result must then be presented in a format that can easily be read by the project manager, who will have been taught how to read it. It will therefore have to be prepared in the form of a report. The report must include sufficient drawings of the structure to enable its construction (see Appendix 3 for examples of such drawings), details of the materials to be ordered, notes on the construction methods to be used, and a Bill of Quantities. The last mentioned is a list of all the quantities of material that will be required, and an estimate of the number of person days needed to complete the projects.

CHAPTER 13:
COMPONENTS OF STRUCTURES RELATED TO CONTROLLING WATER FLOW

13.1 Spillways and spillway design

The concept of spillways

As previously explained, most of the structures to be used in wetland rehabilitation will be required to handle at least a portion of the flood event, if not all of it, without being damaged. The spillway is the component of the structure that carries the prescribed flood either over (as in a weir or chute), through (as in a drop inlet spillway), along (as in a spreader or stormwater canal), or around (a bypass spillway, as in an earthen storage dam) it. Therefore in each of the various structures to be used in wetland rehabilitation, the spillway section is identified and forms an integral part of the design of the structure. If the spillway capacity is insufficient and cannot convey the total expected flood, the structure could be over-topped and will be in danger of being washed away. This is one of the reasons why care must be taken in estimating a suitable discharge (Q) when designing spillways.

Determining elevation (height) of the spillway in the landscape

Deciding on the elevation (height) of the overflow section of the structure is important if the idea is to restore the gully bottom up to original ground level, and especially if there is a large amount of sediment in the flood waters. If the gully upstream of the structure is filled to this level and colonised by vegetation, the chances are that sediment will build up further in the spillway itself. This sediment build up will tend to block the spillway and could cause failure of the structure through over-topping. It could also cause the sediment to move into the adjacent floodplain or wetland with effects damaging to the restoration process. In this instance it is necessary to ensure that the spillway is 'self-cleaning' of sediment. Bearing in mind, however, that the spillway is usually constructed as a relatively wide and flat section, it tends to be one of fairly low velocities. It is therefore subject to sediment deposition. This is another reason why it is necessary to carry out conservation measures in the catchment area as well as addressing the results of the erosion.

In nature, valleys tend to be sculptured to a parabolic-type cross-section, the lowest point coinciding with the stream channel. When floodwaters flow down the stream the lowest point of the channel always carries water flowing at the highest velocity. This tends to keep the channel open. In deciding upon the elevation of the spillway in the situation described in the paragraph above, therefore, the lowest point of the parabola is sought. This lowest point is called the thalweg, named after the geographer who first identified the mechanism. Figure 13.1(a) illustrates the situation. It requires a small topographic survey to fix the elevation required of the spillway. It is repeated, however, that this point is required to fix the maximum elevation option of the spillway only in the case of heavy loads of sediment coming out of the catchment area. Should this be the case, it would be preferable to first carry out conservation measures in the catchment prior to attempting restoration of the wetland.

Alternatively, in many wide and flat floodplains/wetlands the cross section is as illustrated in Figure 13.1(b). Sediment

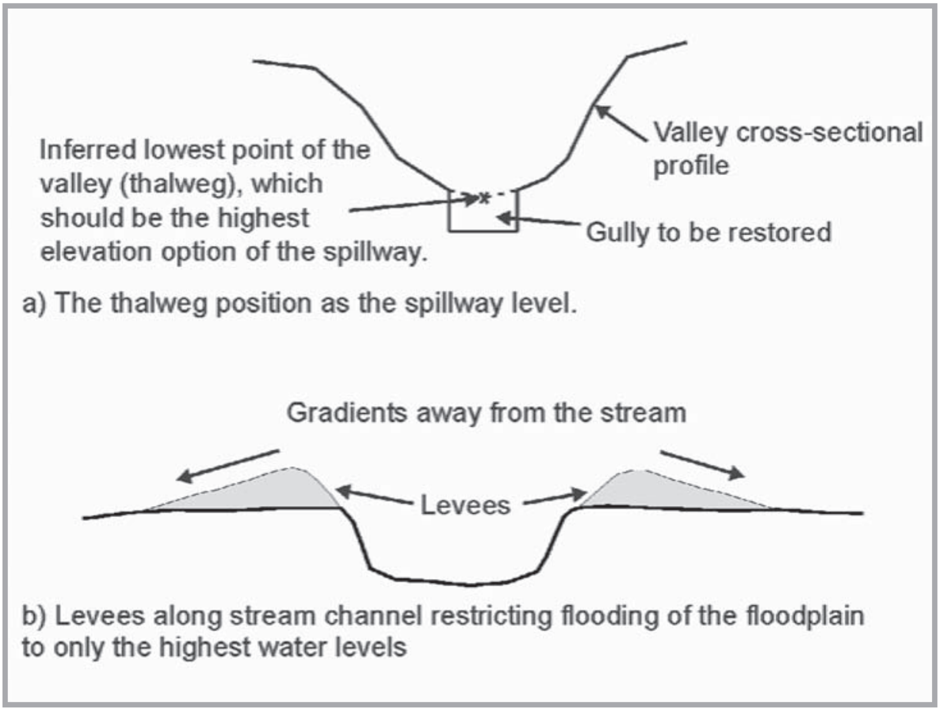


Figure 13.1: Cross-section of a valley showing: (a) required elevation of spillway as determined by inferred elevation of thalweg, and (b) levee formation along channel bank

has deposited as levees on the banks, and there is a reverse gradient away from the stream. The levees are robbing the flats of all but the highest floodpeaks. The levees should be removed, and the material made available for other reclamation/ rehabilitation work.

Spillway design features relating to discharge

The capacity (discharge), as mentioned above, is not the only issue in determining the size of spillway. Many structures that will be used in wetland rehabilitation will rely for their stability on both their mass (to obviate overturning and to overcome or release uplift pressure) and the friction (to stop sliding) that builds up between the base of the structure and the foundation on which it rests. When water builds up behind the structure and above the spillway level, forces are exerted on the structure that will tend to cause it to either overturn or to slide if they are not taken into account. The depth of water flowing over the structure causes part of this force. The deeper the overflow depth the greater the over-turning moment of force will become. This depth of overflow (symbol h) is therefore as much a part of both the spillway design and the structure design, as is the height of the structure. Varying either the depth or the width of the spillway may accommodate discharge over the spillway. It is therefore very important that both the maximum overflow height of the structure, the possible width of spillway, and the Q value be carefully measured and the final (or design) depth of overflow (aka. wet freeboard) is determined (see Figure 13.2).

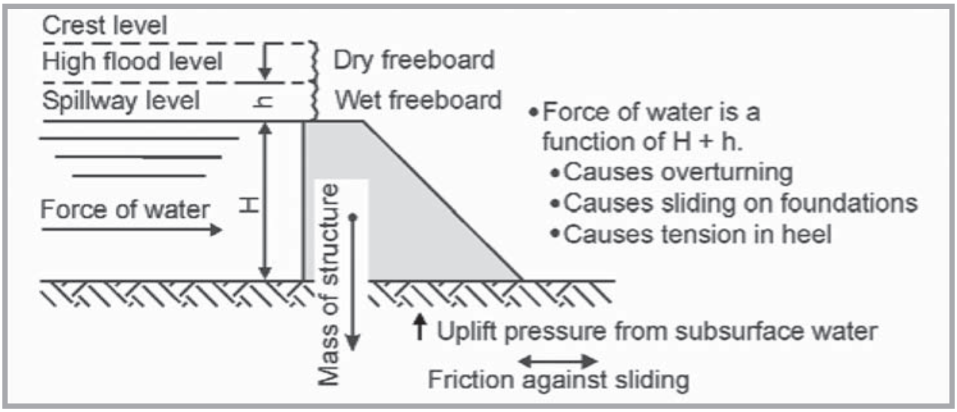


Figure 13.2: Design requirements for stability of a mass gravity structure

A safety factor is generally built into the spillway, so that when it is flowing full the splash through wave action that occurs will not cause over-topping and damage to the structure. Where an earthen embankment forms the major portion of the structure, a further safety problem arises. No matter how well soil is compacted, it generally settles with time, and the depth that water may flow through the spillway before it over-tops the berm, is diminished. When domestic animals are allowed free range onto the embankment, paths will be eroded into the crest, reducing the height originally created above the spillway level. This will lead to failure of the embankment when a flood peak close to that chosen in the design flows over it. An extra height is therefore built into the design, termed a 'dry freeboard' which is added to the height of the structure above the high flood water level. Design water depth (h) is termed the wet freeboard, and the extra that is added for safety is termed the dry freeboard (Figure 13.2/3). This latter height is not used in the design of the structure for stability purposes. The calculation for the value of the wet freeboard is demonstrated in Chapter 18. That for the dry freeboard differs for different situations. The latter values are also given in Chapter 18.

In most instances the spillway cross section is in the form of a rectangular shape (see Figure 13.3). Usually the width of spillway will be governed by the available width of the gully. In order to reduce velocities it is best to make the spillway as wide as possible. Note an option that can be used to lengthen the spillway is illustrated in Figure 9.3. A formula is then used to determine the depth of water that will ensure that the constructed spillway will be able to conduct all of the design floodwater without the structure being overtopped. There are different formulae for determining the dimensions of the different types of spillways (e.g. central notches as for weirs, chutes and drop inlets (for earthen embankments), culverts, etc.) and they are given along with the designs in Chapters 19 to 22.

In other instances the reverse will be the case, where maximum depth of water is the controlling input and length of spillway is the derived value. This would be the case where the gully is wide and the Q value relatively small. Economics would then dictate choosing a spillway width narrower than the gully width. The reason for controlling the height of structure would be to either contain all the runoff within the gully (spillway as

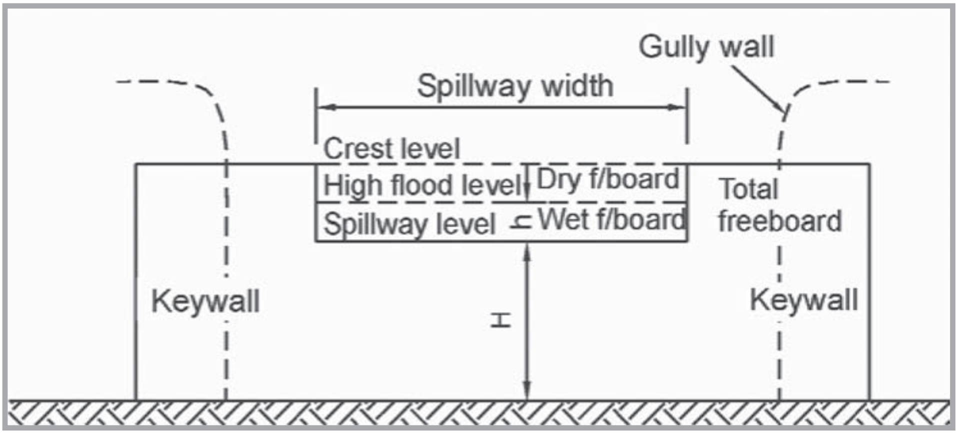


Figure 13.3: Cross-section of a gully showing components of a spillway

wide as possible), or to push some or all of the runoff out onto the original ground surface (spillway narrow to increase the depth of overflow). Refer to Chapter 21 for more details.

Choosing an appropriate design discharge

Having decided upon the type of structure to be built, having measured up the site, and before the actual design is carried out, the next step is to determine what Q value must be used in the design of the structure. The concept of estimating Q has been discussed in Chapter 3, and the detailed calculations required are in Chapter 15.

The background to determining the Q value that will be required needs some explanation so that designers without the necessary background will be able to make informed decisions. One is not going to design a soil plug that will be capable of surviving a biblical flood that occurs very seldom. The concept of flood frequency therefore needs careful consideration.

Flood frequencies display similar frequency characteristics to those of rainfall intensities, although two similar storm events occurring at different times will not necessarily result in similar flood peaks due to possible differences in conditions in the catchment area. Thus, in a given locality, very high floods may have a chance of occurring once in a hundred years; lesser floods once in ten years, and very small floods once or more often in a wet season. Flood frequency is very important in the safe design of hydraulic structures. A structure designed to withstand a 1 in 100 year flood frequency should be safe against failure, but will also be very costly. On the other hand a structure that is designed to cope with a flood of one year frequency may be low priced, but could be washed away every year or two. The design of hydraulic structures is therefore a compromise between initial cost, maintenance costs, and safety. From practical experience over many years it is customary to design ordinary soil conservation works strong enough to cope with floods having a 10 to 25 year frequency or return period. In the case of larger works where failure could result in loss of life or damage to public property, longer return periods are used. In terms of this manual, the flood frequencies that are recommended for use in designs are given in Table 13.1.

Table 13.1: Tentative flood frequencies recommended for the Level of Expertise-type structure required

Level of Structure	Flood frequency in years
Level 1 (small structures on catchments <50 ha)	10
Level 2 (moderately sized structures oncatchments 50-500 ha)	20
Level 3 (large structures on catchments >500 ha)	25-50 (unless requirements of Dam Safety regulations of National Water Act dictate otherwise)

Although the flood frequencies are indicated in Table 13.1, these do not indicate the probabilities of equaling or exceeding these in the time indicated. For example, there is a 65% chance that a 10 year flood will be equaled or exceeded in a 10 year period and a 41% chance that a 10 year flood will be exceeded in a 5 year period. The appropriate question then becomes, is 40% an acceptable risk that rehabilitation works will be washed away within 5 years of completion? Alternatively, is it likely that funds will be found to do major repair work once the rehabilitation project on a particular wetland is completed? The recommendations in Table 13.1 are not 'cast in stone', however, as there will be situations that will dictate otherwise. Accessibility is a point to consider. Structures that are remote may need a greater design floodpeak in order to reduce the cost of maintenance. The final solution to the problem is, as always, an economic one. The designer must consider capital cost against the regular cost of maintenance.The durability of a structure should not only be related to its capital cost but also to the likelihood of its being repaired or replaced if damaged, and to the social, political and economic consequences of failure.

13.2 Other components of structures used in water control

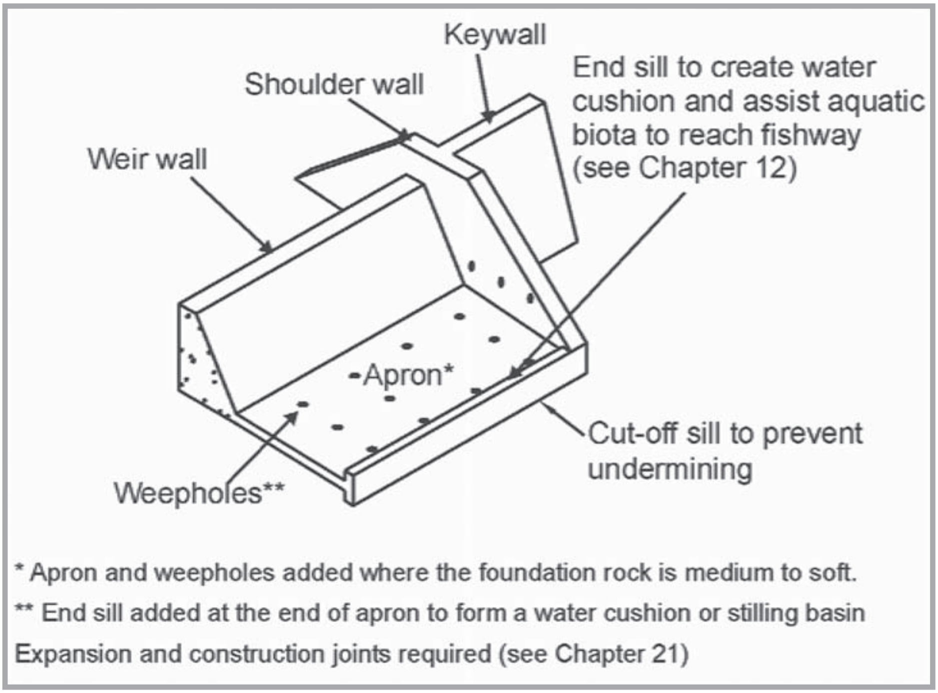
The previous section in this chapter was concerned with the movement of water over, through or by-passing mechanical structures through the use of spillways. However, care also needs to be taken that water does not seep under or sideways around a structure, and in so doing undermine or outflank the structure. One also needs to ensure that energy imparted to water as it flows over a structure does not erode material from below or the side of the structure and thus jeopardize it.

Components to prevent seepage

In most instances the structure being built will be embedded in the soil profile out of which the gully has formed. This requires the use of

- a waterproof bond between the soil and the solid materials such as concrete and gabion rock. Achieving a waterproof bond is not a simple matter, but needs to be addressed. Uncontrolled water movement below-ground could result in the soil surrounding the structure being eroded away from them. This is even more of a problem where the soil is highly erodible.
- Key walls, which are an extension of the overflow portion of the weir and are built into the adjacent gully bank (see Figure 13.4), prevent moisture seeping around the structure.
- Cut-off sills (a structure buried in the ground to prevent seepage, see Figure 13.4) prevent moisture from seeping underneath the structures. The soil is firmly compacted around them in order to assist in sealing off the structure.

  Likewise, when building an earthen bank onto a soil base, one must be careful of subsurface layers of coarse unconsolidated material such as sand and gravel deposits. Tunnels created by



* Apron and weepholes added whetre the foundation rock is medium to soft
** End sill added at the end of apron to form a water cushion or stilling basin
*** Expansion and construction joints required (see Chapter 21)

Figure 13.4: Components of a weir

moles or termites that will cause leaks that could result in the failure of the structure also cause problems.

- Key trenches (trench excavated along beneath the embankment, filled with clay type soil to form a waterproof layer) are therefore very necessary components for the safety of all hydraulic structures built of soil.

Components to prevent erosion around the structure

The following are principal components of weirs and chutes that prevent splash erosion and downstream erosion, and are illustrated in Figure 13.4.

As water cascades over a structure, its velocity and energy to lift and erode sediment increases. This energy needs to be dissipated and the splash created by falling water managed such that the structure is not undermined.

Aprons are the mattresses constructed on the bottom of the gully downstream of the structure in order to protect the foundation from being undermined by the water falling through the spillway. Should the structure be undermined, it will be destroyed. This aspect is extremely important especially when the apron is constructed of gabions. The force of the falling water tends to segregate the rocks and leads to the break-up of the apron. Even a relatively low drop will cause damage unless the entire mattress is thoroughly grouted once the rocks have settled properly.

Cut-off sills are constructed underground around the apron in order to stop the apron from being undermined. They are also very important in preventing under-cutting at the entrance to chutes.

Stilling basins are pools created below a structure to ensure that the energy of falling water is dissipated by falling onto a cushion of water rather than onto bare soil or rock. End sills are constructed at the lower edge of the apron in order to dam up a small portion of the water overflowing the structure to form such a pool that the runoff exiting it falls onto water. This helps protect the apron from damage by the falling water. It also tends to reduce rapid changes in the temperature of the concrete apron, thus reducing the chances of damage to it by expansion and contraction. The end sill is generally incorporated into the cutoff sill as a single entity (Figure 13.4). A hydraulic pump will form at the end sill during high flows, which will tend to erode the banks of the channel downstream of the stilling basin. Bank protection should extend at least 3 to 5 times the water depth downstream of the sill.

Shoulder walls are used on weirs in gullies to stop the splash of water, especially downstream of the structure, from damaging the join between the structure and the gully. Shoulder walls are also specified upstream where large depths of overflow, together with high velocities, could cause whirlpools to form, threatening to put the keywalls in jeopardy. They are also incorporated into chutes as the side walls of the structure (see Figure 13.4).

Foundations

Foundations are exceedingly important for maintaining the stability of a structure. Structures tend to be heavy, and if the foundation material is weak it may fail in time, and the same will happen to the structure upon which it stands. All soft and loose surface material must be removed and the new surface firmly compacted (if of soil) before any construction commences. One of the techniques used where a weak foundation is encountered (e.g. shale) is to make the base width of the structure wider than required for the design of structures on hard rock foundations. This helps by spreading the load more. Another is to strengthen the foundation with imported, stronger material, such as building a concrete structure on a soil base to create a rafted weir. Here, a steel reinforced concrete slab with a heel excavated into the soil is laid down, and the structure built thereon.

Very often the foundation condition will determine the choice of structure to be used. Various options are dealt with in Chapters 19 to 22, but all instances of suspect foundations should be regarded as Level 3 (Chapter 16).

As important as the correct building of rehabilitation structures, is the aspect of ‘tying’ them into the soil surround of the gully into which they are built. Water is a solvent, and under the pressure of water and gravity, and given time, it will tend to find its way along any weak plane that may exist between a solid structure and the soil. The bond between structure and soil must therefore be as strong as possible otherwise problems (including failure) will occur, either through undermining or outflanking. In order to overcome this problem and to ensure that the soil will adhere as closely as possible to the various components of the structure, the following is mandatory:

Earthen structures such as plugs and berms

Before any building is undertaken, all vegetation, roots, mushy soil and sediment is removed and stockpiled for later use in covering the final product. Where larger structures are involved (1.5 m and higher), and especially where there is a possibility of subsurface layers of sand, a key trench is dug along the centre line of the structure and then in-filled with good clay soil and firmly compacted. Where a vertical gully bank is present, compacting fresh soil directly against it will not suffice – a weak bond will allow water to seep along it and open up a passageway for water to scour out a tunnel. This could lead to destruction of the structure. The vertical wall MUST be sloped first, to a slope no steeper than 1:1, before compacting soil against it. The excavated soil may, of course, be used as fill if it meets the design criteria. This will include ensuring that the soil is moist enough for proper compaction.

No matter how well the soil is compacted it will still remain slightly porous. When the embankment is required to hold back a stretch of water, that water will tend to seep through the wall as shown in Figure 19.1. While the initial movement of that water is in a horizontal direction, gravity will tend to pull it downwards in what is called the Line of Saturation (L of S). The soil below the L of S is saturated and therefore unstable. The crest width must be wide enough and, more particularly, the side slopes must be flat enough so that the L of S does not seep out of the downside slope of the bank. Should it do that, there is a distinct possibility that the said side slope, being now unstable, will slip, causing what is called a Slip Circle. If the slip circle is large and deep enough water will then seep out faster and lead to the destruction of the embankment. If the foundation material is not permeable enough to remove this phreatic water, a drainage blanket of sand or chip stone can be laid, as indicated in Figure 19.1, to remove it (see Chapter 28 for further detail).

Concrete structures

The concrete-soil interface MUST be sloped slightly to enable the soil to be compacted against it. A slope of 1: 0.2 (i.e. H/5) is a general rule of thumb, but poorer soil could require a slightly flatter slope. If built on weathered rock foundation, the desiccated skin must be chipped off. It is always a good idea to paint the rock with a 1: 1 (by volume) cream of cement-sand before laying the concrete.

If concrete is caste up against an earthen wall in order to save one side of shuttering, the setting concrete will pull slightly away from the soil surface due to shrinking that takes place during drying leaving a thin pathway for water to move along. It is therefore preferable not to do this and to build away from the soil bank even if it then needs the extra shuttering. With relatively small structures one could caste against the soil wall, but then, once the concrete has hardened, a narrow trench must be dug between the concrete and the soil and this trench filled with compacted soilcrete (see Chapter 28 for information on soilcrete).

Key walls must be cast against smooth form work as rough form work prevents effective compaction against the concrete face, leaving a soft uncompacted zone of soil that will leak. Once cast, form work can be stripped and backfilling and compaction can proceed. If there is any chance of leakage the downstream face of the key wall must be backfilled with a maximum of 150 mm of sand to make a filter to trap soil particles that may be washed out of the gap.

As indicated earlier, water underground exerts a force upward in an attempt to escape pressure on it. Any structure built where the uplift pressure exists must be either heavy enough not to be lifted by it, or ‘weep holes’ must be inserted in the concrete to allow the pressurized water to escape. In concrete weirs, therefore, the components where weep holes must be allowed for are the apron slab and the shoulder walls. Key walls do not need them. The weep holes are typically of the order of 50 mm in diameter and spaced approximately 1 to 2 metres apart. They are formed by placing short lengths of piping (which have an outside diameter the required size) in position before the concrete is caste around them (see Chapter 22 for further information).

CHAPTER 14:
ESTIMATING MEDIAN ANNUAL RUNOFF (MAR)

14.1 Introduction

The success of any rehabilitation of a degraded wetland is heavily dependent upon a suitable source of water. The supply of water will generally come in the form of base flow and storm rainfall runoff from the catchment upstream of it. In areas where the catchment is stressed due to the planting of crops such as timber and sugarcane plantations, and/or the construction of water storage dams, water for the wetland and the stream issuing from it may be limiting. It is therefore necessary that the actual long-term Median Annual Runoff (MAR) is determined before planning and the expenditure of funds are considered. This value of MAR must then be compared with the requirements of the wetland for the sustainable and healthy growth of vegetation within it. If there is insufficient runoff for the requirements of the wetland type, for instance, the project can obviously not succeed in its entirety. What was previously a permanently wet wetland may have to be stabilised as a seasonal or temporary wetland where runoff is limiting. An alternative would be to create zones of varying degrees of dampness as the available water allows.

It should be noted that there is little known regarding the consumption of water by vegetation in a wetland. It is therefore difficult to know exactly how much water is required by a particular wetland. Some research has shown that, during peak summer growth the evapo-transpiration (Et) from actively growing wetland vegetation can be similar to that of a free water surface area, but that it tends to be less when the plants are in a winter dormant period. (Chapman, 1990). Due to a lack of data in this regard, estimated measures are used.

The wetland under consideration for rehabilitation may in fact have degraded solely because of the lack of sufficient water to sustain the vegetation and other wetland species in it. Where a change in land use and practices in the catchment area of the wetland has resulted in a reduction in the amount of annual runoff taking place out of a catchment, there could conceivably be insufficient water available to regain, totally, the original status of the wetland prior to the degradation taking place. A change in land use from natural grassland, for instance, to plantation forestry or sugar cane, would result in a reduction of the annual runoff feeding the wetland. The construction of storage dams would likewise result in less water being available to re-wet a wetland that has degraded through the action of a gully eroding through it. Urban development upstream will increase the MAR but may change its distribution over time making it less beneficial to the wetland.

There is therefore a need to estimate the long-term nett runoff out of a catchment (after the effect of storage dams has been taken into account), and to compare it with the needs of a functioning wetland once the engineering part of the rehabilitation had taken place. If it is found that there is insufficient water available to regain the original state of the wetland, then either a lower standard of ultimate wetland rehabilitation must be accepted, or the attempt to rehabilitate it should be abandoned altogether.

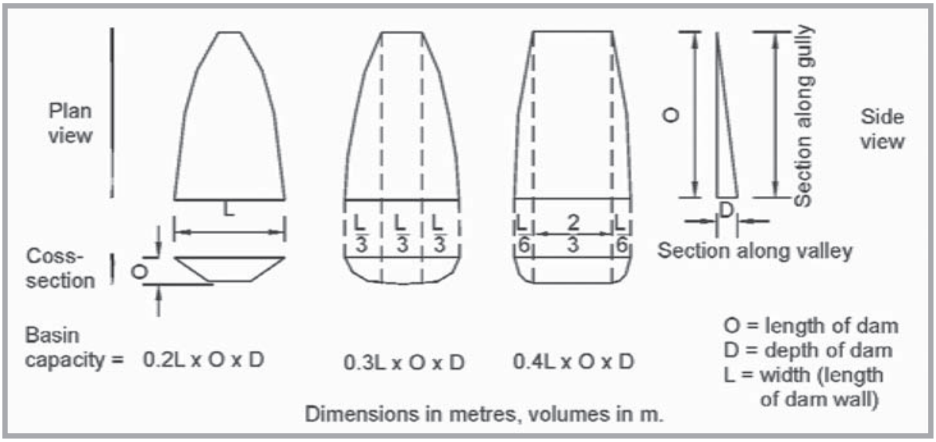


Figure 14.1: Assessing dam basin storage based on three different basin shapes

14.2 Measuring the amount of water held in a small storage dam

The design and construction of large irrigation dams is frequently preceded by a topographic survey of the terrain to determine the most economic size of storage. This survey is carried out by irrigation firms, by the Engineering Section of the provincial Departments of Agriculture, by individual civil engineering concerns, and by the Department of Water Affairs and Forestry. One of the reasons for the survey is the calculation of the storage capacity of the dam. If this has been done the farmer or land user should be able, in most cases, to advise on the capacity of the dam, or to give the name of the concern that carried out the survey. If this information is not available Figure 14.1 will help to ascertain a rough estimate of the capacity of the dam.

It is difficult to determine the exact amount of water that will be abstracted annually from a storage dam. If it was built for irrigation purposes then water will be extracted from it at regular intervals. Evaporation from a free water surface can be very high, depending on the depth of the water – shallow water tends to lose water through evaporation faster than deep water. Regular and strong winds can help remove water even faster. It is therefore suggested that, having ascertained the basin capacity of the dam, a figure double this be subtracted from the MAR as the effective volume of water available from the catchment for wetland rehabilitation.

14.3 Determining median annual runoff

There are a number of methods of determining MAR, but the one chosen is probably the simplest to use. It is based on the Water Research Commission Report TT82/96 which incorporates the ACRU Report 46, 1997, ISBN 1 86845 271 9 (Schulze, 1997).

The National Department of Water Affairs and Forestry (DWAF) has divided the South African drainage system into a number of Drainage Regions. The Drainage Basins have been further divided into main and subsidiary catchments within the drainage basins. The fourth order of subdivision is termed the Quaternary Catchment (QC). This fourth order of subdivision is regularly used in catchment planning, and is the one used also by the Working for Wetland organisation to index its projects (Figure 14.2).

Among much other data, the *South African*

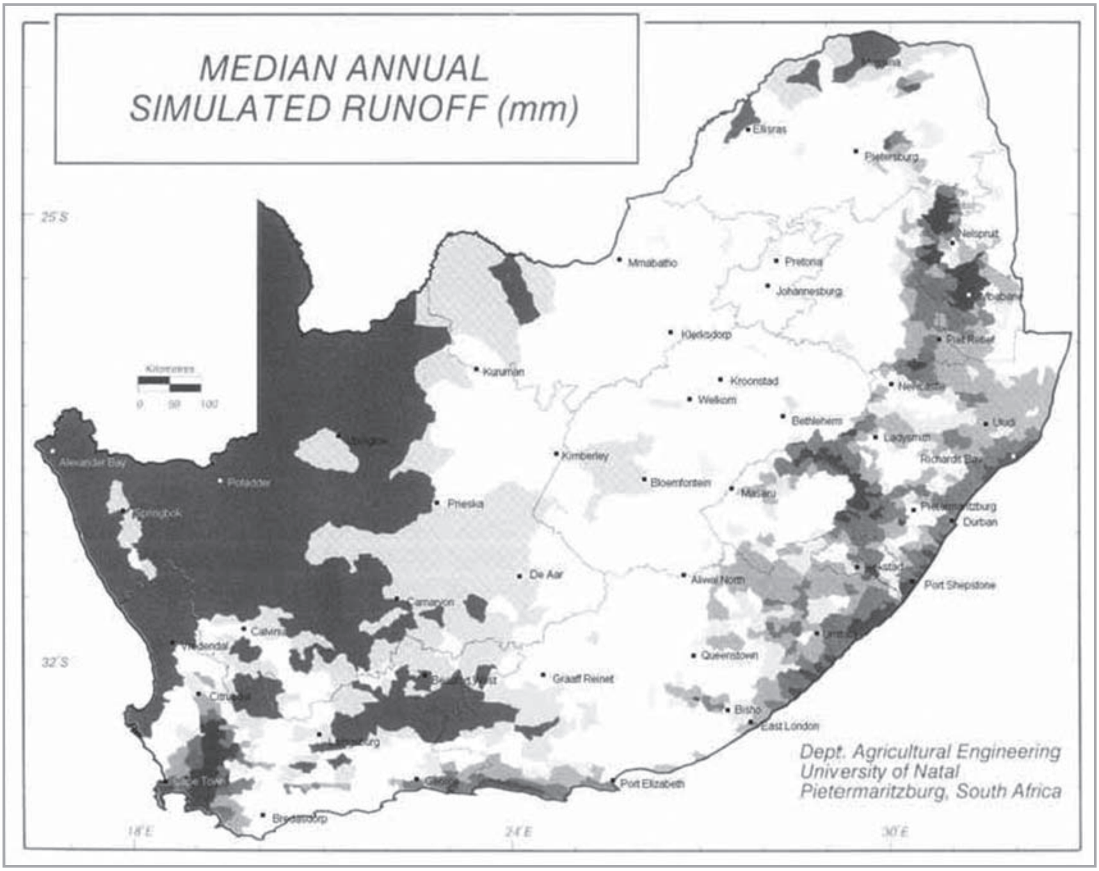


Figure 14.2: Median annual simulated runoff from quaternary catchments

Atlas of Agrohydrology and Climatology (SAAAC) (Schulze, 1997) records the simulated median annual runoff for each and every quaternary catchment in the land, using the ACRU model, in terms of millimetres of runoff. Note that while the acronym MAR generally refers to Mean Annual Runoff, the authors of SAAAC chose Median Annual Runoff as being more realistic. Runoff from catchments varies according to such parameters as land slope, soil type, rainfall intensity zone, ground cover, etc. The compilers of the SAAAC have taken all of these aspects as averages into account in determining the runoff values for each quaternary catchment. Because of the variation that occurs due to the parameters mentioned above, the values recommended are given in the SAAAC as a range between upper and lower limits. The designer should, therefore, take the specific parameters (i.e. specific land slope, soil type in terms of infiltrability, soil cover and degree of cover, etc.) of that portion of the quaternary catchment that lies upstream of the structure to be designed, and calculate a more specific MAR as recommended below:

- Identify the quaternary catchment number and refer to the Table no. xx on the website no. xx to obtain the range of runoff values for it.
- A choice of the actual estimated runoff value is made from the range of values as follows –

- For QCs with flat slopes (0-3%), deep (± 1.2 m), well-drained soils and excellent ground cover, use the lowest runoff value in the range.
- For QCs with moderate slopes (3-8%), moderately deep (± 0.75 mm) soils and a moderate ground cover, use the middle value in the range.
- For QCs with steep slopes (>8%), shallow (<500 mm) soils and poor ground cover, use the highest runoff value in the range.
- For QCs intermediate to the three categories of slope, soil depth and ground cover, use the intermediate runoff values in the range.

- Measure the size of the catchment in hectares
- Multiply the chosen runoff value (in mm) by the area of catchment (in ha) and by 10 to obtain the MAR in cubic metres of water.If the runoff value is, for example, 25 mm, and the size of the catchment is 35 ha, the average annual runoff will be:

  MAR = 25 x 35 x 10 = 8750 cubic metres

- It should be noted further that the QCs in the exercise are considered as individual spatial entities – the runoff generated in the specific catchment was not added to that QC downstream of it. If therefore a project needs to be designed in a wetland that is in the second QC from the watershed, the runoff values from both QCs must be added together.The runoff values for each catchment have been indicated on a map (Figure 14.2) for reference purposes only.

14.4 Determining the required annual water usage of the wetland

Having determined the final MAR available out of the catchment, which will be the original MAR minus that amount abstracted by any storage dams, one must then compare this with the amount of water necessary to sustain the wetland and its functions.

Once again there is a problem. Investigation into evapo-transpiration and other water losses from wetlands in the RSA is in its infancy. These losses will be dependent on climate, soil type, vegetation species present, etc. and, for example, rehabilitating what was a permanently wet wetland will require more water for its proper functioning than will a seasonally wet wetland. Then there is the question of the Reserve. In terms of the National Water Act, any planned storage on a stream must make allowance for a water supply to pass through it. This is required for the health of the length of the stream or river only, let alone for the people living and working downstream, who are also reliant on its water and therefore entitled to a portion of it.

This is a problem for the scientists to solve. In the meantime, and until such time as answers to these questions are available, it is suggested that the following be used as the minimum amounts of runoff required for rehabilitating wetlands (Table 14.1).

Table 14.1: Water usage for rehabilitating wetlands

Degree of wetness required	Water use per day (mm)	Period of requirement (months)	Total water requirement (TWR) (mm)
Temporary	4	4	480
Seasonally	5	5	750
Permanently	6	6	1080

14.5 Determination of possible restriction on rehabilitation methods

In determining whether there is sufficient runoff to re-create a suitable wetland, the following procedure should be followed:

- Determine the size of the catchment in hectares (A_c)
- Consult Figure 14.2 in order to determine the initial MAR (mm_c) for the QC involved, and calculate the initial MAR (Z_c).

  Initial MAR= A_cx mm_cx 10 = Z_c m^3
- If there are any storage dams in the catchment area, determine the storage volume (Z_d m^3) of each, using Figure A 3.1.
- Determine the area of wetland (in ha) to be rehabilitated (A_w)
- Based on the apparent wetness that the degraded wetland appears to have been, choose an appropriate total water requirement TWR (mmw) and convert to cubic metres – by multiplying the area of temporary, seasonal and permanent zones by the appropriate TWR in Table A 3.2. Thus:

  TWR = A_w x mm_w x 10 = Z_w m^3
- The water available for the Reserve = Z_w – (Z_c – 2Z_d) m^3. If the answer is in the negative it means that there will be insufficient runoff for the Reserve, and the calculation will have to be repeated using a lower TWR, until a positive answer is attained. If this is not possible with the lowest TWR, it means that the attempt to rehabilitate should be abandoned, and only stabilization of the erosion carried out.

CHAPTER 15: ESTIMATING RUNOFF DISCHARGES (Q)

15.1 Introduction

The basic object of soil conservation works is to control surface runoff, and not to store it. Velocity and rate of flow is therefore far more important than volume of runoff. Soil conservation works have to deal with flowing water, conveying it from one point to another in a manner that will not cause further erosion, and disposing of it safely through spillways, waterways and other structures without damage to themselves.

The rate at which runoff flows down watercourses, whether they are well-vegetated streams or degraded gullies, is therefore important. You will recall (see Chapter 3) that the flowing water has energy by virtue of its volume and velocity

$E = \frac{1}{2}(\text{Mass x Velocity}^2)$

and that energy will impinge on any structure standing in its way.

The structure must be designed to withstand the energy of the water, which will cause it to overturn and/or slide from its appointed place if not strong enough to withstand those forces. A reliable estimate of the runoff rate or discharge with which a structure has to cope is therefore the foundation on which the design should be based. An error in this figure could result in overtopping and damage, or even in the complete destruction of an expensive structure.

15.2 Estimation of runoff discharges

The most reliable method of estimating runoff rate and discharge values is the actual measurement of flood flows for a sufficiently long period of time. However, this is obviously not practical on small catchment areas and for small structures. Estimating Q is also not a very precise exercise, for the reasons given elsewhere. So many variables are involved that only fairly reliable estimates can be made. There are many formulae for estimating Q, and they range in complexity and reliability.

Runoff peak discharges should always be calculated using at least two but preferably three different methods and the practitioners judgement used to decide on a design value.

In Chapter 16 the concept of Levels of Expertise is considered and recommendations made regarding, amongst others, the relationship between the Level of the structure, the size of catchment area, and the formula to be used for calculating Q from the specific catchment. Level 1 structures will therefore be designed for 10 year return periods because the structures are likely to be small and fairly inexpensive to repair. Level 2 structures will be designed for a 20 year return period, and the designer (a Professional Engineer) will decide the return period for Level 3 structures.

Two different methods are described in this manual: the Soil Conservation Service Method, and the Rational Formula Method. For larger catchments the reader should consider two other methods namely the Standard Design Flood (Alexander, 2002) applicable to areas greater than 1000 ha, and a proportion of the Regional Maximum Flood (Kovacs, 1988).

15.3 The Soil Conservation Service (SCS) Method

The SCS Method is recommended for use on catchments up to 50 ha. It is derived from the one used by the Soil Conservation Service of the U.S. Department of Agriculture (SCS, Engineering Field Manual. Chapter 2). In order to simplify the procedure as much as possible for Level 1 structures, the formulae in use have been solved for a large number of examples, and the answers presented in tables shown below together with the parameter values that went to make up the Q value given. The main factors affecting runoff are taken into account, and a step-by-step procedure to determine Q is presented below and summarised in Figure 15.1

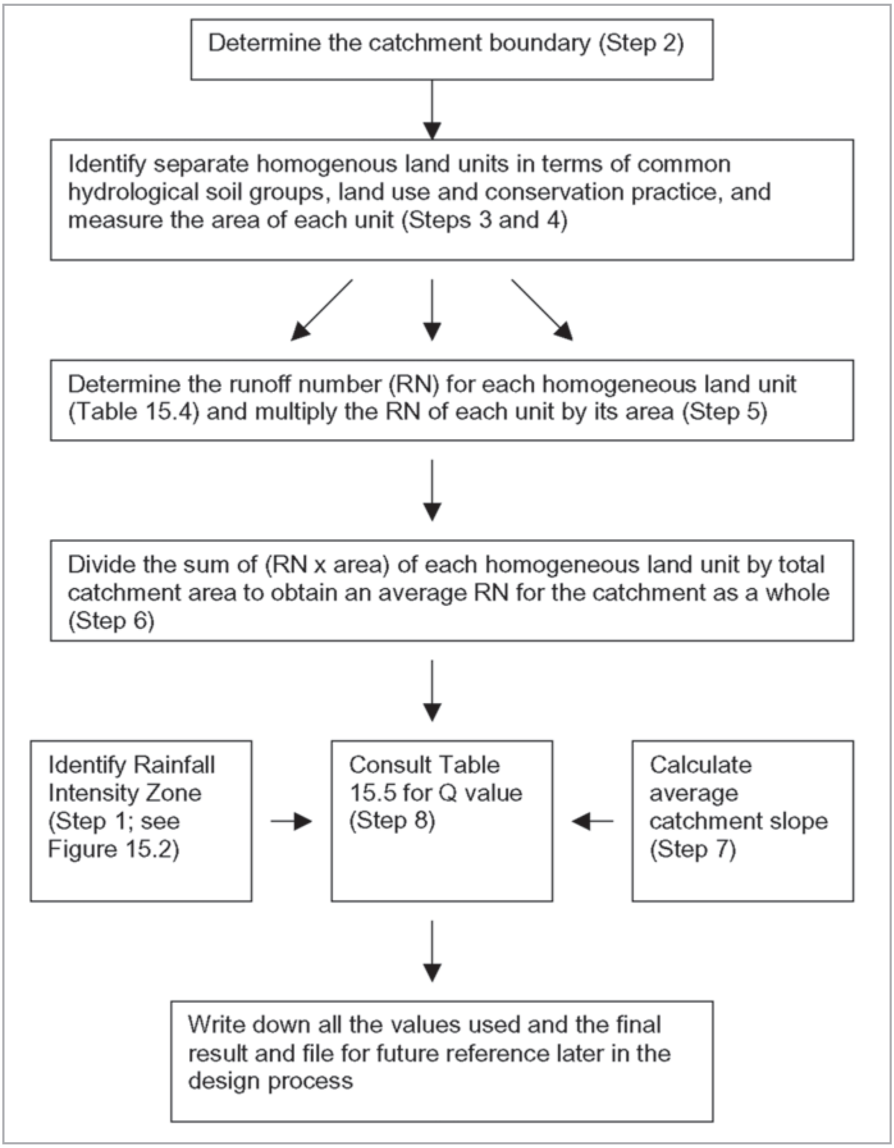


Figure 15.1: Summary of step-by-step procedure for estimating the Q value by the SCS Method. See Appendix 1 for details on mapping techniques.

a) Rainfall intensity:

The rainfall intensity zone and its related maximum 24-hour rainfall is identified from the map in Figure 15.2. In the accompanying legend are the corresponding rainfall amounts that can be expected within each zone.

Step No. 1

Find the rainfall intensity zone in which the site under investigation falls (Figure 15.2).

b) The size of catchment area is required:

Step No. 2

Consult a topographic map of a suitable scale. The 1:10 000 scale orthophoto is the best, otherwise the 1:50 000 will have to suffice. Draw in the watershed as indicated by the contour lines and measure the area of the catchment. Map out also the areas of differing land use and measure their areas as well (See Appendix 1). Note their individual soil types from the initial visit to site, as well as the conservation practice in each unit.

c) Hydrologic properties of soil

The soil, its moisture status, organic matter content and extent of urban development (if any) affect Q more than any other factor. The following are of special importance, and the more accurately they are identified the more accurate will the computed Q be, and therefore the safer will be the structure:

- The infiltration rate, which is determined by conditions on the soil surface.

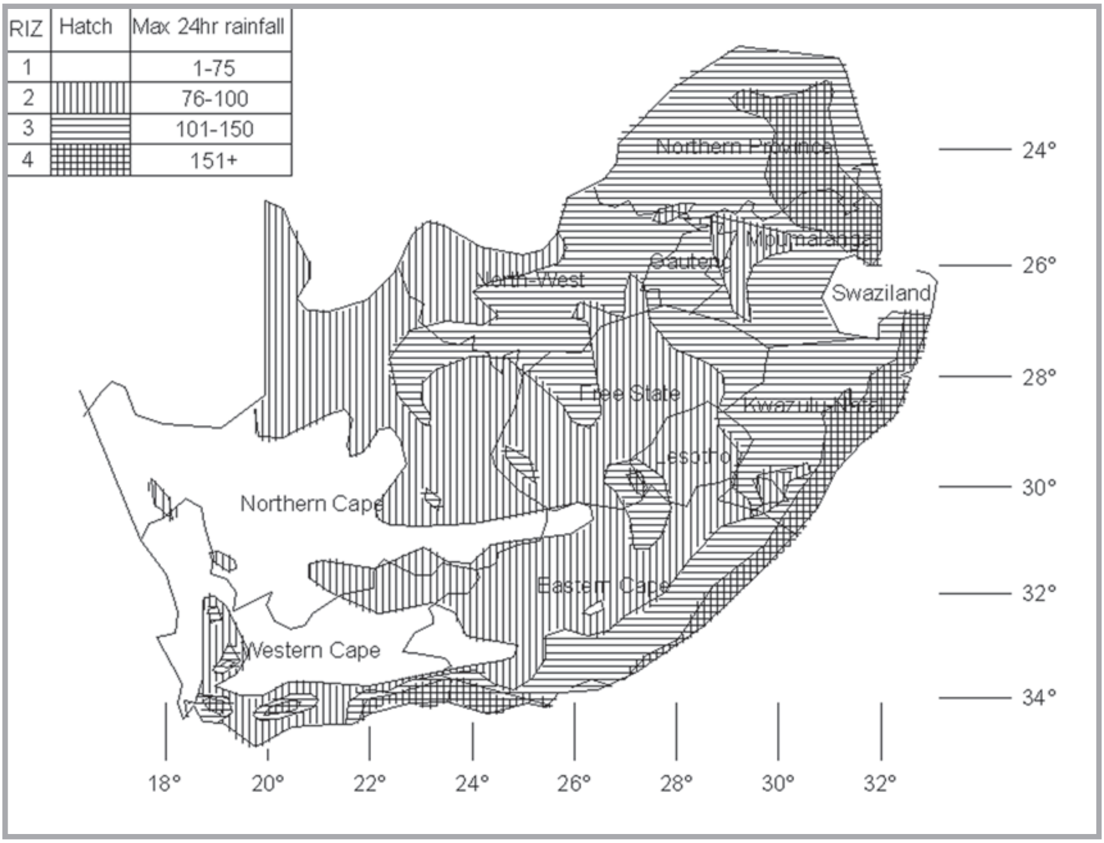


Figure 15.2: Rainfall intensity zones (RIZ) within South Africa (Dept. Agric. and Fisheries. Agric. Eng. 1981. Tech. Man. Soil Conservation)

- The permeability of the soil profile, i.e. the rate at which the water moves through the soil profile, and which is determined by the nature of the different soil horizons.
- The water storage capacity, which is dependent on the soil texture and depth of soil. The finer the texture and the greater the depth, the greater will be the storage capacity of the soil profile.

In simplifying the process, soils can be grouped into so-called Hydrologic Soil Groups (HSG) as set out in Tables 15.1 and 15.2 below. Note that where the specific soil type is not quite one class or the other, an intermediate classification is in order (e.g. A/B, B/C, C/D). Where a number of soils in the catchment vary in their classification, an average HSG value, weighted by areal distribution, should be calculated. See an example of the calculation later. For those conversant with the Biomial Classification System for soils in South Africa, Table 15.2 should be of assistance.

Step No. 3

See Tables 15.1 and 15.2 below and note the final HSG for the soils in the catchment under investigation.

If, for example, a catchment of 20 ha has 10 ha of HSG A soils and 10 ha of HSG B soils, the final HSG will be A/B.

If a 50 ha catchment has 20 ha of B, 20 ha of C, and 10 ha of D soil, the final HSG for the catchment as a whole will have an average HSG of approximately C.

Table 15.1: Description of Hydrologic Soil Groups.

HSG	Description
A	• Low runoff potential. Infiltration and permeability rates are high, even when thoroughly wetted. Deep, well drained, to excessively drained sands and gravels. These soils have a high rate of water transmission.
B	• Moderately low runoff potential. Moderate infiltration rates, effective depth and drainage. Moderately fine to moderately coarsely textures. Permeability is slightly restricted.
C	• Moderately high runoff potential. Infiltration rates are low. Permeability is restricted by layers that impede downward movement of water. Moderately fine to fine textures.
D	• High runoff potential. Very slow infiltration and permeability rates. Clay soils with high shrink/swell potential, permanently high water tables, clay pans or clay layers at or near the surface, or shallow soils over fairly impervious material.

Table 15.2: Description of Hydrologic Soil Groups

Soil form	HSG	Soil form	HSG	Soil form	HSG	Soil form	HSG	Soil form	HSG
Arcadia	D	Estcourt	D	Katspruit	D	Nomanci	B	Valsrivier	C/D
Avalon	B	Fernwood	A	Kranskop	A	Oakleaf	B	Vilafontes	A
Bainsvlei	A/B	Glencoe	B	Kroonstad	C/D	Pinedene	B	Wasbank	C
Bonheim	C	Glenrosa	B/C	Lamotte	A/B	Rensburg	D	Westleigh	C
Cartref	C	Griffin	A	Longlands	C	Shepstone	A	Willowbrook	D
Champagne	D	Houwhoek	C	Magwa	A/B	Shortlands	B		
Clovelly	A/B	Hutton	A	Mayo	A	Sterkspruit	D		
Constantia	B	Inanda	A	Milkwood	C	Swartland	C/D		
Dundee	B/C	Inhoek	C	Mispa	C	Tabankulu	C		

Note: One notch adjustments may be made to the hydrologic soil grouping within soil forms (Table 15.2 above) and according to soil series based on the following considerations. One notch refers to half a group, e.g. B to B/C, etc.

1. Texture: Soils with A-horizon clay contents exceeding 35% may be downgraded one notch. Where clay content is less than 6% and coarse sand makes up at least 35% of the soil fraction, the soil may be upgraded.
2. Leaching: Dystrophic or well-leached soils in high rainfall areas may be upgraded, while eutrophic or poorly leached soils in arid areas may be downgraded.
3. Watertable: Where a high watertable exists in a soil that does not normally have one, the soil should be downgraded.
4. Surface crusting: Where crusting is evident in soils that do not normally do so, soils may be downgraded, and vice versa.
5. Soil depth: Typically deep soils should be downgraded when found in the shallow phase (when the profile is less than the defined 1.2 metres deep).
6. Bottomland soils found in upland situations could be upgraded one notch.

Source: Schulze, 1979.

d) Effect of land use and vegetative cover

Foliage and litter reduce the sealing effect of the soil surface by raindrop impact, and thus help to maintain the infiltration potential of the soil. Vegetation and ground litter retards the flow of runoff over the ground, thus allowing more time for infiltration to take place. This latter also tends to attenuate flood peaks. Soils with a good cover therefore usually have a good open structure which allows high infiltration and permeability rates. Conversely, soils that are packed hard by excessive traffic, overgrazing and heavy cultivation, and suburban areas with a large proportion of tarmac and buildings, will result in reduced infiltration rates.

e) Conservation practices

Practices such as contour tillage and conservation tillage will tend to slow down and hold back some of the runoff. Well maintained contour banks increase the distance that runoff must flow, and also reduce the velocity of the flowing water, thus allowing more infiltration time and lower flood peaks. In all instances, arriving at the 'conservation condition' is an exercise in judging how much effective cover is available. One must also judge what percentage of the land use is in different stages of 'conservation condition' at any one time, and choose an 'average' condition as indicated above for differing land uses.

So for instance, a catchment totally planted to sugar cane may have been compartmentalized so that, at any one time some of the land will be bare and fallow, some may have less than 50% canopy cover, and some will have 100% cover. The designer must then work out what the average condition will be, weighted according to the size of each differing block of sugar cane.

Step No. 4

Note the type of land use and vegetation in the catchment under investigation, as well as the presence of conservation practices and the condition in which they occur, for later use in Table 15.3. This must be done for each of the soil type compartments identified in Step No. 2.

f) Combined effect of soil type, vegetation and conservation practices

The effects of these three parameters are so inter-woven in the runoff process that they cannot be easily separated into different compartments. The so-called Runoff Number (RN) is therefore used for the combined effect, and the values of the RN for the catchment can be determined from Table 15.3 below.

Step No. 5

Using the factor values found in paragraphs b) to d) above, find the RN in Table 15.3 (following page) for the particular conditions found in the catchment in respect of each soil type-land use-conservation practices compartment identified in Step No. 2.

Step No. 6

Multiply the area of each compartment by its identified RN, total them all up, and divide this total by the total area of the catchment in order to arrive at a weighted average RN for the catchment as a whole.

g) Effect of slope

Other things being equal, the steeper the slope, the lower will be the effect of surface storage, the faster the water will flow, and the higher will be the value of Q. Three different slope classes or factors are recognized, as shown in Table 15.3.

Step No. 7

The average slope of the catchment, once again weighted by area if necessary, is noted, for final calculation of Q for the specific catchment area.

Table 15.3: Slope factors for calculating runoff discharge

Average % slope range	**Slope factor/code**
0.1-2.9 3.0-7.9 8.0 plus	Flat (F) Moderate (M) Steep (S)

h) With the following known:

- the area of the catchment in hectares, measured off the topographic map,
- the Rainfall Intensity Zone (RIZ) identified and the 24-hr rainfall amount determined from Figure 15.2
- the average slope of the catchment calculated from the topographic map and the slope category obtained from Table 15.3
- the average Runoff Number determined from Table 15.4, the Q value may now be determined.

Table 15.4: Runoff Numbers for use in determining runoff discharges

Land use	Practice	Condn	**HSG**						
			A	**A/B**	**B**	**B/C**	C	**C/D**	D
Fallow	Straight row	-	77	82	86	89	91	93	94
Row crops	Straight row	Poor	72	77	81	85	88	90	91
	Straight row	Good	67	73	78	82	85	87	89
	On contour	Poor	70	75	79	82	84	86	88
	On contour	Good	65	70	75	79	82	84	86
	Contour banks	Poor	66	70	74	77	80	81	82
	Contour banks	Good	62	67	71	75	78	80	81
Small grain	Straight row	Poor	65	71	76	80	84	86	88
	Straight row	Good	63	69	75	79	83	85	87
	On contour	Poor	63	69	74	79	82	84	85
	On contour	Good	61	67	73	78	81	83	84
	Contour banks	Poor	61	67	72	76	79	81	82
	Contour banks	Good	59	65	70	75	78	80	81
Sugar cane	Bare fallow	Cover 0%	54	*	80	*	89	*	92
	On contour	<50%	48	*	68	*	78	*	81
	On contour	>50%	23	*	52	*	68	*	77
	On contour	100%	6	*	28	*	55	*	63
Pasture	Rows on contour	Poor							
	Rows on contour	Fair	47	57	67	75	81	85	88
	Rows on contour	Good	25	46	59	67	75	80	83
	Irrigated	Good	6	14	35	59	70	75	79
			35	41	48	57	65	68	70
Orchards	No ground cover	-							
	Ground cover	-	48	59	68	74	79	82	83
	Ditto + contour banks	-	39	44	53	61	66	69	71
			22	38	52	61	68	72	75
Plantation	-	Poor	52	62	72	77	82	85	87
		Fair	41	53	64	69	74	77	80
		Good	30	43	56	61	66	69	72
Grassveld	-	Poor	68	74	79	83	86	88	89
		Fair	49	61	69	75	79	82	84
		Good	39	51	61	68	74	78	80
Natural forests	-	Poor	45	56	66	72	77	80	83
		Fair	36	49	60	68	73	77	79
		Good	25	47	55	64	70	74	77
Bushveld	-	-	28	34	44	53	60	64	66

*No values for these situations could be found in the literature, but an average between the two adjacent values should not be far out.

Step No. 8

Determine the Q value by referring to Tables 15.5(a)-(d).

Table 15.5(a): Runoff discharges (Q) in m³/sec.

Area (ha)	**Rainfall Intensity Zone 1 (See Fig. 15.2)**											
	RN 60 for slope factor			RN 70 for slope factor			**RN 80 for slope factor**			**RN 90 for slope factor**		
	F	M	**S**	F	M	**S**	F	M	**S**	F	M	**S**
2	0.03	0.04	0.04	0.08	0.11	0.13	0.19	0.24	0.30	0.34	0.38	0.93
5	0.05	0.07	0.09	0.15	0.23	0.30	0.36	0.51	0.65	0.70	0.92	0.99
7	0.06	0.08	0.12	0.19	0.29	0.40	0.45	0.65	0.88	0.90	1.28	1.40
10	0.07	0.11	0.15	0.23	0.37	0.55	0.57	0.89	1.20	1.20	1.65	2.00
15	0.10	0.14	0.19	0.30	0.48	0.75	0.75	1.20	1.70	1.55	2.25	3.00
20	0.12	0.16	0.22	0.37	0.58	0.93	0.90	1.45	2.15	1.85	2.80	3.85
25	0.13	0.17	0.25	0.42	0.68	1.10	1.02	1.70	2.55	2.15	3.30	4.60
40	0.17	0.24	0.37	0.57	0.90	1.50	1.40	2.30	3.50	3.00	4.70	7.00
50	0.19	0.28	0.43	0.64	1.10	1.75	1.65	2.70	4.05	3.50	5.50	8.20

Table 15.5(b): Runoff discharges (Q) in m³/sec.

Area (ha)	**Rainfall Intensity Zone 2 (See Fig. 15.2)**											
	RN 60 for slope factor			RN 70 for slope factor			**RN 80 for slope factor**			**RN 90 for slope factor**		
	F	M	**S**	F	M	**S**	F	M	**S**	F	M	**S**
2	0.07	0.10	0.12	0.16	0.23	0.25	0.31	0.39	0.52	0.49	0.55	0.56
5	0.13	0.18	0.28	0.30	0.46	0.60	0.60	0.87	1.09	1.03	1.36	1.40
7	0.16	0.23	0.37	0.38	0.58	0.80	0.75	1.14	1.42	1.35	1.80	2.00
10	0.20	0.29	0.47	0.48	0.75	1.15	0.95	1.50	1.95	1.75	2.365	2.80
15	0.25	0.38	0.63	0.62	1.00	1.50	1.26	1.95	2.75	2.30	3.30	4.20
20	0.29	0.45	0.78	0.75	1.28	1.85	1.53	2.40	3.50	2.80	4.15	5.50
25	0.33	0.51	0.92	0.87	1.40	2.20	1.80	2.80	4.20	3.20	4.90	6.60
40	0.46	0.70	0.20	1.20	1.90	3.00	2.40	3.90	6.00	4.40	6.90	9.90
50	0.54	0.82	0.40	1.40	2.20	3.60	2.80	4.50	7.00	5.00	8.00	12.0

Table 15.5(c): Runoff discharges (Q) in m³/sec.

Area (ha)	**Rainfall Intensity Zone 3 (See Fig. 15.2)**											
	RN 60 for slope factor			RN 70 for slope factor			**RN 80 for slope factor**			**RN 90 for slope factor**		
	F	M	**S**	F	M	**S**	F	M	**S**	F	M	**S**
2	0.20	0.29	0.37	0.36	0.48	0.54	0.58	0.71	0.89	0.79	0.90	0.91
5	0.37	0.55	0.80	0.66	1.00	1.35	1.12	1.60	2.00	1.70	2.20	2.25
7	0.45	0.70	1.05	0.82	1.30	1.80	1.42	2.10	3.00	2.20	3.00	3.30
10	0.57	0.90	1.40	1.06	1.70	2.40	1.70	2.70	3.60	2.85	4.00	4.60
15	0.73	1.18	1.90	1.40	2.20	3.25	2.35	3.70	5.10	3.80	5.45	7.00
20	0.88	1.43	2.30	1.70	2.70	4.10	2.90	4.60	6.50	4.60	6.80	9.00
25	1.00	1.65	2.75	1.90	3.20	4.90	3.40	5.40	7.60	5.30	8.00	10.8
40	1.37	2.20	3.70	2.60	4.40	6.80	4.50	7.30	11.0	7.10	11.3	16.0
50	1.55	2.60	4.30	3.00	5.00	8.00	5.20	8.50	42.0	8.40	13.2	19.5

Table 15.5(d): Runoff discharges (Q) in m^3/sec.

Area (ha)	Rainfall Intensity Zone 4 (See Fig. 15.2)											
	RN 60 for slope factor			RN 70 for slope factor			**RN 80 for slope factor**			**RN 90 for slope factor**		
	F	M	**S**	F	M	**S**	F	M	**S**	F	M	**S**
2	0.36	0.53	0.64	0.57	0.78	0.83	0.84	1.09	1.36	1.10	1.22	1.253.
5	0.66	1.00	1.44	1.05	1.65	2.05	1.65	2.30	2.88	2.30	3.00	104.50
7	0.82	1.30	1.90	1.33	2.15	2.85	2.15	3.00	3.90	3.00	4.20	6.409.
10	1.05	1.70	2.60	1.70	2.70	3.95	2.70	4.00	5.25	3.95	5.50	402.30
15	1.40	2.20	3.50	2.20	3.60	5.25	3.51	5.50	7.50	5.15	7.50	5.102.
20	1.65	2.60	4.30	2.70	4.40	6.55	4.30	6.70	9.50	6.25	9.40	507.00
25	1.90	3.00	5.00	3.15	5.10	7.80	5.00	7.90	11.2	7.25	11.2	
40	2.50	4.10	6.80	4.30	7.00	11.0	6.80	10.6	16.5	10.01	15.6	
50	2.90	4.70	7.80	4.80	8.00	13.0	7.80	12.5	19.0	1.9	18.0	

Example of a Q value calculation using the simplified SCS Method

Consider a catchment area near Witbank, Mpumalanga, the size of which was determined from a topographic map as being 47 ha. The land use consists of 15 ha of conventionally cultivated land and 32 ha of veld.

The cultivated land comprises a shallow Avalon soil (depth 700 mm into laterite) with a clay content of 15%. The land slope is 5%, and is without any contour banks.

The rangeland is divided up into a steep 10 ha section, with shallow soil and a poor basal cover. The rest lies on a 2% slope, similar depths and also with sparse growth and weeds.

Solution:

1. Witbank lies in Rainfall Intensity Zone 3.
2. The total catchment size is 47 ha.

3/4. Size of each homogenous unit is 15, 10 and 32 ha respectively.

5. Calculating the Runoff Number per unit of land use:
   - 15 ha cultivation, flat slope, straight row — HSG A/B: 15 x 77 = 1155
   - 32 ha (10 + 22) rangeland in poor condition — HSG D: 32 x 89 = <u>2848</u>

   Total sum of Area x RN = <u>4003</u>
6. Divided by total area of catchment (47 ha) gives an average RN of 85
7. The ave. slope of the catchment is $\frac{15 \text{ ha} \times 5\% + 10 \text{ ha} \times 10\% + 22 \text{ ha} \times 2\%}{47 \text{ ha}}$

   = 4.6% which is Moderate
8. The Q for 47 ha, with RN = 85, with moderate average slope and situated in Rainfall Intensity Zone 3: Table 15.5 (c):

   For 40 ha, Q = 7.30 m^3 /sec (RN = 80), and = 11.30 m^3 /sec (RN = 90), and

   For 50 ha, Q = 8.50 m^3 /sec (RN = 80), and = 13.20 m^3 /sec (RN = 90).

   For 47 ha, therefore, and by interpolation of the above, Q = 10.2 m^3 /sec.

15.4 The rational formula method

The Level of Expertise limitation requires that a more sophisticated formula be used in estimating Q values for catchment areas 50 to 7000ha. The formula recommended for use in this range of catchment sizes is called the Rational Formula Method. This formula was first proposed in 1851 by the Irish engineer Mulvaney. It has been improved upon over the years until it is now apparently the most widely used for determining peak flows from small catchments (less than 7000ha). Both the RSA Departments of Water Affairs and Forestry, and those of the provincial Departments of Agriculture use it today.

The formula states:

$$Q = \frac{C_T \times I_T \times A}{360} \quad \text{where}$$

Q = Peak flow in cubic metres per second

C_T = a runoff co-efficient, or dimensionless catchment characteristic that intimates the proportion of the rainfall that will run off the catchment during a design return period storm. It varies with storm recurrence interval (RI) C_T = C100 x F_T,

where

C_{100} is the 100 year runoff coefficient, and F_T is the adjustment factor for RI.

I_T = The average rainfall intensity (mm/hr) over the whole catchment area upstream of the site, for a given duration or period of time. In the Rational Method the time taken for runoff from the furthermost part of the catchment area to reach the site is called the Time of Concentration. By this time runoff from all parts of the catchment will be passing the site, and the flood will have reached its peak. This value is obtained with the assistance of Figure 15.3 Enter the Duration block with the Mean Annual Precipitation for the area, and go vertically up to the intersection with the previously calculated Time of Concentration for the catchment (see Table 15.6a). Then travel horizontally to the left into the Return Period block, and to intersect with the chosen Return Period. In wetland rehabilitation it will be 10 years for smaller works (i.e. Level 1 structures) and 20 years for larger ones (Level 2 structures). Proceed vertically downwards to intersect with the requisite Rainfall Region diagonal, and thence horizontally to the right in order to obtain the point rainfall depth of rain in millimetres. This value is now the rainfall amount that may be expected in the chosen Rainfall Zone, within a given Return Period (or Frequency) and during a given time period or Duration (i.e. the Time of Concentration). Rainfall intensity is then found by dividing the point rainfall by the time of concentration. This is entered into the Rainfall Factor block in Tables 15.6(e) below.

A = Effective area of catchment in hectares

360 = A conversion factor, changing millimetres per hour multiplied by hectares, to cubic metres per second.

The use of the coaxial diagram can be avoided by application of one of the Intensity Duration Frequency (IDF) equations. The most common of these are the:

Modified Herschfield Equation (Adamson, 1981), and

Regression formula of the Opten Noord and Stephenson (1982).

The Herschfield equation and its supporting data may be obtained from Department Environment report TR102. Op ten Noord and Stephenson (1982) give different equations for inland and coastal regions as given opposite.

$$\text{Inland:} \quad i = \frac{(7.5 + 0.034\ MAP)\ R^{0.3}}{(0.24 + td)^{0.89}}$$

$$\text{Coastal:} \quad i = \frac{(3.4 + 0.023\ MAP)\ R^{0.3}}{(0.20 + td)^{0.75}}$$

Where:

i = average rainfall intensity over time td (mm/hr)

MAP = mean annual precipitation (rainfall) for the site (mm/yr)

R = Recurrence interval (years)

td = storm duration = catchment time of concentration (hours)

These equations were derived from the same data as the coaxial diagram of Midgley (Figure 15.3). They are easy to calculate and require only the location and MAP of the site.

Note: Tables 15.6 form a complete calculation sheet comprising a number of different sections, leading the designer through the procedures, and all they have to do is follow the sections and choose the correct factors in turn.

The above formula is based on a number of assumptions which will not be dealt with here, except to say that the most important one is the assumption that the return period (frequency of event) of the peak flow is the same as that of the rainfall intensity and duration. Despite the shortcomings inherent in the formula it does seem to give good results as long as it is used with great care and circumspection. It simplistically describes the rainfall-runoff process. The 'I x A' portion of the formula describes the result of the rate of rainfall, falling on an impervious catchment and giving rise to maximum runoff discharge. This is, in turn, modified by all the physical factors embodied in the 'C' factor; those that tend to extract runoff from the maximum possible.

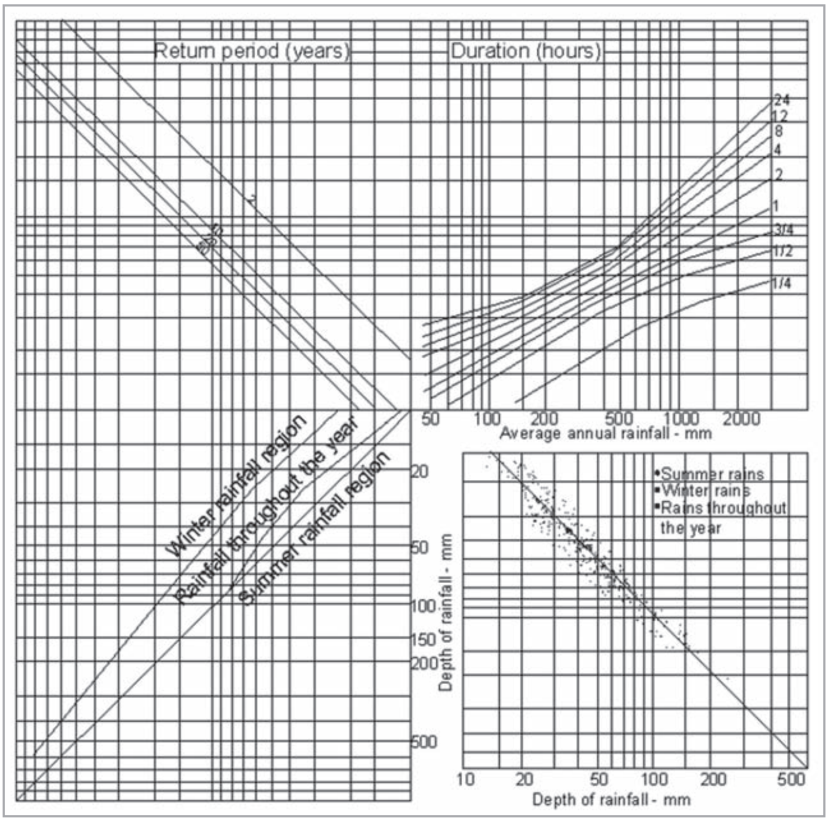


Figure 15.3: Depth-duration-return period diagram for determining point rainfall

A further significant assumption is that maximum runoff occurs only once all parts of the effective catchment area are contributing to the Q value that passes the measuring point or site for rehabilitation. In other words, the rainfall must continue at the required intensity from the hydrologically most distant part of the catchment, through to where the structure is to be built. This duration is called the 'Time of Concentration' (T_c). The sub-formula for Tc is given in Tables 15.6, and comprises two components – overland flow (where dispersed or sheet flow takes place, and concentrated flow that occurs in streamlines and gullies.

The average slope of water course is defined as the slope of a line that cuts through the plotted gradient of the water course, intersecting it in such a manner that there are equal areas on either side of the intersection of the areas being bounded by the plotted profile on the one hand, and the plotted slope on the other (see Figure 15.4). According to many authorities the slope is well approximated by the S_{1085} slope. Both are shown in Figure 15.4.

The answer is mathematically obtained by using the formula

$$S_{1085} = \frac{H_{85} - H_{10}}{0.75L} \quad \text{metres/metre}$$

In the example,

$$= \frac{33 - 2}{0.75 \times 4000} = 0.01\text{m/m}$$

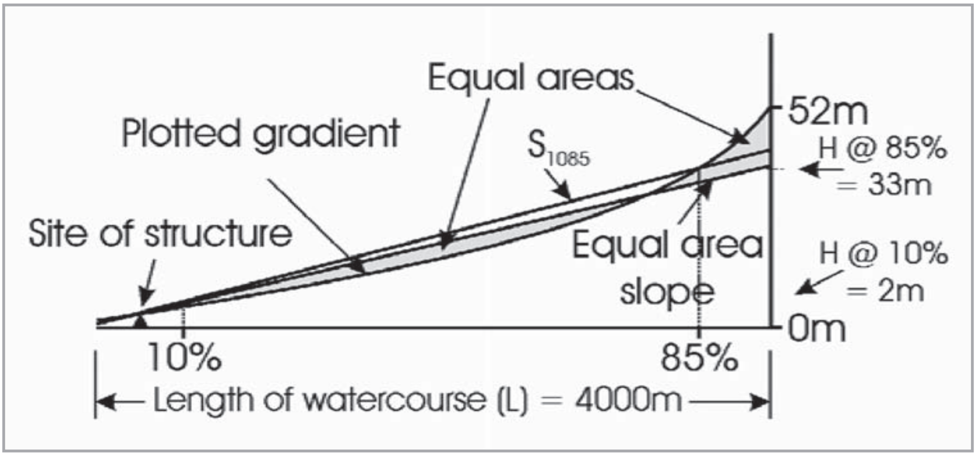


Figure 15.4: Explanation of determining equal areas and S_{1085} slope.

Tables 15.6: Calculation sheet for determining peak discharge for a chosen return period The tables presented on pages 154 to 156 (Table 15.6) can be photocopied for use by those professionals qualified to design level 2 structures.

Table 15.6(a): Calculation sheet for determining peak discharge for a chosen return period

DISCHARGE ESTIMATION: WfW REGION ………………………..

Wetland name: ……………..............	Lat.: …………….	Long.: …………..
Quaternary catchment No.: …………	Designer: ………..	Date: ……………

Height to top of catchment …..m
Longest length of flow (L): ……..m
Ave. slope (s) = …….. m/m
Length of overland flow L_o = ……m
Length of watercourse L_w = ……m
H_{10} = …..m
H_{85} = …..m
Size of catchment A = ………..ha
Geology: Dolomitic / Other.
If Dolomitic, - % of area

Catchment physical characteristics as a percentage of the area of catchment							
Land use : Rural ….%						Urban …..%	
Land slope (%)		Permeability (%)*		Vegetation (%)		Use (%)	
Wetlands, pans(<3)	0	Very	0	Thick bush**	0	Lawns	0
Flat (3-10)	0	Moderate	0	Light bushlands	0	Industrial	0
Hilly (10-30)	0	Semi-perm	0	Veldgrass	0	Residential	0
Steep (>30)	0	Impermeable	0	Bare	0	Streets	0
Total	100	Total	100	Total	100	Total	100

*Use the Hydrologic Soil Group Concept A-D
**Includes sugarcane and timber plantations

Mean Annual Precipitation = …….. mm
Rainfall Region: Winter … Year round … Summer..√..(Tick correct climate)
T_o (Overland flow) = $0.604[(r \times L_0 \div \sqrt{s_0})]^{0.467}$ * = …-… hours
(L_0 = length of overland flow) (r – see box below; s = slope of overland flow m/m)

Values of r : Paved area = 0.02, bare soil = 0.1, sparse grass and annually cropped lands = 0.3, moderate grass = 0.4, thick bush, forest and sugarcane = 0.8

$S_w = \dfrac{H_{85} - H_{10}}{0.75L}$ = ……m/m

T_w (Watercourse) = $(0.87L_w^{\ 2} \div 1000s_w)^{0.385}$* = …..hrs ($L_w$ & s_w relate to the watercourse only)

**If a scientific calculator is not available use logarithm tables or, as a last resort, the square root.*

Total Time of Concentration $T_c = T_o + T_w$ = ……… hours

Consult Figure 15.3 for point rainfall using the calculated T_c, the return period and the rainfall region.

See Table 15.6(e) for further use of point rainfall.

Table 15.6(b): Recommended values of runoff co-efficient for rural areas

COMPONENT	CATEGORY	MAP (mm)		
		<600	**600 - 900**	**>900**
Slope steepness C_s	<3% 3-10% 10-30% 30-50% >50%	0.01 0.06 0.12 0.22 0.26	0.03 0.08 0.16 0.26 0.30	0.05 0.11 0.20 0.30 0.34
Permeability of soil Cp	Very permeable Permeable Semi-permeable Impermeable	0.03 0.06 0.12 0.21	0.04 0.08 0.15 0.26	0.05 0.10 0.20 0.30
Vegetal cover Cv	Dense bush, forest,sugarcane Cultivated land, scrub Grassland Bare surface	0.03 0.07 0.17 0.26	0.04 0.11 0.21 0.28	0.05 0.15 0.25 0.30
Interpolate between columns if MAP is between 570 and 630, or between 860 and 950 mm. Interpolate between values where conditions dictate.				

Table 15.6(c): Recommended values of runoff co-efficient for urban areas

OCCUPATION	RUNOFF CO-EFFICIENT	COMMENT
Lawns: • Sandy, flat • Sandy, steep • Clay, flat • Clay, steep	 0.05 to 0.10 0.15 to 0.20 0.13 to 0.17 0.25 to 0.35	Use linear interpolation for intermediate values
Residential: • Single dwellings • Apartments	 0.30 to 0.50 0.50 to 0.70	
Industrial: • Light industry • Heavy industry	 0.50 to 0.80 0.50 to 0.90	
Business: • Downtown • Suburbia	 0.70 to 0.95 0.50 to 0.70	
Streets	0.70 to 0.95	

Table 15.6(d): Return period adjustment factor: to be applied to the calculated Runoff co-efficient

RETURN PERIOD	RURAL
T (years)	F_T
10 20 50	0.85 0.90 0.95
Where $C_T = F_T(C_S + C_P + C_V)$	No adjustment for urban conditions

Table 15.6(e): Rainfall factor

RETURN PERIOD (years)	10	20	50	Notes
Point rainfall for Time of Concentration				Enter values (in mm) in column for chosen Return Period
Point rainfall intensity (mm/hr)				Ave. I_T = point rainfall $\div T_c$
Area reduction factor (ARF)*				Area reduction factor only in respect of lakes and dams – subtract from area of catchment (A)
Average rainfall intensity I_T (mm/hr)				

*The ARF is a conversion from point rainfall to actual rainfall over the total area for a large catchment. Use ARF = 1.0 for area < 10 km². Use either the graph of Alexander (1990) of the equation of Opten Noord & Stephenson (1982)

ARF = (1.04 -0.08Ln(A))(td^(0.02A^0.28))
Where
A = catchment area (km²)
td = storm duration (hour)

Experience in calibrating a PCSWMM model up to 50 km² against the proportion of RMF (Kovacs 1988) is that an average of the two values works best.

Table 15.6(f): Runoff factor

RETURN PERIOD (years)	10	20	50	Notes
Rural C_1				Enter adjusted co-efficient values in chosen return period column
Rural C_2				
Lakes		-		
Area weighted average C_T*				

* Calculation of composite C_T

Rural:
$C_I = C_S$ = ... =
+ C_P = ... =
+ C_V = ... =

Urban:
C_2 = ... =

Weighted
Average Total C = ... =
Q_T = ... = ...m³/sec
Q_T adjusted = ...m³ /sec

Table 15.6(g): Peak discharge (QT) for chosen return period

RETURN PERIOD (years)	10	20	50	Notes
$Q_T = 0.00278 \times C_T \times I_T \times A$ m³ /sec.				*This factor is the same as 1/360(See Table 15.6(d))
Corrected peak flood				

CHAPTER 16:

RECOMMENDED LEVELS OF COMPETENCY IN DESIGNING REHABILITATION STRUCTURES

This manual has been produced as a guide for whoever is intent on attempting wetland rehabilitation, and who may need assistance. Some of these persons have not necessarily qualified in any level of civil engineering or in wetland rehabilitation, nor may they have much practical knowledge in this field. Design of structures is not a simple matter, and funds will become less available if *ad hoc* rehabilitation, carried out in all sincerity, results in a number of failures through incompetence. There is a need, therefore, to consider the competency of persons who should work with civil engineering structures, and more specifically, within wetlands, whether it be in planning, survey, design and/or construction work. It cannot be expected of a person to design, implement, and/or monitor a structure if he/she has not had the necessary training and subsequent experience in the subject. There is also the aspect of approval of works designed. The person approving funds for the project must satisfy him/herself of the correctness of the project before recommending the granting of funds. Table 16.1 below offers an opinion on the expertise that should be required for the purposes of designing, implementing and monitoring wetland rehabilitation work.

Finally, and most importantly, there are the requirements of the Engineering Profession Act, No. 46 of 2000. Very briefly and in part, the Act sets out to "*provide for the registration of professionals, candidates and specified categories in the engineering profession…*" In terms of this Act, anyone actively practicing in the following categories must be registered with the Engineering Council of South Africa established simultaneously in terms of this Act: Engineer, Engineering Technologist, Certificated Engineer or Engineering Technician; either as a registered Professional or as a Candidate. No one may practice in any of the categories contemplated without such registration, and the Candidates without supervision and control by a registered Professional. Before employing anyone to design any works, one will have to enquire regarding their registration with the Engineering Council.

People registered in accordance with the Engineering Professions Act (Act 46 of 2000) must take account of the "*Rules of Conduct for Registered persons: Engineering Professions Act: 2000*" published in Government Gazette No 28605 of 17 March 2006, and in particular "*registered persons may not undertake or offer to undertake work of a nature for which their education, training or experience have not rendered them competent to perform*" and must realise that work on wetlands and water courses requires special knowledge and experience.

The limitations on the Levels have been set with due regard to the:

- complexities of civil engineering design
- degree to which one can risk simplification of the design procedures
- inexperience of most of the wetland workers in carrying out designs
- damage and fruitless expenditure that could arise as a result of their inexperience.

It was considered necessary to set three aspects of structure design that should be collectively applied in granting the authority. The danger of structure failure increases dramatically with height and depth of overflow, and the estimation of runoff intensity requires more experience and insight with larger catchment areas. Structures over 5.0 m in height may also require special permits under the Dam Safety Section of the National Water Act, that by law require higher qualifications and experience of the designer.

Table 16.1: Levels of expertise recommended for the design, implementation and monitoring of wetland rehabilitation work

Level of structure required	**Maximum** height[1] of structure (m)	Depth of **overflow (mm)**	**Maximum** velocity through **structure (m/s)**	**Maximum** velocity through **structure (w/s)**	Runoff intensity calculation method	**Maximum size** of catchment area (ha)	Authorized designer	Implementation	Monitoring
1	2.0	250	1.5	1.5	Simplified SCS method or equivalent	50	Certifiedwetland worker Gr 1[2]	Certifiedwetland worker Gr 1[2]	Certifiedwetland worker Gr 1[2]
2	5.0	500	3.0	3.0	Rational Method or equivalent	7000	Nat Dip Tech (Civ Eng or equivalent)	Certified wetland worker Gr 1[2]	CertifiedWetland worker Gr 1[2]
3	>5.0	>500	>3.0	>3.0	ACRU wetland simulator or equivalent	>7000	Civil Engineer	Certifiedwetland worker Gr 2[2]	Certifiedwetland worker Gr 2[2]

1. Maximum height means height from the foundation to crest level.Attention is drawn to the requirements of the Dam Safety Regulations embodied in the National Water Act.
2. Wetland workers who have attended suitable training courses and have been tested by persons, suitably qualified in civil engineering, and have been certified to be proficient enough to carry out the required work.

CHAPTER 17:

THE USE OF MANNING'S FORMULA FOR VELOCITY IN CHANNELS

17.1 Introduction

It is often necessary in erosion control to determine the velocity of flowing water under various conditions of slope, soil type (generally in terms of soil erodibility) and vegetation conditions. If velocity can be reduced and controlled without using the hard option (i.e. the construction of weirs and chutes), not only will costs be radically reduced but the question of maintenance could also be made much simpler.

As was discussed previously, the presence or absence of vegetation in a channel, be it a natural water course or an erosion gully, will have a distinct influence on the velocity of runoff flowing along it, and therefore the chance of accelerated erosion taking place. A dense stand of vegetation in a channel, for instance, will reduce the speed of flow through friction, while denudation of the vegetation in that same channel will cause whatever water flows along it to increase in velocity. In a like manner, the deeper water flows along a given channel, the swifter it will flow, with the same result. Put another way, water flowing along a deep, narrow channel will flow faster than if the selfsame channel was wider and the water was able to spread and therefore flow at a shallower depth. While the energy head of the flowing water is reduced, this also allows friction between the water and the surface of the channel to play a greater part in slowing down the runoff. It is often possible to control the speed of flow, and therefore the rate of erosion, by either establishing a dense stand of suitable vegetation in an erosion gully, or to widen the gully. A combination of the two possibilities may be the final, best choice.

The solution to this type of problem lies firstly in determining the runoff intensity that can be expected out of the catchment above the problem site and which was dealt with in Chapter 15. Secondly, in determining the erosion hazard of the gully; and finally in finding out how much vegetation to introduce and/or by how much to modify the gully itself.

The soft option of using suitable vegetation to reduce the velocity of flowing water and thereby the erosion potential of a site is termed bioengineering. While an example of the use of Manning's Formula to do this is given below, the various practical methods of establishing vegetation is discussed in Chapter 6.

From the above it should be evident that, if one is to consider both soft and/or a combination of soft and hard options in counter-acting erosion in a gully, it is necessary to determine the velocity of flowing water. This must be carried out under different conditions of slope, gully shape, soil type and vegetation conditions.

It is not feasible to wait until a certain flood event occurs and then be on hand to measure the velocity of the flowing water. Instead, when the value of V is required for design purposes, Manning's Formula is used.

Manning's Formula is only applicable to uniform flow, i.e. when the cross section and the slope of the water course are unchanged for a reach length of at least 5-10 times the width of the flow, and when there is no downstream obstruction which may cause the water to back up.

Manning's Formula

$$V = \frac{R^{2/3} x S^{1/2}}{n} \text{ metres per second, ...(Eqn. 1)}$$

where

V = velocity of flow in a channel, measured in metres per second

R = Hydraulic radius of the channel

= Cross sectional area of flow in the channel divided by the surface, or perimeter of the channel that is wetted by the floodwater:

$$= \frac{\text{Area of flow } (m^2)}{\text{Wetted perimeter (m)}} \qquad \text{..........................(Eqn. 2)}$$

S = Slope of the channel measured in metres fall per metre length.
The slope (and shape of gully) must be measured over a distance of at least 25 times the depth of flow and where the parameters are uniform over the 25 m length. This depth of flow would be taken as that indicated by the highest water level marks on the walls of the gully.

n = Mannings co-efficient of roughness of the channel.
See Tables 17.1 and 17.2 below.

Note that this is an empirical formula, derived as a result of observed results of experimentation, and factors fitted to best meet the observed reactions. The symbols should therefore not be transposed either side of the equal sign in order to derive one or other factor.

Table 17.1: Some Roughness co-efficients for Manning's Formula in various environmental settings

Stream/gully conditions	Manning's co-efficient
Straightened, bare earth canal	0.02
Winding, natural stream with some plant growth	0.035
Mountain stream with rocky streambed	0.04-0.05
Winding stream with abundant plant growth	0.04-0.05
Sluggish stream with very abundant plant growth	0.065
Very sluggish stream with extremely abundant growth	0.112

Table 17.2 Calculation of Mannings n factor (after Venn te Chow*)

Channel condition		Value	
Material involved	Earth Rock cut Fine gravel Coarse gravel Concrete	n0	0.020 0.025 0.024 0.028 0.015
Degree of irregularity	Smooth Minor Moderate Severe	n1	0.000 0.005 0.010 0.020
Variations in channel cross section	Gradual Alternating occasionally Alternating frequently	n2	0.000 0.005 0.010
Relationship of vegetation height to flow depth	Flow depth 1-2 times the height of vegetation: Vegetal cover : Fair Good Excellent	n4	0.010 0.020 0.025
	Flow depth equal to height of vegetation: Vegetal cover: Fair Good Excellent	n4	0.025 0.030 0.035
Degree of meandering	Minor Appreciable Severe	m	1.000 1.150 1.300

* Venn te Chow. Open channel Hydraulics. International Students Edition

The calculated n value is the result of the summation of n_o through n_4, multiplied by m.

Once an approximate depth of flow has been calculated using Manning's Equation, calculate the Froude number:

$$F = \frac{Q^2B}{gA^3}$$

where
A = cross sectional area of flow
B = width of surface of water

If F > 1.0 flow is supercritical, the flowing water will not turn corners, wave height will be large and special problems can be expected.

If F <1.0 flow is subcritical (tranquil) and much easier to manage. If F cannot be kept <1.0 by control structures and managing slope and roughness, a Level 3 design is required.

17.3 Maximum non-eroding velocities

On the subject of velocities, it should be understood that there is a threshold maximum velocity for each and every material used to line and so protect the material of a channel or spillway, which, if exceeded, will cause the breakdown of the said lining (Table 17.3). A lining of concrete, for instance, is very much stronger than brickwork, and the former will provide very much better and more durable protection against high velocities than will the latter. Another example would be a gully or drainage ditch, the soil of which is eroding. Lining the gully walls with suitable living vegetation may solve the problem, if that vegetation is strong enough to withstand the energy of the water flowing down the gully. This is the essence of bioengineering in water channels. In attempting to control

Table 17.3: Maximum non-eroding (aka. non-scouring) velocities for various materials in soil conservation design (SA Dept. of Agric. Tech, undated. *Soil Conservation Engineering Manual*)

TYPE OF LINING	Maximum velocity against scour (m/s)
Bare, coarse, sandy soil*	0.5
Bare, sandy loam*	0.7
Bare, firm, clay loam*	1.0
Poor grass cover on erodible soil*	1.0
Fair grass cover on moderately erodible soil*	1.2
Good grass cover on erosion resistant soil*	1.5
Dense kikuyu mat on erosion resistant soil*	2.5
Dense wetland vegetation on erosion resistant soil	2.5
Lining of rock masonry 375 mm thick**	3.0
Lining of concrete in geocells 100 mm thick**	3.0
Lining of interlocking blocks(Armaflex)**	3.0
Lining of gabion mattresses**	3.0

* These materials will not take long duration flow without damage

** If 2x v^2 / 2g (m) > slab thickness (m) the slab could lift unless it is well anchored

the water erosion in a gully one needs to either find a suitable plant specie(s) that will protect the gully walls/bed from further damage, or another that will assist in reducing the velocity of the water.

17.4 The effect of slowing down the velocity of water in a channel

When seeking a solution of this nature, one must also bear in mind that slowing down the velocity of runoff flowing in a channel will automatically result in an increase in the depth of the water. Equation 3 read in conjunction with Figure 17.1 will explain this.

Q = A x V ....(Eqn. 3)

Where

Q = Flow rate (m^3 per sec)

A = Area of flow = W x d (m^2)

V = Velocity (m/s)

W = Average width of channel (m)

d = Depth of flow (m)

This equation indicates that A (the cross sectional area of flow) is indirectly related to V. If V, therefore, is slowed down by the vegetation, A must increase. If the flow width (W) is unchanged, d (the flow depth) must increase.

Where this option is chosen, the designer must specify planting of the chosen species at least up to the new calculated flow depth. A freeboard of 500 mm should be added to guard against splash damage. However, with shallow gullies and drains, the slowing down of the velocity could have the benefit of lifting some of the runoff into the adjacent wetland.

17.5 An example illustrating the frictional effect of a change in lining

With reference to Figure 17.1, consider an eroding gully or drain, the dimensions of which are as indicated in solid lines. It lies at a gradient of 2% (i.e. 0.02 m per m in terms of Manning's formulation). The channel walls are bare, and, with reference to Table 17.2 above, Manning's 'n' value is of the order of 0.02. The channel flows full with high intensity storm runoff.

From the data given, the derived information for use in Manning's Formula (Eqn. 1 above) is:

Cross sectional flow area = 3.75 m^2. The wetted perimeter 'p' = 3.1 m, and 'R' therefore = 1.21. This makes $R^{2/3}$ equal to 1.07.

Using Manning's Formula, velocity when

the gully is flowing full is 8.0 m/s, and Q (discharge through it) is 30 m^3 per sec. (Q = A x V). This is the reason the gully is eroding so badly.

In an attempt to stabilise the gully, planting it to suitable wetland vegetation is to be considered. This will change the 'n' value to approximately 0.04. Solving Equation 1 with this new 'n' value, the flow velocity during high intensity runoff will drop to 3.7 m/s, and the discharge to 13.87 m^3 per sec. The rest of the Q will lift out of the gully and hopefully spread over the adjacent wetland. The V = 3.7 m/s is, however, still too high and the gully will continue eroding, albeit at a slower rate. See Table 17.3. Bioengineering in this instance will not solve the problem completely.

17.6 An example of using a change in the shape of the gully

The broken line in Figure 17.1 indicates a constructional change in the shape of the gully – purposefully making it shallower and wider. The channel is made only 1 m deep but 3 m wide at the base and with gentle shoulders of 1:3. Because of this change, and particularly with the shallower depth, it is expected that a better plant growth will eventuate and so the expected 'n' value is increased to 0.055.

A = 5.5 m^2, p = 9.3 m, R = 0.59, and $R^{2/3}$ = 0.70.

Solution of Equation 1 therefore gives

V = 1.8 m/s and Q = 9.90 m^3 per sec.

Velocity is now well within the maximum for wetland vegetation (Table 17.3) and the adjacent wetland will benefit even more from the expected spillover.

Chapter 7 indicates how the channel should be re-shaped and stabilised. Chapter 6 also discusses the finer points of establishing vegetation.

17.7 Using Manning's Formula to estimate runoff intensity Q

Equation 3 reads:

$$Q = A \times V \ (m^3 \text{ per sec})$$

This can be re-written as

$$Q = \frac{A \times R^{2/3} \ S^{1/2}}{n} \ m^3 \text{ per sec}$$

Establish the high water mark in the gully. This will indicate flow depth. Measure the shape (and flow depth) and gradient of the gully (see Section 17.2 above). Calculate cross sectional area of flow as well as the wetted perimeter. Estimate the frictional value of the gully 'n', and then use the above formula for determining the Q value. This method may be used for minor works in small catchments (Level 1 structures – see Chapter 16). It is a bit risky to use it for major works, but could be a backup for checking on the conventional methods of runoff intensity predictions.

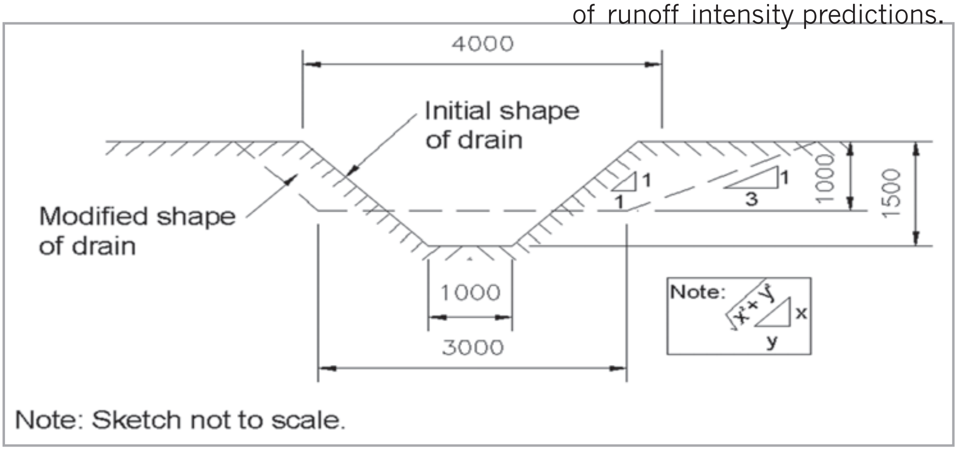


Figure 17.1: Modifying the shape of a gully in bio-engineering

CHAPTER 18:

DETERMINGING FREEBOARD FOR ALL WATER CONTROL STRUCTURES

The wet freeboard is the depth of flow through a spillway at the time of design flood peak, and is given the symbol h – generally expressed in mm units. This is added to the dry freeboard (Table 18.1) to obtain total freeboard. If the answer is smaller than the total freeboard as shown in column 3 in Table 18.1, then the dry freeboard is increased to ensure the minimum dimension recommended. When the structural material is soil the values are for soil that has been firmly compacted at the optimum moisture content for maximum dry density. Otherwise the values below apply equally to gabion and concrete structures. The calculation of wet freeboard is discussed in Chapter 21.

In spite of what has been discussed above, it is sometimes possible (in the case of earthen structures) to reduce total freeboard to less than the minimum by stabilising the downstream gully banks so that the structure will survive as a 'drowned structure' during a flood event. This is especially possible with a box weir (Figure 9.3).

Unless it is intended and expected that flow will overspill the banks of the channel the minimum freeboard should be v^2 / 2 g (m) to ensure that the freeboard is higher than the potential wave runup height. (Where v = velocity of flow and g = 9.8 m/s$^{2.}$

Table 18.1: Recommended freeboards on water control structures in natural catchments, irrespective of type of structure or construction material used (RSA Dept. of Agriculture)

Maximum catchment size (ha)	Minimum dry freeboard (mm)	Minimum total freeboard (mm)
100	500	1000
250	750	1500
500	1000	1800

CHAPTER 19:

EARTHEN DIVERSIONS

Earthen diversion embankments are designed to divert water into a portion of the wetland that acts as a natural spillway known as a side or bypass spillway (See Figure 19.1(a)).

19.1 Determining the width of a bypass spillway

In order to determine the width of spillway to accommodate the design discharge Table 19.1 should be consulted. The values have been derived from formulae that are not necessary to consult for the purposes of this manual.

Determining the width of spillway involves two steps:

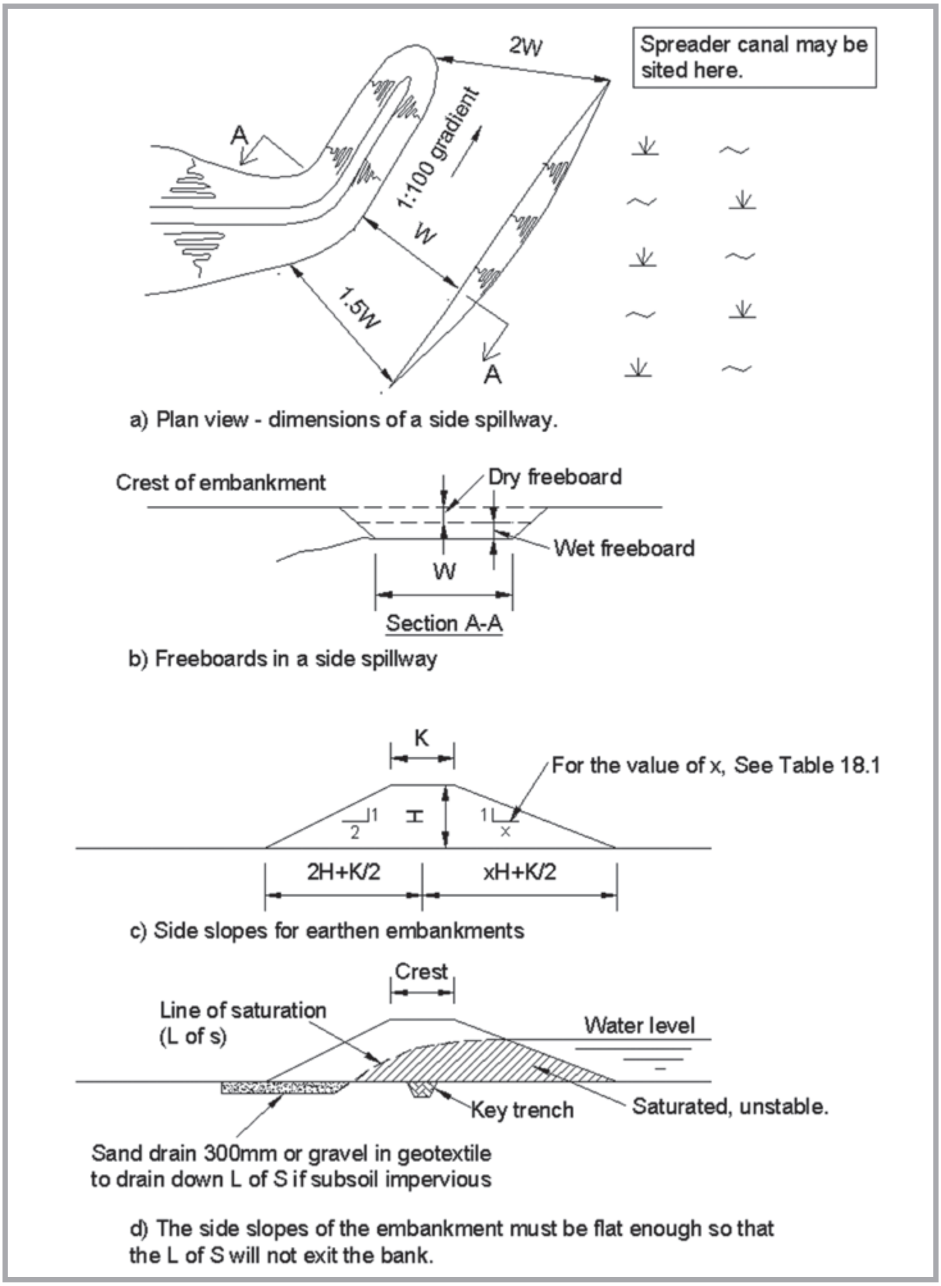
- According to the soil type in the side spillway, read the value of q in the final row of Table 19.1. This q represents discharge per metre width of spillway.
- Width of spillway (W) is determined by relating total discharge (Q – see calculation in Chapter 15) to the discharge per metre (q) as follows:

W (the width of spillway) = Q/q metres

The answer thus obtained is for an earthen spillway, level in width but at a gradient of 1:100, without any vegetation present protecting the soil from erosion. If there is a good vegetation cover already present in the planned spillway, the q value in the adjacent (righthand) column (Table 19.1) can be used in calculating the width of the spillway (W). See Figure 19.1 for details.

Table 19.1: Discharge through earthen side spillways at a gradient of 1: 100

Soil type in side spillway	**Sand to** sandy loam	**Sandy loam** to loam	**Loam to** loam clay	**Loam clay** to clay	Clay, laterite, etc. kikuyu mat	Rock		
						Soft	Medium	Hard
Permissible velocity in spillway (m/sec)	0.3	0.6	0.8	1.1	1.3	1.4	1.7	2.0
Flow depth (mm) (wet freeboard)	150	300	450	650	750	900	1200	1500
q: discharge per metre width of spillway (q = r×b)	0.05	0.18	0.36	0.72	0.98	1.26	2.00	3.00



a) Plan view - dimensions of a side spillway.

b) Freeboards in a side spillway

c) Side slopes for earthen embankments

d) The side slopes of the embankment must be flat enough so that the L of S will not exit the bank.

Figure 19.1: Design aspects of earthen embankments

19.2 Guidelines for crest width and side slopes of the embankment

Irrespective of whether the structure is a so-called 'soil plug' one metre high or an earthen diversion embankment 5 metres high, the recommended side slopes are as shown in Table 19.2. The various methods of achieving these slopes during construction are illustrated in Chapter 29. These side slopes take account of the need to maintain the Line of Saturation that builds up within an earthen structure that dams up water (see Figure 19.1d).

Particular care must be taken to ensure that adequate compaction of the surface of steep embankments. The embankment should be overfilled to a width about 0.5 to 1.0 m greater than the finished width and trimmed back to fit the profile (Figure 19.2)

Table 19.2: Recommended minimum side slopes and crest widths for earthen structures (dimensions in metres)

Wall height	Waterside paved*		Waterside unpaved		Crest width K (m)
	Waterside	Downside	Waterside	Downside	
0-2.5	1 : 1 ½	1 : 2	1 : 2	1 : 2	2.5
2.6-3.5	1 : 2	1 : 2	1 : 2 ½	1 : 2	3.0
3.6-5.0	1 : 2 ½	1 : 2 ½	1 : 3	1 : 2 ½	3.5
For average conditions			1 : 3	1 : 2	-
Soil not easily compacted			1 : 4	1 : 2	

* In this context 'paved' means that the slope is packed with a layer of rock 250 mm thick, from bottom to top, in order to protect it from the erosive action of waves.

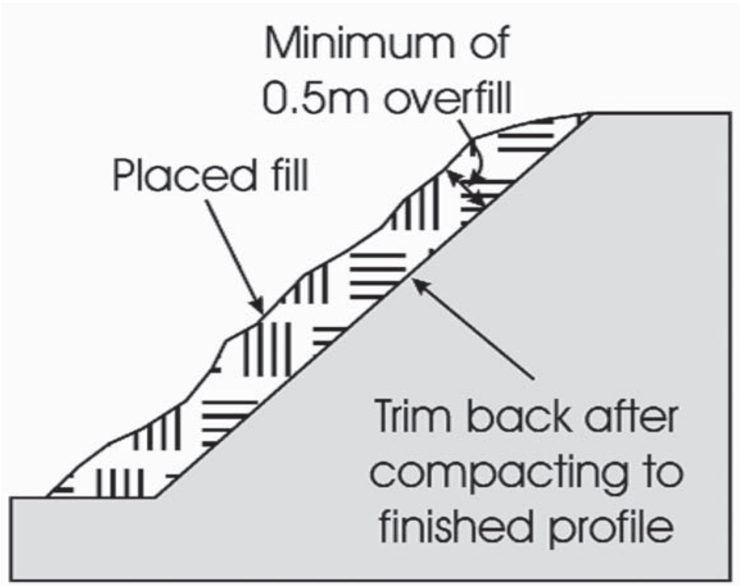


Figure 19.2: Overfill required on a steep embankment

CHAPTER 20:

RECOMMENDED LEVELS OF COMPETENCY IN DESIGNING REHABILITATION STRUCTURES

20.1 Storm water drains/canals

Storm water canals (aka. storm water drains) could also be dealt with under Chapter 13 as they are, in effect, used to divert runoff from a problem area to a safe disposal point. However, they are similar in effect to Spreader Canals, and so it is considered appropriate to deal with their design at this point.

Figure 4.9 in Chapter 4 illustrates the case where a storm water drain could be used to collect runoff that is causing a fanning out of multiple headcuts, and to channel it into a single chosen point where the safe disposal could be dealt with more economically. There are precautions to this option and they are as follows

- If the catchment area above the proposed drain is badly degraded and yielding excessive amounts of sediment, biological and mechanical measures should be instigated there first in order to reduce the amount of sediment. Storm water drains are designed and surveyed to intercept runoff and carry it in a non-erosive manner to a disposal point. Their gradients are necessarily lower than that of the topography from whence the runoff comes. The runoff will therefore obviously flow slower than previously, and with the drop in velocity, a large portion of the sediment carried in suspension will be deposited in the drain. This will result in the need for regular maintenance. If the sediment is not removed timeously the drain will lose its capacity and overtop during a heavy rainfall event. Further erosion will follow, and the entire project could be in danger of failure.
- In the drier areas of the country, vegetation very often depends largely on runoff for its water needs. Diversion of runoff from such areas could cause desiccation of the ground cover lower down the slope. In this instance the diversion should be designed in such a manner as to allow a portion of the runoff to pass through/over/under it. This is not always feasible, and points to a very serious negative side of a storm water canal, especially in the drier areas of the country.
- The easiest method of constructing a storm water canal, and usually the most cost-effective, is to make it out of the *in situ* soil material. Two problems will automatically occur if this path is followed:
  - The subsoil in a soil profile is often more erodible than the topsoil. Excavating into the soil surface in order to create capacity for the canal (see Figure 20.1) may cause the canal to be eroded into a gully if special precautions are not followed. Where the velocity of the runoff in the canal must needs be greater than the maximum non-scouring velocity of the subsoil material, the ditch will have to be excavated at least 150 mm deeper and better soil imported to cover the problem subsoil. One of the obvious solutions will be to stockpile the topsoil removed during excavation, and use it to protect the subsoil by bringing it back again once the necessary depth (plus the 150 mm topsoil removed) has been excavated. The double handling, or the importation of suitable soil from elsewhere, will have its down sides, and costs will escalate. The covering soil will need to be protected from erosion, and so vegetation will need

to be established within it. In this instance care must be taken in the selection of the type of plant material used. Bearing in mind the relatively slow velocity built into the design of the canal, any vigorously growing plant species could slow down fairly radically the flowing water in the canal, to the extent that it could no longer cope with the higher rates of runoff. Over-topping will then occur that would do damage to both the canal itself and the area below it. A low-growing, sod-forming type of species, suited to the climate, would offer the best solution.

- Domesticated herbivores especially, tend to congregate on artificial earthen structures. They also trample footpaths across them. Both of these actions cause damage to the earthen embankment that normally forms part of the structure, and this could lead to failure through over-topping during a high runoff event.

The implementation of earthen canals should therefore be planned with due care for the problems associated with them. Types of storm water diversion structures;

- The earthen type and its associated problems have been discussed above, and Figure 20.1 has reference. Soil that is excavated to form the canal is compacted in the form of a berm on the lower side of the canal in order to increase the capacity of the structure. It is this berm that can become a problem if not regularly maintained. It is most easily built and compacted with a tractor and plough. Using hand labour will require extra effort in achieving optimum compaction.
- An alternative to the above is the Spreader Canal form (see Section 20.2), but built at a gradient to lead runoff in the required direction, and where the excavated soil is stockpiled upslope of the canal. Breaches left along its length are fashioned to allow runoff to enter the canal. While being more expensive than the type described above because of the lack of a berm to increase capacity, this type lends itself to allowing a portion of the runoff to spill over along its length and so wet the area down slope. This is achieved by pegging the canal at a gradient, but restricting the capacity of the canal so that it cannot divert all of the runoff intercepted.
- Both of the above types will require a fair amount of maintenance. The third type is normally the most expensive, but maintenance will be much reduced. It comprises a brick or concrete wall on a concrete foundation. Runoff builds up behind the wall in a triangular shape in cross section. Its cost efficiency relies on the slope of the land across which it is built. It will work well on a flat slope (<1%). The steeper the slope, however, the higher the wall will have to be built in order to ensure the required capacity. On the other hand, wetting the area down slope is simple – sufficient holes are left in the wall at ground level to allow runoff to filter through as the mass of the runoff moves along the structure. The one drawback is that it can only be designed after a proper survey along its proposed route has been carried out, and if the land slope changes frequently along the length, its design could be a nightmare, unless one can couple the design with some excavation. The shorter the length of canal required the easier it will be to design. The writer has seen this type of diversion constructed of rock-filled gabions. They do have the benefit of allowing seepage through them without any special modifications, but the cost (much more expensive than thin-walled concrete) and the problem of theft of the wire, should rule them out.

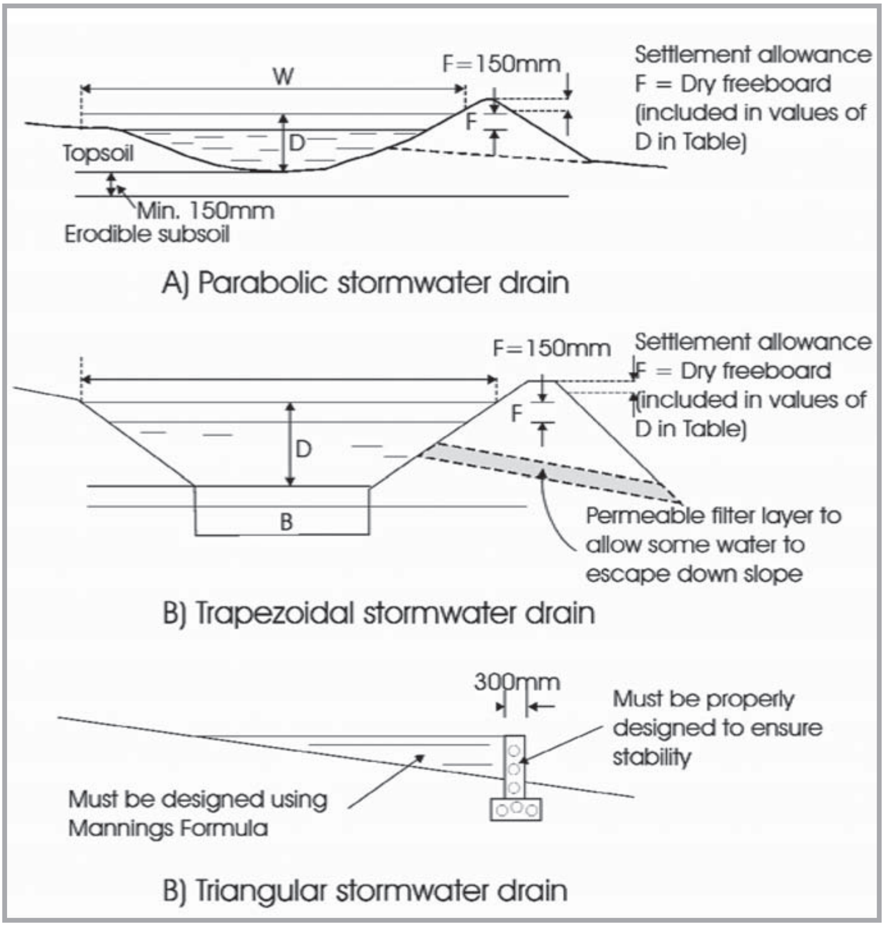


Figure 20.1: Different types of diversion structures

The design is carried out using Manning's Formula (see Chapter 17). It is therefore an iterative process, knowing beforehand the Q value, the approximate gradient required, the maximum non-scouring velocity for the soil type, and assuming an n value and size of canal. The result must give a final gradient and canal depth that will allow a velocity not more than the non-scouring one chosen, and the width and depth, along with the velocity, must result in sufficient capacity to ensure that the canal will not over-top during the design flood.

Fortunately, it is possible to calculate a number of options and to draw up a table of values. One then merely studies the table to choose an option with the correct discharge capacity and velocity. The engineers of the Department of Agriculture have done this any number of years ago, and with their kind permission Tables 20.1and 20.2 are presented below. Note that these structures are usually designed for a 10-year return period (flood frequency) instead of 20 years as for the larger structures whose repair will be extensive and costly if flood damaged.

It should be obvious from the tables that the parabolic shaped canal has a lower capacity than that of the trapezoidal type for the same depth and top width. The positive side of the parabolic shape is that lower runoff values are kept in narrower widths lower down in the drain, velocity is higher here, and consequently sediment is not be as easily deposited as can be the case with the trapezoidal shape. Sediment deposits reduce the capacity of the drain. Note that, in using the tables instead of carrying out the calculations, and under certain conditions, one need not adhere strictly to the two input values of velocity and Q. It will be acceptable to choose a combination of dimensions that will err on the lower side in respect of the velocity as long as the capacity is in order. It will also be in order to choose a combination where the capacity is larger as long as the velocity does not exceed the limit due to soil type. Making the capacity measurably larger than needed will of course result in unnecessary expenditure.

An example of the use of the tables follows: Suppose the Q value from a catchment area for a 10 year return period is calculated at 2.00 m3/s. Because of the soil type, in respect of maximum non-eroding velocity, the velocity of the flow in the canal may not exceed 1.20 m/s. Consulting two tables (Tables 20.2 and Table 20.3), the following options that could be considered are given in Table 20.1 below.

These are all very close to the required V and Q values. The flatness or steepness of the terrain, the gradient available, the soil depth and its erodibility, and the construction method, will all be taken into account in choosing the best solution. If the slope is >1%, one would tend to choose the option with a greater depth. This will reduce the amount of excavation. On the other hand, where the subsoil is very erodible, the choice would tend towards a canal with the shallower depth.

Table 20.1: Parabolic and Trapezoidal Options

Parabolic					Trapezoidal					
Gradient (%)	Depth (mm)	Topwidth (m)	Velocity (m/s)	Q (m^3/s)	Gradient (%)	Depth (mm)	Bottom width(m)	Top width(m)	Velocity (m/s)	Q (m^3/s)
0.25	0.90	6.00	0.75	2.00	0.20	0.10	2.40	5.50	0.70	1.32
0.50	0.95	4.00	1.20	2.20	0.20	0.30	2.40	4.90	1.00	1.24
0.75	0.76	5.00	1.20	2.20	0.30	0.50	2.40	4.30	1.10	1.21

Table 20.2: Dimensions (W) for parabolic-shaped storm water drains. All dimensions in metres

Gradient %	0.25					0.50					0.75					1.00				
Velocity (m/s)	0.45	0.60	0.75	0.90	1.20	0.45	0.60	0.75	0.90	1.20	0.45	0.60	0.75	0.90	1.20	0.45	0.60	0.75	0.90	1.20
Depth (mm)	0.54	0.82	0.91	1.04	1.34	0.40	0.61	0.70	0.76	0.95	0.36	.055	.061	0.64	0.76	0.32	0.49	0.55	0.58	0.67
Q (m3 / sec) :																				
0.20	3					3	3				4	3				5	3	3		
0.50	5					7	4	3			10	5	3				6	4	3	
0.70	7	3	3			10	5	3				7	4	3			8	5	3	
1.00	9	4	3				7	4	3			10	6	4				7	5	3
1.20		5	4	3			8	5	4				7	5	3			9	6	3
1.50		7	5	3			10	6	5	3			8	6	3				7	4
1.70		8	5	4				7	6	3			9	7	4				8	5
2.00		9	6	4				9	6	4				8	4				9	6
2.20		10	7	5			9	7	4				9	5					10	6
2.50			8	5	3				8	4			10	6						7
3.00			9	6	4				10	5				7						8
3.50			10	7	4					6				8						10
4.00				8	5					7				9						
5.00				9	6					9										
6.00					7					10										
7.00					8	*														
8.00					9															
9.00					10															

*The blank spaces indicate instances where the gradients are too steep and the discharges too great for the maximum non-eroding velocities applicable, and therefore requiring an impracticably large width and depth of storm drain. Where this is a problem, choose a different combination of dimensions, or plan to incorporate a permanent vegetation cover in the drain, thereby allowing a higher velocity. See Table 17.3 in Chapter 17 for maximum non-eroding velocities for a range of materials.

Table 20.3: Dimensions for trapezoidal-shaped storm water drains

Dimensions (m)			Gradient 0.1%		Gradient 0.2%		Gradient 0.3%		Gradient 0.5%		Gradient 0.8%		Gradient 1.0%	
B	D	W	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
1.20	0.15	1.8	0.3	0.06	0.4	0.08	0.5	0.10	0.6	0.13	0.7	0.16	0.8	0.17
	0.30	2.4	0.4	0.21	0.5	0.25	0.7	0.31	0.8	0.40	1.1	0.51	1.2	0.57
	0.45	3.3	0.5	0.46	0.7	0.52	0.8	0.63	1.1	0.82	1.3	1.01	1.5	1.16
	0.60	3.6	0.5	0.82	0.8	0.85	0.9	1.07	1.2	1.38	1.5	1.74	1.7	1.95
	0.75	4.3	0.6	1.30	0.9	1.32	1.1	1.61	1.4	2.07	1.8	2.63	1.9	2.95
1.8	0.15	1.8	0.3	0.09	0.4	0.12	0.5	0.14	0.6	0.19	0.8	0.23	0.8	0.26
	0.30	2.4	0.4	0.30	0.6	0.39	0.7	0.48	0.9	0.62	1.1	0.79	1.2	0.88
	0.45	3.3	0.5	0.62	0.7	0.75	0.9	0.92	1.1	1.18	1.4	1.50	1.6	1.68
	0.60	3.6	0.6	1.08	0.8	1.24	1.0	1.53	1.3	1.95	1.6	2.44	1.8	2.78
	0.75	4.3	0.6	1.67	0.9	1.87	1.2	2.29	1.5	3.06	1.8	3.68	2.1	4.08
2.4	0.15	1.8	0.3	0.12	0.4	0.16	0.5	0.19	0.6	0.25	0.8	0.31	0.9	0.35
	0.30	2.4	0.4	0.38	0.6	0.50	0.7	0.61	0.9	0.79	1.1	1.03	1.3	1.12
	0.45	3.3	0.5	0.79	0.7	0.99	0.9	1.21	1.1	1.59	1.5	1.98	1.6	2.21
	0.60	3.6	0.6	1.34	0.8	1.61	1.0	1.98	1.3	2.55	1.7	3.23	1.9	3.63
	0.75	4.3	0.7	2.04	0.9	2.38	1.2	2.92	1.5	3.77	1.9	4.76	2.1	5.33

20.2 Spreader canals

These are canals that are excavated in the wetland in order to receive runoff from a gully via the diversion structure and spread it across the degraded wetland. The diverted water is enabled to flow the length of the canal, to fill up to the lip of the canal, and then to overflow over its length, spreading slowly down the slope of the wetland (Figure 20.2) on a wide front.

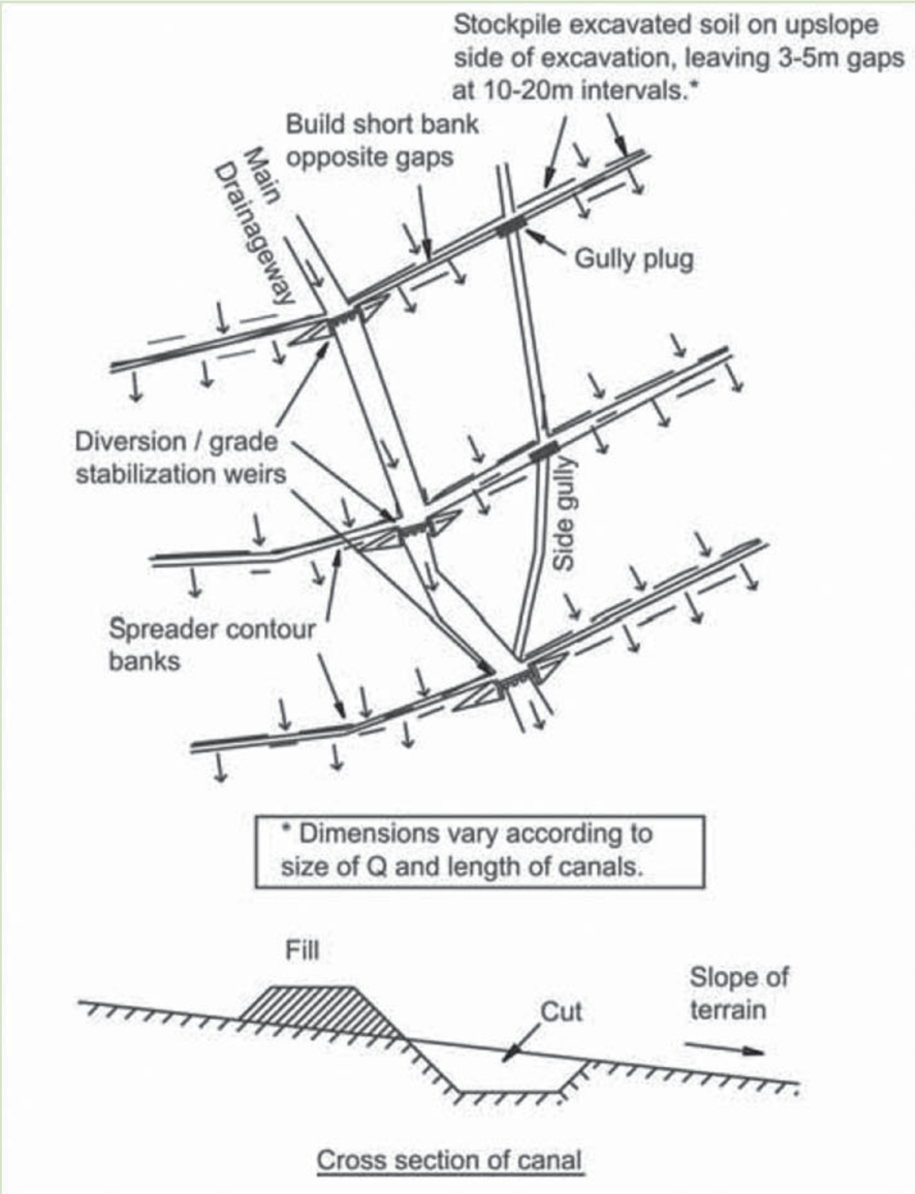


Figure 20.2: Inverted contour banks as spreader canals

The first problem to be overcome is that it should not be designed to carry all the runoff passing down the gully. If the Q value at the structure is large this could require a very large excavation in order to accommodate all the runoff. Another reason is that it is always preferable to handle smaller amounts of runoff, as large volumes of water get progressively more difficult to control effectively. A further reason is that it is better to use a number of spreader canals to achieve a better spread of water at regular intervals, rather than to divert masses of it at the top end.

Another problem with a spreader canal is what to do with the soil excavated. It will be too expensive and time-consuming (especially with hand labour) to remove the soil altogether. It cannot be stockpiled below the canal, as this will interfere with the pattern of water spreading. It can only be stockpiled, economically, upslope of the canal. As this will interfere with the runoff reaching the canal from the area upslope of the canal, the berm of stockpiled soil must be interrupted at regular intervals to allow this runoff to move into the canal.

The stockpiled soil cannot be simply dumped, otherwise it will be washed into the canal and its efficiency destroyed. The stockpiled soil must be adequately compacted and planted to suitable vegetation.

A further problem occurs where the gully does not have a perennial base flow, and during dry periods the level of the runoff collected in the basin behind the diversion structure drops. The water in the canal dries out, water seeps from the wetland into the canal, and thence back into the basin behind the structure, in effect draining the wetland. The spreader canal must therefore be provided with a 1% gradient away from the structure and into the wetland for the first 25 to 50 metres to get the water away from the gully. Thereafter it should be surveyed with a zero gradient for the rest of its length, up to its final planned length. If, however, the canal is to be in excess of 100 m in total length, then the second section should be excavated with a flat gradient of approximately 0.1% (i.e. after the first 1% section). This will enable the diverted water to flow the length of the canal while maintaining a level lip.

Figure 20.2 illustrates a typical system of spreader canals as used to rehabilitate degraded floodplains in the western and north-western Karoo where they have been constructed to great effect. The canals should initially be approximately 500 mm deep and 2 to 3 m wide. Spacing them down the length of the wetland will largely depend on the number and spacing of diversion structures in the gully. The recommendation for the western Karoo is 200 to 300 m apart. Alternatively, there is no reason why extra spreader canals can not be put in place without necessarily connecting them to a diversion structure. They could be excavated, with zero gradient in this specific instance, merely to collect any runoff that has started to concentrate, and to re-spread the water further downslope.

The efficient functioning of the canal will be largely dependent on the effective diversion of runoff from the gully entering the canal, and the lip of the canal remaining level (Figure 20.3). It is advisable to fix the elevation of the entrance to the canal by constructing a concrete sill or apron across it. Not only will this enable the correct leveling off of the entrance, but it will also stop vegetation growing in the entrance area and obstructing the flow of water into the canal. At this point one of the initial objectives is brought into play:

- If the base flow is to be diverted into the wetland, the elevation of the entrance sill to the canal must be constructed so that it is slightly lower than the spillway level of the diversion structure. The actual height difference will depend on the size of the stream, but 50 to 100 mm should be quite sufficient. The pegging out of the spreader canal must take account of the elevation of this point.

- If, however, the base flow is to remain in the gully, then the spillway level of the structure must be 50 to 100 mm lower than the level of the canal entrance sill. That will allow the base flow to pass over the structure, but some of the flood waters flowing deeper than the height difference just mentioned will pass into the canal entrance. Figure 20.3 illustrates the entrance requirements, and Figure 20.4 shows the construction requirements of the spreader canal.

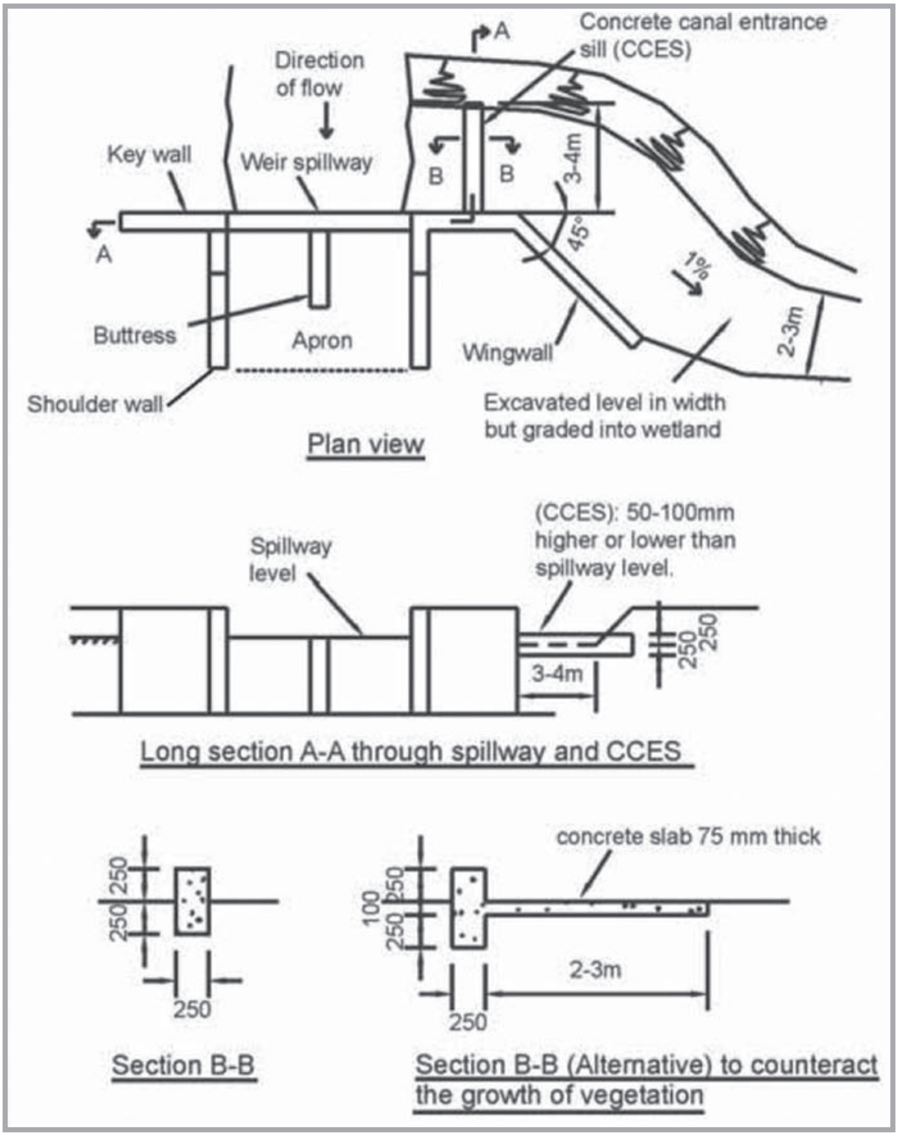


Figure 20.3: Detail of the spreader canal entrance

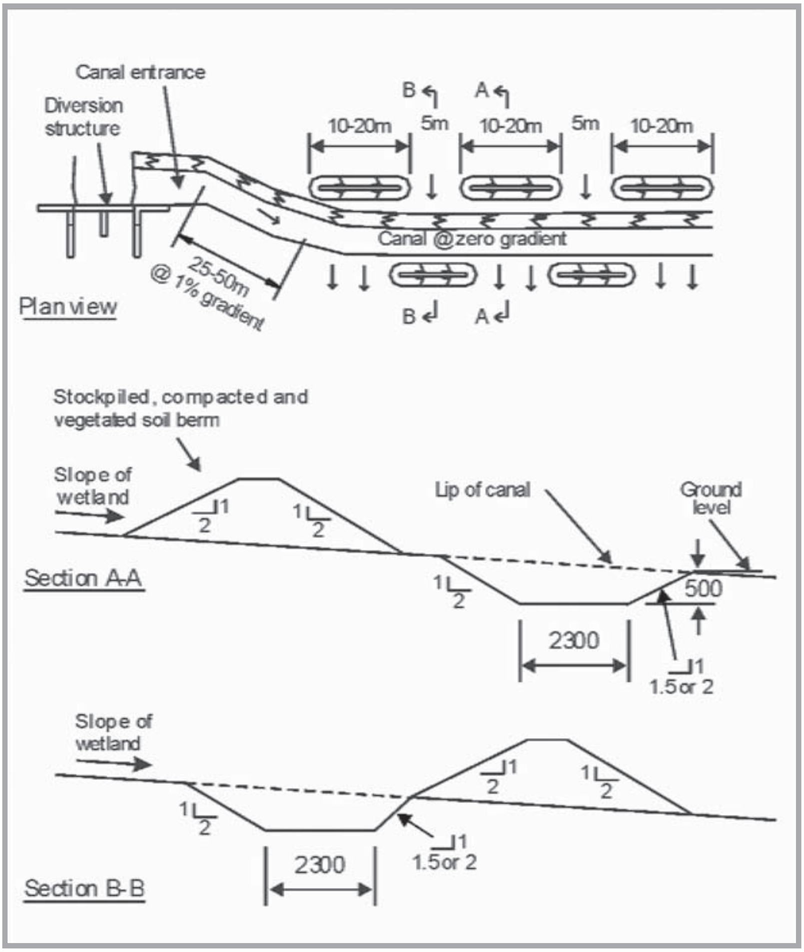


Figure 20.4: Detail of a spreader canal

CHAPTER 21:

WEIRS

21.1 Introduction

Weirs are free overflow structures such as rock packs, weirs and chutes, that serve to move water from a region of high elevation to one of lower elevation over a very short distance, and in so doing, ensure that the water thus moved remains largely in the gully (unless otherwise planned) and lacks energy to erode any further. The water moves over these structures through a centre spillway.

Determination of wet freeboard (h)

In considering the design and use of free overflow structures, determination of the dimensions of the wet freeboard of the spillway (Figure 21.1) is step number 1. One starts by determining both the design peak flood value in m^3/s (Q, see Chapter 15) and deciding upon the proposed width of the spillway (symbol W, in metres). The latter will usually approximate to, or be slightly less than, the gully width. The formula for determining h is:

$Q = c \times W \times h^{3/2}$ m^3/s,

where c = 1.8.

This formula is rewritten

$h = \left\{ \dfrac{Q}{c \times W} \right\}^{2/3}$ metres, giving the wet freeboard h.

Since many planners may not have the means to work out the above equation (i.e. a scientific calculator), Table 21.1 below offers the solution to this equation for standard depths of overflow. Having chosen the width of the spillway notch (W), calculate q (= Q ¸ W) and find h from Table 21.1.

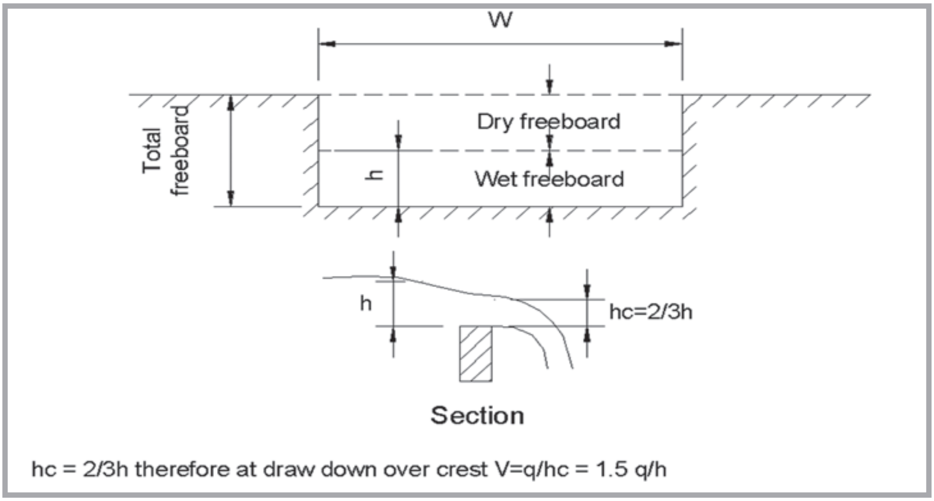


Figure 21.1: The freeboard in a spillway

Table 21.1: Discharge through rectangular notch spillways used in weirs and chutes

q (m^3 /m)	0.05	0.11	0.16	0.23	0.29	0.37	0.46	0.55	0.64
h (m)	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
v (m/s)	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9

21.2 Mass gravity concrete/s and rock masonry weirs

These are structures, the dimensions of which must allow for resistance of the structure to overturning and sliding as a result of the force of water exerted on them. The design inputs are therefore height of structure (H), wet freeboard (h), and strength of foundation (Figure 21.2). Calculations assume density of dry concrete of not less than 2250 kg/m^3, density of water 1000 kg/m^3, and a foundation of strong rock. For the purposes of this manual, hard rock is defined as rock that cannot be excavated with a pick. The rock used in construction must be dense, unweathered igneous-type or metamorphic material (e.g. Granite, basalt, quartzite or Table Mountain sandstone). Table 21.2 indicates the top (t) and base (b) width requirements of the mass gravity weir, given H and h. The wet freeboard is provided in bold text in the top row of the table. The width of the top of the weir varies according to the wet freeboard, and is provided in the second row. The width of the base of the weir depends upon the height of the weir H (presented in column 1), and depth of overflow (h).

The dimensions are based on the formulae t = 2/3 h, and b = 2/3(H + h), but they should only be considered valid within the limits of the values of h and H given in Table.21.2. The weir is constructed either of:

- concrete mix B (Tables 28.1, 2 and 3), with the volume of concrete bulked up with 'plums' (solid, dolerite rock 250-300 mm in size) to a maximum volume of 30%, or
- rock masonry, using suitable rock (quarried handstone is suitable) in a mortar (mix 1 pocket of cement to 150 litres of sand). The joints between individual rocks should not be more than 25 mm thick.

Rock masonry is proving to be a good, cost effective alternative to concrete. It can be aesthetically attractive, and combines the advantages of both gabions and concrete, while eliminating the disadvantages of both. It does not require the shuttering needed for concrete, has the attractiveness of gabions, and can be built at a faster pace than the former. It tends to be cheaper than either of the other materials, but buttress weirs are still the cheaper option, see Figure 21.3. See Chapter 28 for more details on concrete and rock masonry construction.

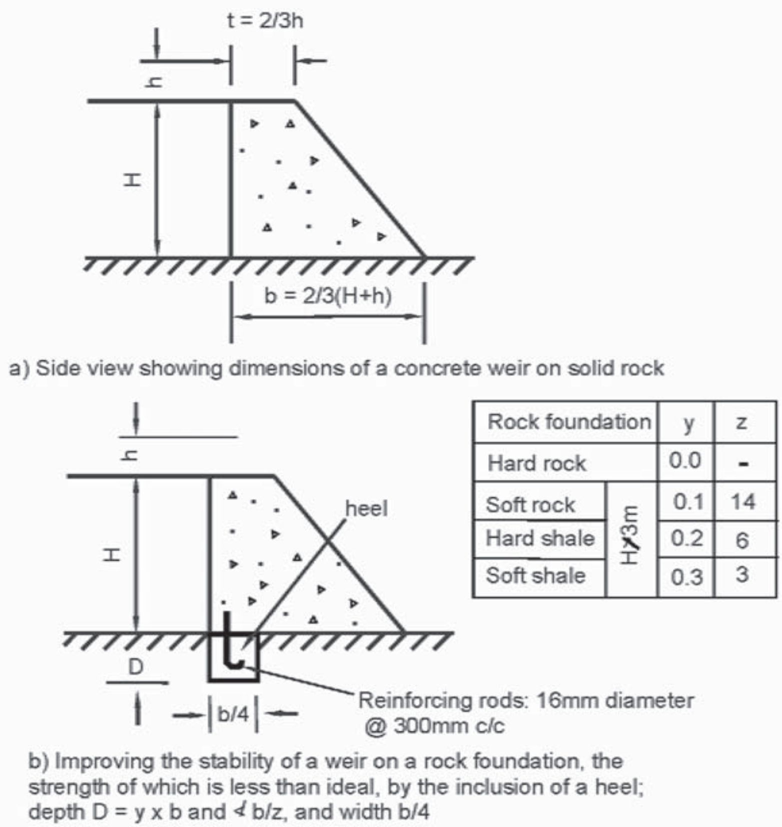
Table 21.2: Top (t) and base (b) widths (in metres) for mass gravity concrete weirs on solid rock slab

Height of structure	Depth of **overflow**	Widths (in metres) for given h and H				
H (m)	h (m)	0.10	0.20	0.30	0.40	0.50
	t	0.10	0.13	0.20	0.27	0.33
0.50	b	0.40	0.47	0.53	0.60	0.67
0.75	b	0.57	0.63	0.70	0.77	0.83
1.00	b	0.73	0.80	0.87	0.93	1.00
1.25	b	0.90	1.00	1.03	1.10	1.17
1.50	b	1.07	1.13	1.20	1.27	1.33
1.75	b	1.23	1.30	1.37	1.43	1.50
2.00	b	1.40	1.47	1.53	1.60	1.67
2.25	b	1.57	1.63	1.70	1.77	1.83
2.50	b	1.73	1.80	1.87	1.93	2.00
2.75	b	1.90	1.97	2.03	2.10	2.17
3.00	b	2.07	2.13	2.20	2.27	2.33

- Note that the cement referred to here is strength class 32.5N. See Chapter 28 for further detail.

For a weaker, weathered rock foundation, the base width will remain the same, but the structure must be keyed into the foundation using a heel to prevent it from sliding. Figure 21.2(b) gives the dimensions for three options (soft rock, hard shale, soft shale) as to the size of heel. The depth of the heel depends upon the strength of the rock and is calculated as a slope from the toe of the structure, given as a ratio (z: 1).

For an earthen foundation on which a concrete weir is to be built, a steel reinforced concrete heel and slab must first be constructed. The weir is then built on top of this 'artificial' foundation. While the weir dimensions remain unchanged from that prescribed for a solid rock foundation, the slab design must be considered a Level 3 structure, and a person qualified to carry out the slab design requested to do so. The same is required for a weir greater than 3 m in height on a soft rock foundation.



Rock foundation		y	z
Hard rock		0.0	-
Soft rock	H ≯ 3m	0.1	14
Hard shale		0.2	6
Soft shale		0.3	3

Figure 21.2: Design of a mass gravity weir on (a) solid rock and (b) low-strength rock foundation

21.3 Concrete buttress weir: see Figure 21.3

Once again H and h are known from local site conditions. Use the graphs in Figure 21.4 for options on the wall thickness of either t = 0.3 m (Figure 21.4(a)) or t = 0.4 m (Figure 21.4 (b)) to determine the spacing of buttresses (B). To do this find the intersection of h and H and interpolate to get the appropriate spacing between the buttresses (B). Note that the buttress spacing is center-to-centre (Figure 21.3).

Note that this is the situation where the overflow wall is built as a unit with the keywall, and the shoulder is constructed afterwards. Where the overflow wall is built separate to the key and shoulder walls, the final spacing between the last buttress and shoulder wall must be B/2.

The weir is constructed of concrete mix C (Table 28.1, 2 and 3) or stronger. Do not use plums for bulking up the concrete volume of the overflow wall when building buttress weirs. Plums may however be used in all of the other components. See Chapter 28 for further details on concrete work.

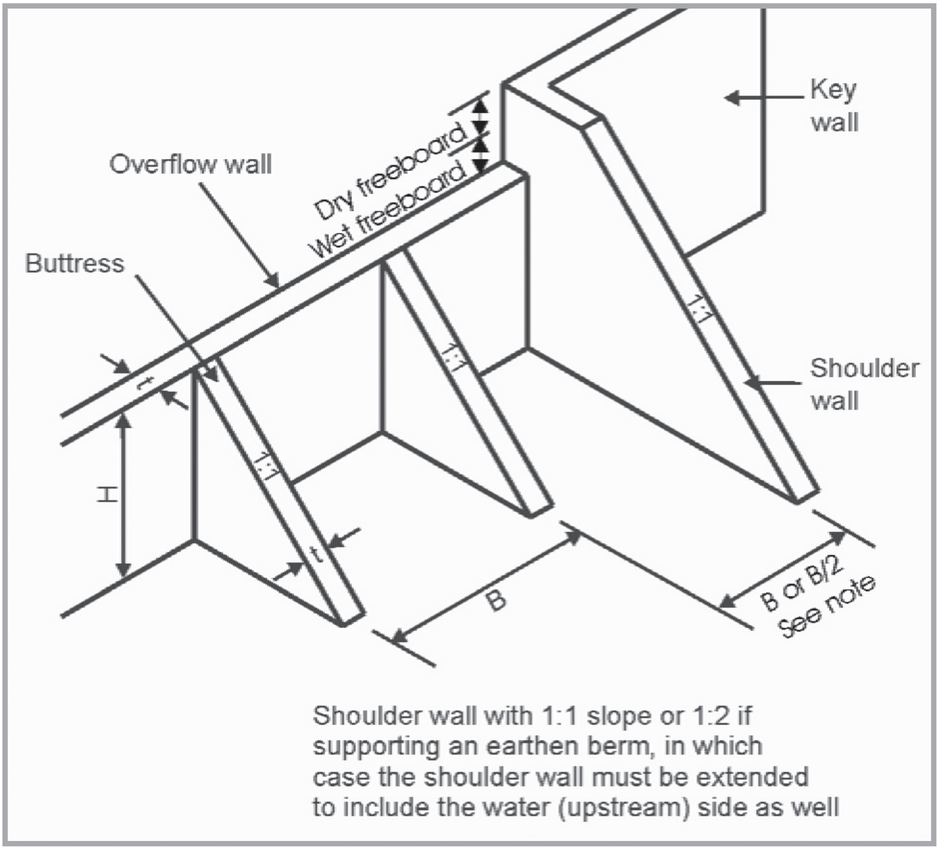


Figure 21.3: Buttress weir showing dimensions to be determined

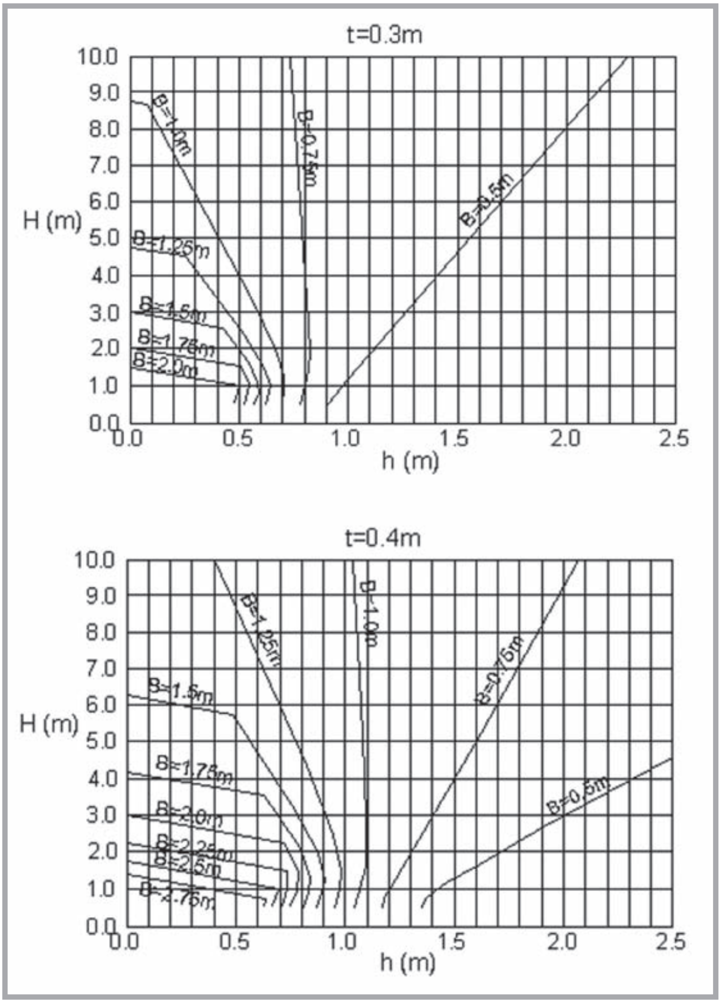


Figure 21.4: Graphs for choosing the distances between buttresses (B)
for two wall thicknesses (t = 0.3 m and t = 0.4 m). Values for H and h are already known

21.4 Arch weirs

Arch weirs really come into their own on wide gullies and where transport costs of construction material become prohibitive. The national Department of Agriculture has compiled a comprehensive document (still in draft form) on their design. It is too bulky to reproduce here, but the Chief Engineer at any of the provincial Departments of Agriculture could be approached for a copy.

Their benefit lies in the fact that their design attempts to make optimum use of the compressive strength of concrete. The result is a thin-walled weir where the force of the water is transferred to buttresses and the shoulder walls. The Department of Agriculture recommends a low-strength concrete mix for the overflow wall, and plums in the buttresses will also help reduce costs. The number of arches required depends on the limit for slenderness ratio (a ratio of wall thickness to wall length), with wall thickness not less than the internal radius of arch divided by 50. Absolute minimum thickness recommended is 300 mm.

The construction of arch weirs used to be restricted to sites with strong rock foundations. The Departmental engineers have recently, however, produced designs for rafts as well, enabling these structures to be built on stable but softer foundation materials.Construction of these weirs (of a relatively small size) is not considered a problem for Working for Wetland contractors as long as the shuttering to be used comprises corrugated iron sheets bent to the required radius by a firm specializing in this technique. There are many of them in the country, as farmers often require circular corrugated iron reservoirs for stock drinking purposes. Two sets of sheets of the curved iron are separately bolted together to form the inner and outer supports for the concrete. Spacers for wall thickness are also simple to insert. The standard width of sheet (600 mm) makes an ideal height for pouring the concrete, and because of the corrugations the sheets can be easily lifted and fitted in place for greater wall heights.

21.5 Rafted weirs

The design of the overflow and components do not differ from mass gravity and buttress weirs, but rather on the design of a reinforced concrete slab and heel on which the aforementioned structures are to be built. In other words, the raft makes possible the construction of concrete weirs where no rock formation exists. The design is fairly complicated and best left to a civil engineer – therefore a Level 3 structure.

21.6 Gabion construction weirs (Weirs over 3 m in height are recommended to be Level 3 structures)

Because gabion baskets are a standard 1 m x 1 m in cross section, any structure built of them is immediately larger than the requirements for concrete or rock masonry up to 3 metres in height, and with a wet freeboard not more than 500 mm. The design cross section is therefore in a simple one to one ratio – for a metre high structure the cross section width is also 1 m. For a two metre high structure the base width is two metres high. This applies as long as:

- the soil foundation is firmly compacted
- the structure is firmly wired to a gabion mattress, which also provides for an apron – see below for specifications for aprons
- the baskets and mattress are completely filled with rock having a minimum density of 2600 kg per m^3. The rocks packed against the wire mesh must all be larger than the mesh openings. The rock fill after packing having a maximum porosity of 30%. This implies that the rocks must be very well packed, with smaller ones fitted into the interstices between the larger rocks, and with the final density of the total structure having a density of approximately 1800 kg per m^3
- the baskets are fastened together as specified by the manufacturers.

If the rocks are properly packed, 20% more rock must be ordered than the volume of baskets in the structure would indicate. The problem arises because the rock is sold on a loose mass basis. If the rock is ordered by volume the quarry automatically converts this volume to tonnes by multiplying the cubic metres by 1.4 – the usual conversion ratio. One cubic metre of loose handstone from a quarry weighs in the region of 1.4 tonnes. The gabions however, need to be carefully packed to reach the desired mass of structure. In selling by weight, the rock is weighed loose, and that is the reason for the need to increase the volume ordered by 20%.

There are two ways of designing gabion weirs. One is the conventional method with the 'staircase' effect facing downstream Figure 21.5 (a). The other is for the 'staircase' facing upstream Figure 21.5 (b). The latter is the more cost effective as the weight of water and soil behind the structure presses down on the staircase, providing more stability and reducing the possibility of the structure sliding or overturning. In this instance the cross section dimensions may be reduced, resulting in a saving on cost. However, in this latter instance the vertical face downstream allows for a perfect waterfall, without the energy dissipation of the former method. The overflow water therefore exerts very much more energy on the apron, and in the structures that are more than two metres in height the damage that can be caused more than outweighs the benefits of this latter method.

Maccaferri offers a design service and free design software for gabion structures. You can consider using Maccaferri's Terramesh rather than gabions in this application

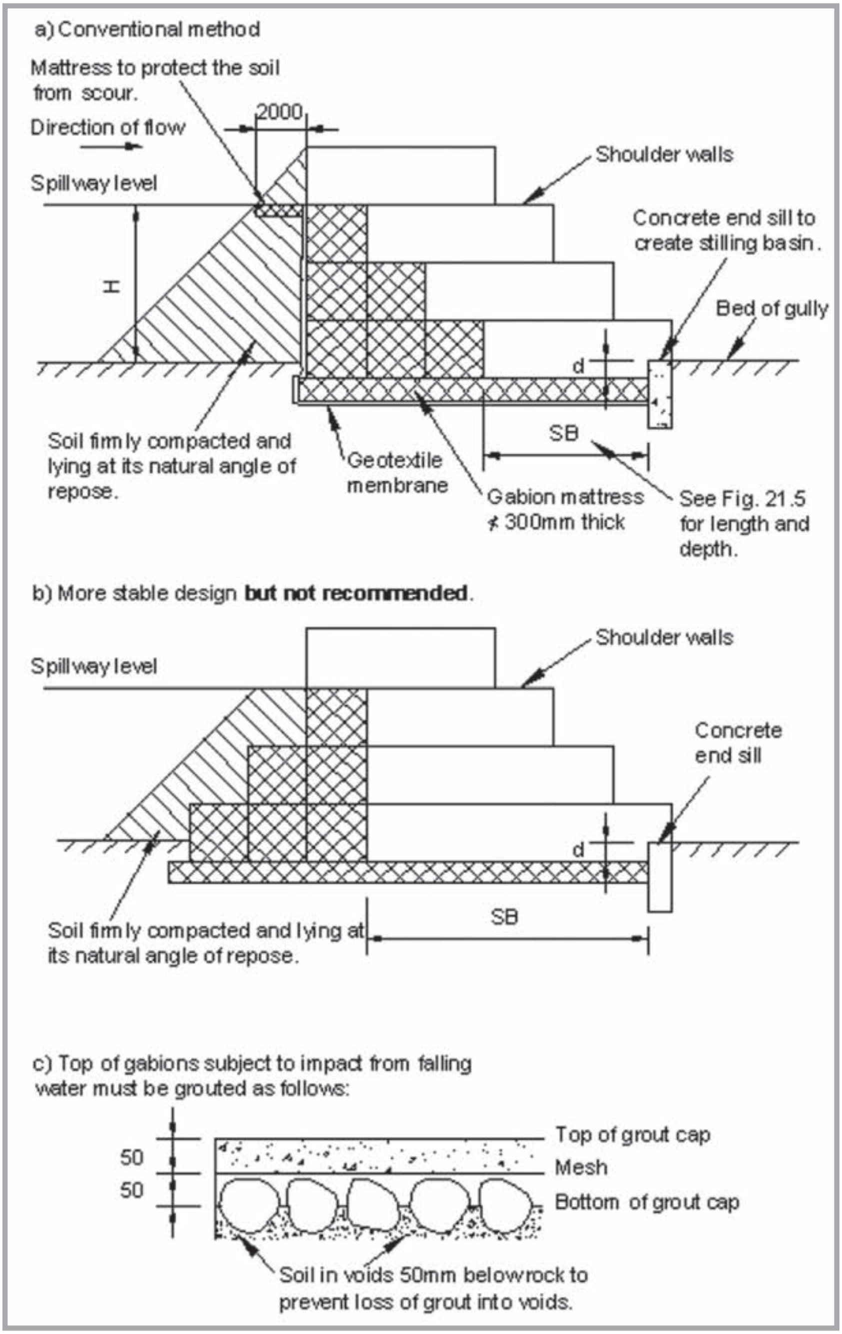


Figure 21.5: Gabion weir design for standard sized baskets

21.7 Shoulder and keywalls

In Chapter 13 the concept of shoulder walls was touched upon. The design requirements are reproduced here in Figure 21.6. Although the drawing is for a concrete structure the dimensions apply equally as minimum specifications for any other type of weir, gabion type included. The soil side of the shoulders, as well as both sides of the keywalls must be 'battered' to a slope of 5:1 (v: h) to allow proper compaction of soil against the smooth concrete. Also shown is an option for shoulder walls for a gabion weir that is no more than 3 metres in height. Note that the stepping back of the successive baskets requires that the underlying soil or sediment must be extremely well compacted to obviate their change in position as a result of settlement. Note also the requirement of a 60 tilt (100 mm in one metre) of the baskets backward of the vertical as shown in Figure 21.6.

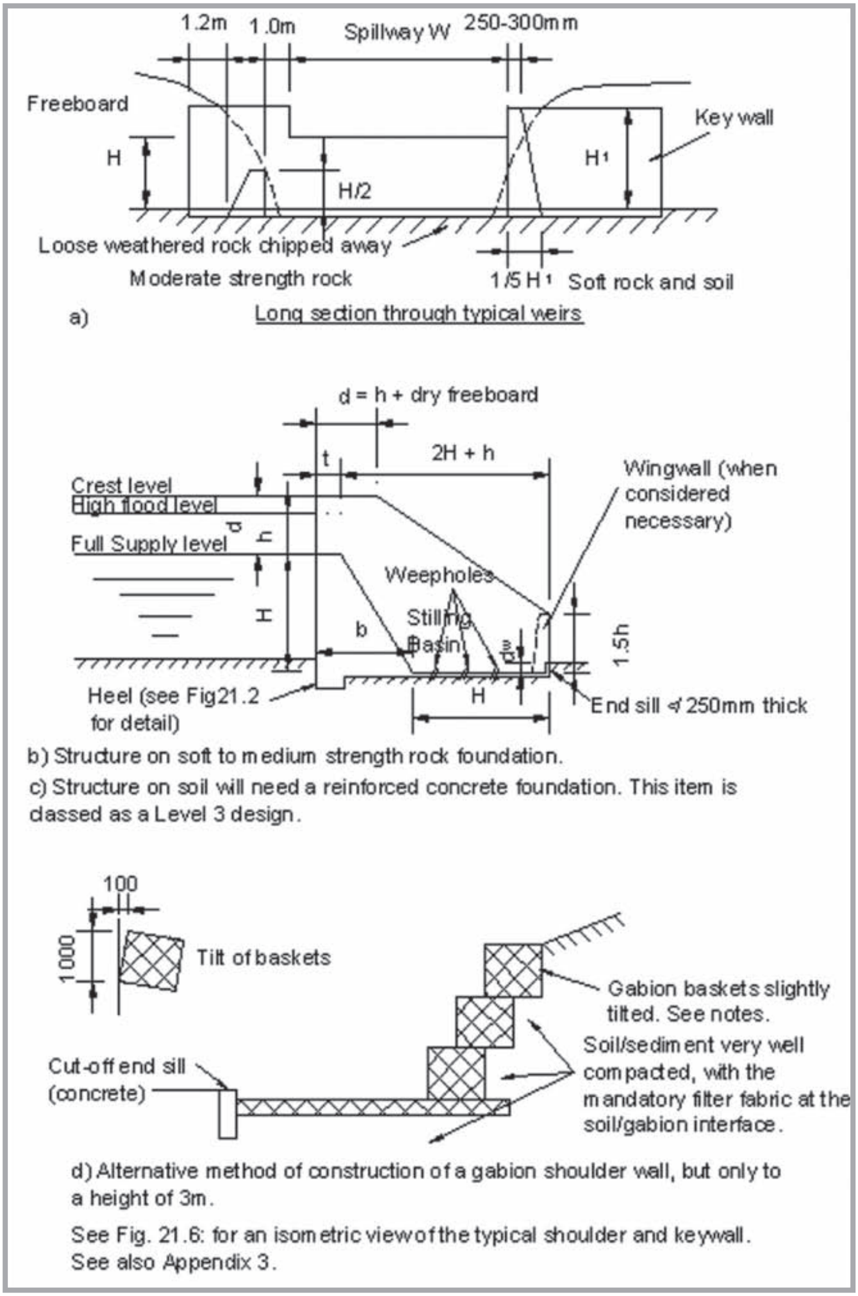


Figure 21.6: Some components of a mass gravity structure – required for gabion weirs as well.

21.8 Stilling basins as energy dissipators

The hydraulics of flow down stepped structures is complex, as is ensuring energy dissipation because almost all of the energy loss takes place in the hydraulic jump and after turbulence in the stilling basin. Adequate energy dissipation downstream of steps is critical, or much of the benefit of the structure will be lost because the energy is transmitted downstream as waves or high velocity flow. A stilling basin is formed on an horizontal apron, surrounded on two sides by the shoulder walls, and an end sill at the downstream end.

A stilling basin should always be provided, and the end sill constructed on the end of the apron at such a length that the hydraulic jump that develops at high flow conditions takes place within the protected reach. If the jump moves downstream the roller can damage the sides as well as the bed of the gully. While a hard, impervious rock formation would not need an apron to protect it, a stilling basin is needed to reduce the velocity of the overflow downstream (see Figure 21.6). The depth of the water cushion (i.e. height of the end sill) is

$dw = \frac{1}{2} (q^2 / g)^{1/3}$

where

$q = Q/W$ m^3/m width of spillway and

g = Gravitational constant = 9.8 m/sec^2

In the smaller catchments the length of the water cushion may be calculated as shown in Figure 21.6.

21.9 Cost comparisons between the different materials for weir construction

The materials for use in building weirs have been described both here and in Chapter 28. The choice of actual material to be used is left largely up to the designer. There are three criteria that need to be discussed here in order to assist the inexperienced:

- Concrete is known to be the strongest and the most durable material
- Gabions will not fit easily in where the need for a fishway arises, as the overflow gets lost in the rock matrix. Probably the only option will be to design a bypass fishway.

The designer should prepare sketch designs for various options, draw up a preliminary schedule of quantities for each, and evaluate the cost. Note that form work (shuttering) and reinforcement can be significant cost components of stressed concrete structures. Similarly, PVC coating of gabions can add greatly to the cost of these structures. Transport distances are also important, as are labour costs. Well supervised labour can be expected to move about 1 m^3 of soft soil or gabion rock per person per day. Motivated workers on a production bonus can more than double this rate. Excavation in hard soil can take considerably more effort than excavation in soft. Where production bonuses are offered the site supervisor must be careful to set fair targets for different material types. A small investment in time on the telephone getting firm process from suppliers can greatly improve the accuracy of cost estimates and potentially save considerable embarrassment later.

21.10 Other minor types

Rock packs, timber weirs and sediment fences are poor alternatives to concrete and gabion weirs. Although fairly popular for use in erosion control, 15% of those inspected by the writer (William Russell) had failed. The key to success is to ensure sufficient freeboard, and to key them properly into the gully banks. They are not considered suitable for structures greater than 1.0 m in height or where $q > 0.1$ m^3/sec/metre width of spillway. It is also vital that vegetation be established as soon as sufficient sediment has accumulated.

CHAPTER 22:

CHUTES

The design of chutes is based on the iterative solution of Mannings Formula with a series of chute capacities, widths and chute slopes, until a maximum velocity for the specific material is reached. Chute dimensions thus determined are usually the most cost effective for that material as its cost is generally high. Cost benefit is realized generally on high Q values with excessive velocities. Danger at the outlet end is high if the energy dissipater is not correctly designed and carefully constructed. They are considered to be Level 3 type structures and will not be dealt with further here.

Figure 22.1 shows a way of reducing velocity as water flows down a chute. This particular chute was built of un-reinforced concrete in geocells, with every fourth cell extended upwards to form the baffle. The baffles are staggered to create as much hindrance to flow as possible. Eight millimetre round bar was used to reinforce the baffle. The chute ends in a stilling basin. See Appendix 3 for the detail of this specific design.

Although it may appear from the photo that scour is taking place downstream of the stilling basin, this picture was taken soon after completion of the structure. A storm of 60 mm in 25 minutes caused slight damage. Natural vegetation has subsequently colonized the area very well.

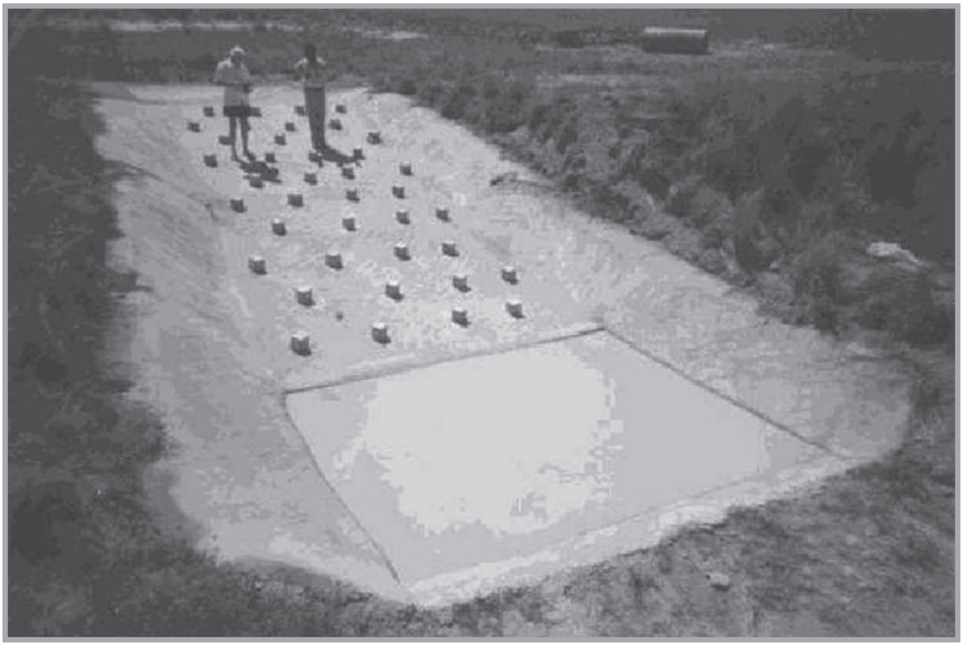


Figure 22.1: A concrete chute with baffles and stilling basin to dissipate the energy of flowing water

CHAPTER 23:

WILDLIFE PONDS

The advice of a wetland ecologist should be sought before constructing an open water pond where none existed previously.

Ponds to recreate bio-diversity need not be excessively large impoundments. In fact the literature suggests that it may be counter-productive to create deep sections of water where there were none before, and that ponds no deeper than 500 mm should in most cases be sufficient. Apart from the digging effort required, the most strenuous operation would tend to be the storage or removal of the excavated material. Inasmuch as an island would be a valuable adjunct to a pond, it will make sense to create the pond and store the excavated material in the middle of it. Depending on the size pond required, more than a single island could be built, thus making the task of shifting the material even simpler. If aesthetics is an issue, the pond could comprise a series of inter-connected ponds of varying size and laid out in a random pattern.

The edge of the pond should be sloped to a gradient of 1: 6 or 8, or even flatter, as many water birds find a large portion of their food in water that is shallower than their leg length. See Figure 23.1.

The source of the water should be fairly reliable, and this will best be the case where the natural water table in the wetland is close to the soil surface. On the other hand it may be necessary to supply the pond with runoff that has been diverted from a stream or gully via a graded canal. This may be either a special canal created especially for the purpose, or it may be a spreader canal that was in any case required for the purpose of spreading runoff water (see Chapter 20).

A caution is offered where the wetland surface comprises peat or an organic topsoil. In creating an excavation into this material, and if it is not possible to ensure a relatively constant replenishment of water that has been lost through evaporation, the water held in the organic layer will tend to bleed out into the pond, thus possibly drying out the pond surround. This should still be in order, as long as the water in the pond does not have an escape route out of the pond. A careful topographic survey will be necessary during the excavation to ensure that there are no low spots along the edge of the pond.

The subsoil on site must be checked to ensure that it is suitably impervious, otherwise a polyethylene film underneath the pond will have to be considered.

Many of the erosion control structures that will be built in wetlands will require earthen embankments on either side in order to concentrate flood peaks through their spillways. A source of suitable soil will therefore be necessary for this purpose. The source area for this soil should always be sought upstream of the structure, and below its full supply level. This in itself will cater to a certain extent for a pool of water, at least until such time as sediment has filled the basin. In sourcing the soil therefore, an attempt should be made to create as wide a pool as possible back of the structure, sloping the sides of the excavation as indicated above. Soil for this purpose should not be taken from downstream of the structure if at all possible.

If the wildlife ponds are to be at all effective they should be fenced off if cattle graze the wetland. See Chapter 25 for specifications for a well-constructed fence.

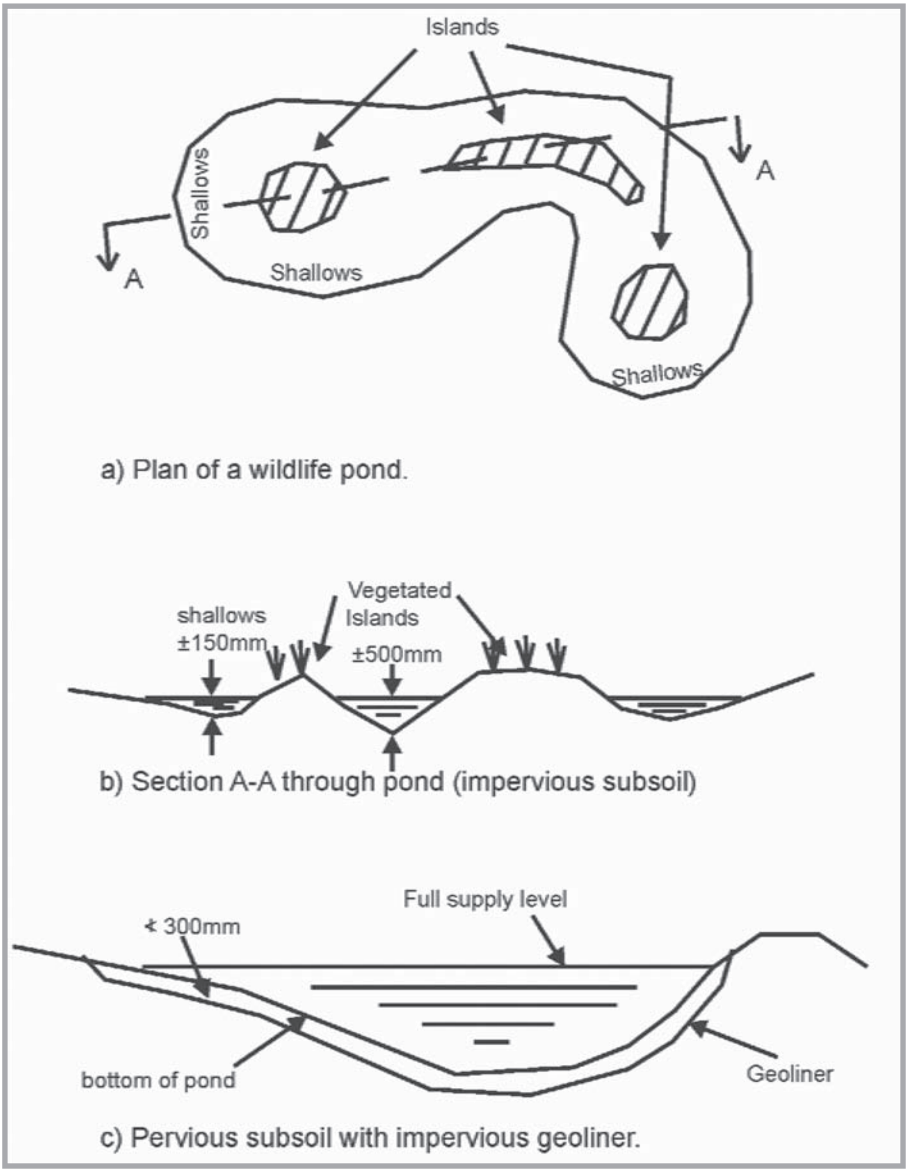


Figure 23.1: Construction of wildlife ponds

CHAPTER 24:

FISHWAY DESIGN GUIDELINES

24.1 Introduction

The following designs are aimed at providing general-purpose structures catering for a range of fish species and sizes from 50-400 mm in length, and one specifically for climbing and crawling species and small fish 20-120 mm in length. This section is a summary of the relevant detail in the document on fishways by Bok *et al*. (2004).

24.2 Fishway dimensions for design purposes

The most appropriate fishway type should have suitable internal hydraulics (water depths, flow velocities, turbulence) to cater for the smallest and weakest swimming species, but with the dimensions suitable for the largest migrants that are targeted. In addition, the fishway entrance (downstream end) and exit (upstream end) should be suitably located in relation to site-specific conditions. Table 24.1 below spells out the design requirements.

Table 24.1: Summary of recommended hydraulic parameters and dimensions for pool type fishways – both vertical slot-and-pool, and weir types

FISHWAY PARAMETER	RECOMMENDATION
Width of pool	At least 2 times length of largest fish provided for
Length of pool	At least 3 times length of largest fish provided for
Depth of pool	• Small fish (20-200 mm) : at least 300 mm (to reduce predation and limit turbulence • Larger fish (>200 mm) : 500 mm – can be deeper to reduce turbulence, if necessary
Maximum current velocities	• Very small fish (20-40 mm): <1.2 m/s • Medium size fish (40-100 mm): <1.5 m/s • Larger fish (>100 mm) : <2.0 m/s
Turbulence	• Very small fish (20-40 mm): <100 watts/ m^3 • Medium size fish (40-100 mm): <150 watts/ m^3 • Larger fish (>100 mm): <200 watts/ m^3
Drop between pools	• Very small fish (20-40 mm) : <50-100 mm • Medium size fish (40-100 mm) : <100-150 mm • Larger fish (>100 mm): 150-300 mm
Channel slope	• Very small fish (20-40 mm): <1:10 • Larger fish (>40 mm): 1: 10-1:8
Fishway entrance (i.e. downstream end)	Generally at the furthest point upstream that the fish can penetrate – in a quiet pool at the base of the barrier
Fishway exit (i.e. upstream end)	• In a quiet, sheltered, low velocity area • The invert of the exit must be at a lower level than the spillway level. *See note1 below* • It may require a control device to regulate flow down the fishway
Auxiliary and Attraction water	• Auxiliary water – extra water provided into a larger entrance pool (i.e. first pool on the downstream end) of fishway to attract fish into it • Attraction water – water that is supplied externally to the fishway in order to attract fish

Note 1: Many South African streams and rivers carry large debris loads during floods. These include anything from plastic bags to tree trunks and branches. This can easily block the entrance to fishways. The following measures may be considered to remedy the situation:

- Submerge the intake
- Position the intake at right angles to the direction of stream flow
- Provide debris deflectors. These usually comprise steel bars spaced wide enough apart to allow the largest targeted species to pass between. They will have to be cleaned out from time to time.

24.3 Pool-and-weir design

This type of fishway can be varied as follows:

1. A full width horizontal weir – the weir is within the confines of the pool
2. A notched weir – the crest is horizontal but has a notch cut into each weir, staggered from one side to the other in the ladder, to supply both a deeper and a shallower flow of water simultaneously, at high flow.
3. A sloping weir – the crest of the weir is not horizontal, but slopes to one side, being high on one side and short on the other. All the weirs slope in the same direction. It will assist creeping and crawling aquatic biota as well as small fish.

24.4 Vertical slot fishways

This type of fishway can be varied as follows:

1. Typical vertical slot with no sill
2. Vertical slot with a high sill – sometimes termed a pool-and-slot fishway.

The vertical slot fishway is only effective at water depths of 500-600 mm, and needs a flow rate of at least 100 l/s upstream of the slot. It is most suited to rivers with relatively high flow rates. It is therefore not considered generally suited to WFW work and no further discussion on it will take place here. Where wetland rehabilitation being carried out along a river that needs this type of fishway, the designer should consult the previously mentioned document by Bok *et al*. (2004).

24.5 The design procedure of pool-and-weir fishways

See Figure 24.1 for a plan view and long section of a pool-and-weir fishway.

With reference to Figure 24.1 the following dimensions need to be determined:

- The drop height (DH) between successive pools, which is the same as the height difference between successive weir crests.
- Length between successive weirs (L)
- The weir thickness (T)
- Width of the pools (B)
- Height of the weir (H_w)
- Shape of the weirs, i.e. sharp crested, sloping in the direction of the flowing water, or broad crested.

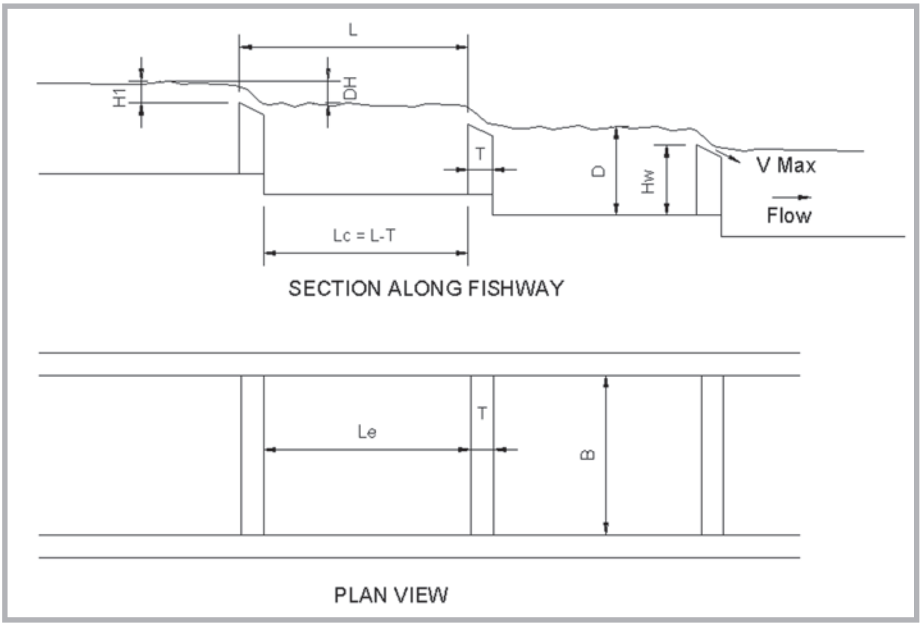


Figure 24.1: Pool-and-weir fishway: Definition of parameters

Other parameters that will be used include:

- Effective length of pools $L_e = L\text{-}T$
- Water level in pools relative to the crest of the weir. Also called the head (H_1)
- Water depth in the pools (D) where $D = H_w + H_1$ for a pool with an horizontal bottom as shown in Figure 24.1. For pools with a sloping bottom use the average depth
- The volume of the pool where Volume = $D \times L_e \times B$ m^3
- The maximum velocity (V_{max}) that occurs in the fishway. This velocity normally occurs where the water flowing over the weir strikes the water in the adjacent downstream pool
- The flow rate or discharge (Q) in the fishway. It is here expressed either in litres/sec (l/s) or cubic metres/sec (m^3/s).

24.6 Selection of dimensions

Various parameters considered

In Table 24.1 some recommendations relative to fishways were summarized. Herewith follows various derivations based on the information given, in order to simplify the design procedure:

- V_{max} normally occurs at the downstream side of the weir. These velocities are therefore a function of the height difference between the water surfaces of successive pools (DH). This velocity is calculated as
  $V = (2 \times g \times DH)^{0.5}$ m/s............Eqn. 1
  where g, the value of gravitational acceleration, = 9.8 m/s^2

Table 24.2 gives the solution to this equation for relevant drop heights. From Table 24.2 it should be obvious that the allowable drop height (DH) is a function of the swimming ability of the weakest swimmers that will use the fishway. The recommended DH and the associated maximum velocities for various fish sizes are given in Table 24.3 below

Note that the swimming abilities of indigenous fish in South Africa are not generally known. Research is underway to investigate this aspect of fishway design, and the recommendations may change in the future.

- **Effective length of pools (L_e)**
  With reference to Figure 24.1 above, L_e may be taken to be three times the length of the largest fish to be catered for.
- **Depth of pools (d)**
  The minimum depth of flow in pool-and-weir fishways is:
  For fish 20-200 mm D = 300 mm
  >200 mm D = 500 mm

Table 24.2: Maximum velocities as a function of drop height between pools in fishways : Solution of eqn. 1.

DH (mm)	V_{max} (m/s)
50	1.0
100	1.4
200	2.0
300	2.4
400	2.8
500	3.1

Table 24.3: Fish size, drop height and associated maximum water velocity

Fish size (mm)	Drop height (mm)	**Max. velocity (m/s)**
20 – 40	70	1.2
40 – 100	150	1.7
100 – 200	200	2.0
>200	250	2.2

These are the minimum. Deeper pools may be used to limit turbulence

- **Width of pools (B)**
  The minimum width should be at least twice the length of the largest fish that will use it. As a rule of thumb make B = 0.6 – 0.8 times L_e
- **Volume of the pool**
  The volume should be sufficient to dissipate the energy of the flowing water. This is a function of the flow rate or discharge (Q) and the DH between pools.
- **Shape of weir**
  See Figure 24.2 for the generally recommended shape of weir wall and crest, irrespective of type of weir.

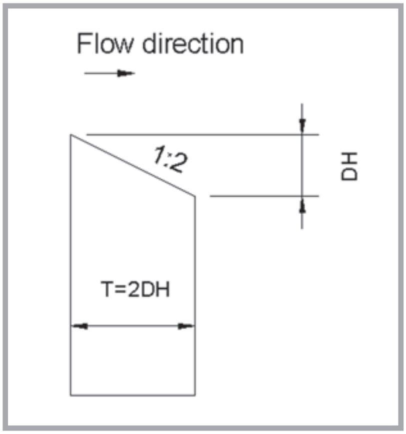


Figure 24.2: Recommended shape of weir

24.7 Design of a pool-and-weir fishway with a full width horizontal weir

Dimensions:

Purpose: General use, fish size 50-400 mm in length

Effective length: L_e = 3x400 mm = 1200 mm

Drop height: DH for 50 mm fish (Table 24.3) = 150 mm

Chosen thickness of weir: (T) = 300 mm, with shape as for Figure 24.2 above.

Width of pool: B = L_e x 0.8 = 1200 x 0.8 = 960 mm, but in this exercise a width of 2 m is used in order to allow comparison with alternative designs later.

Depth of pools for 400 mm fish length = 500 mm, but the pools will be made 900 mm. This is to compensate for the expected high rate of turbulence with increasing head over the wide weir. See Figure 24.3 for dimensions of the pool.

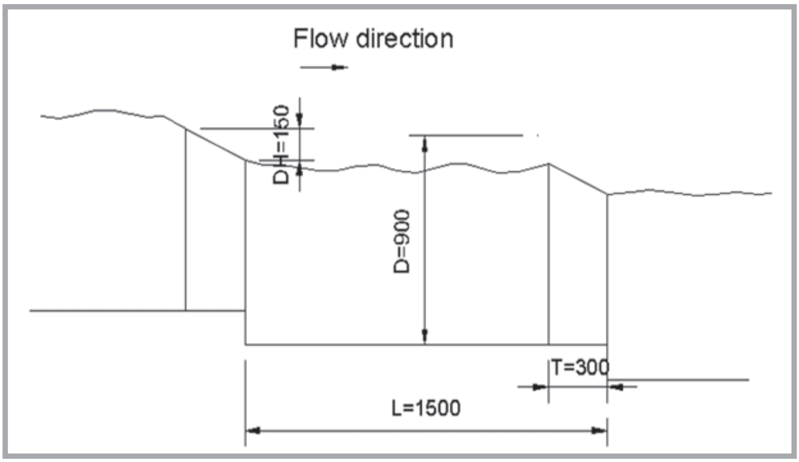


Figure 24.3: Long section through fishway

24.8 Fishway discharge

Calculation of the discharge through a fishway as a function of head (H_1) will be as follows:

For H_1 between 0-150 mm:

$\mathbf{Q = Cd \times (2g)^{0.5} H_1^{1.5}}$ m^3/s ....Eqn 2

Where Cd: a discharge co-efficient = 0.4 for the sharp-crested weir shown in Figure 24.3

g : Acceleration due to gravity = 9.8 m/s^2
H_1 : Head on weir in metres

When H_1 exceeds 150 mm the water level in the pool below the weir will be higher than the crest of the weir, and submerged flow will occur. This will reduce the discharge by a factor of K, where

$\mathbf{K = \{ 1 - (H1 - DH)\}^{0.385} H_1^{-1.5}}$........Eqn. 3
.......with reference to Figure 24.4 below.

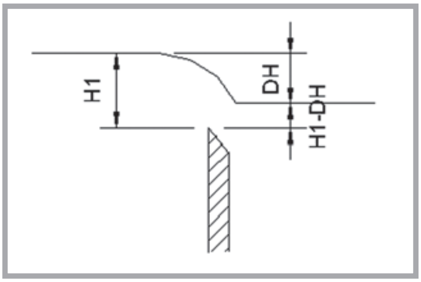


Figure 24.4: Submerged flow

The discharge for submerged (Q_s) flow is therefore:

$\mathbf{Q_s = K \times Q_f}$ m^3/s ....Eqn. 4

24.9 Turbulence

The level of turbulence in terms of power per unit volume in the pool is:

$$\mathbf{P_v = \frac{\rho \times g \times Q \times DH}{L_e \times B \times D_e}} \text{ watts/m}^3 \text{ ......Eqn. 5}$$

Where

P_v: Power dissipation per unit volume in watts/ m^3

r: Density of water = 1 000 kg/ m^3

Q: Flow discharge (m^3/s)

DH: Drop height between pools (m) = 0.15 m in example

L_e: Effective length of pools (m) = 1.5-0.3 = 1.2 m in example

B: Width of pool (m) = 2.0 m in example

D_e: Effective depth in pool (m) = $H_w + H_1$ = 0.9 + 0.15 = 1.15 in example

A turbulence level of 150 watts per m^3 is generally accepted as the upper limit for smaller fish and weak swimmers at this point in time. Ongoing research may ultimately point to higher values for some South African fish in time.

24.10 Evaluation of the example fishway

Evaluation of fishway In order to evaluate the functioning of this design under different heads, Tables 24.4 and 24.5 have been compiled. The latter will allow the determination of the range under which velocities and turbulence will be in order for the size fish that are targeted in the example.

Table 24.4: Summary of fishway dimensions

Item	Dimension (m)
Channel width	2.00
Pool depth	0.90
Cd	0.40
DH	0.15
L	1.50
T	0.30
L_e	1.20
Slope	1:10

Table 24.5: Derived values of fishway functioning under various heads

H_1 (m)	Q_f (l/s)	K	Q_s (l/s)	P_v(watts/m^3)
0.02	10.0	1.000	10.0	7
0.04	28.3	1.000	28.3	18
0.06	52.1	1.000	52.1	33
0.08	80.2	1.000	80.2	50
0.10	112.1	1.000	112.1	69
0.12	147.3	1.000	147.3	89
0.14	185.6	1.000	185.6	109
0.16	226.8	0.994	225.4	130
0.18	270.6	0.973	263.4	150
0.20	316.9	0.950	301.1	168
0.22	365.7	0.927	338.3	185
0.24	416.6	0.904	376.8	203
0.26	469.8	0.883	415.0	219
0.28	525.0	0.864	453.5	236
0.30	582.3	0.845	492.2	252
0.32	641.5	0.828	531.2	267
0.34	702.5	0.812	570.5	282

The problem with this type of fishway is illustrated in Table 24.5 above. After a head of only 180 mm on the weir and a discharge of 263 l/s, the turbulence and power per unit volume will exceed that recommended for small fish. Similarly for the larger fish for which the facility is designed. This fishway will therefore operate as an effective passage only for heads of 180 mm for the smaller fish, and up to 220 mm in the case of the larger ones. If the upstream fishway exit can be controlled then the fishway will remain operative. If not, then only under the lower flows will it be suitable.

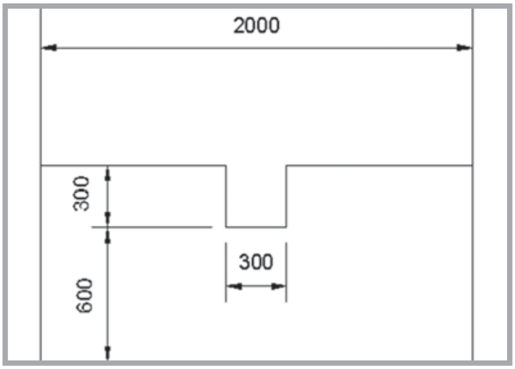


Figure 24.5: Weir with notch

24.11 Design of a pool-and-weir fishway with a notched weir

Dimensions

The fishway is designed as an alternative to that with the full width horizontal weir discussed above.

To enable the extension of the range of heads for which the fishway will be effective, the weir above is provided with a notch 300 x 300 mm as shown in Figure 24.5.

With such a notch the flow will be restricted to the 300 mm width of notch until a head of 300 mm develops in the notch. Thereafter flow will occur over the full width of the fishway. To arrive at a fishway that will cost approximately the same as the fishway in the previous example, the depth of the pool at commencement of flow is reduced to 600 mm.

Fishway discharge

The formula for calculating Q is the same as before.

- For H_1 = 150 mm, free flow exists through the notch, with B = 300 mm
- For H_1 = 150-300-mm submerged flow exists through the notch and a correction must be made as for the previous example
- For H_1 = 300-450 mm submerged flow exists through the notch (B = 300 mm), and free flow occurs over the rest of the weir (B = 2.0-0.3 = 1.7 m)
- For H_1, > 450 mm, submerged flow occurs both in the notch and over the rest of the weir.

Turbulence

- P_v is calculated as for the previous example, with the full width of the weir being used.

Table 24.6: Summary of dimensions of fishway

Item	Dimensions (m)
B	2.0
L	1.5
DH	0.15
Cd	0.4
H_w	0.6
T	0.3
L_e	1.2
B_n	0.3
Slope 1 :	10
D_n	0.3

Table 24.7: Evaluation of the notched weir over a range of heads

Notch					Weir				Total	
H1	**Qf (l/s)**	K	**Qs (l/s)**	Pv	**Qf (l/s)**	K	**Qs (l/s)**	Pv	**Q (l/s)**	Pv
0.02	2	1.00	2	1	-	-	-		2	1
0.04	4	1.00	4	4	-	-	-		4	4
0.06	8	1.00	8	7	-	-	-		8	7
0.08	12	1.00	12	11	-	-	-		12	11
0.10	17	1.00	17	15	-	-	-		17	15
0.12	22	1.00	22	19	-	-	-		22	19
0.14	28	1.00	28	23	-	-	-		28	23
0.16	34	0.99	34	27	-	-	-		34	27
0.18	41	0.97	40	31	-	-	-		40	31
0.20	48	0.95	45	35	-	-	-		45	35
0.22	55	0.93	51	38	-	-	-		51	38
0.24	62	0.90	57	41	-	-	-		57	41
0.26	70	0.88	62	44	-	-	-		62	44
0.28	79	0.86	68	47	-	-	-		68	47
0.30	87	0.85	74	50	-	-	-		74	50
0.32	96	0.83	80	-	9	1.00	9		88	59
0.34	105	0.81	86	-	24	1.00	24		110	72
0.36	115	0.80	91	-	44	1.00	44		136	87
0.38	125	0.78	97	-	68	1.00	68		166	104
0.40	134	0.77	103	-	95	1.00	95		199	122
0.42	145	0.76	109	-	125	1.00	125		235	141
0.44	155	0.74	116	-	158	1.00	158		273	161
0.46	166	0.73	122	-	193	0.99	192		313	181
0.48	177	0.72	128	-	230	0.97	224		352	200
0.50	188	0.71	134	-	269	0.95	256		390	217

Evaluation of the fishway

- Evaluation of its effectivity over a range of heads is now carried out as before. See Tables 24.6 and 24.7.

The advantage of providing a notch is obvious from Table 24.7. At the stage where the notch is flowing full and without spilling over the weir itself (H_1 = 0.3 m), P_v = 50 watts per m^3 at a flow of 74 l/s. P_v reaches 150 watts per m^3 (recommended for small fish) at a head of 430 mm and at a flow rate of 250 l/s. Turbulence then increases rapidly as the head increases and starts spilling over the weir itself. The limit for large fish is reached at a head of 480 mm (P_v = 200 watts per m^3) and a flow rate of 352 l/s.

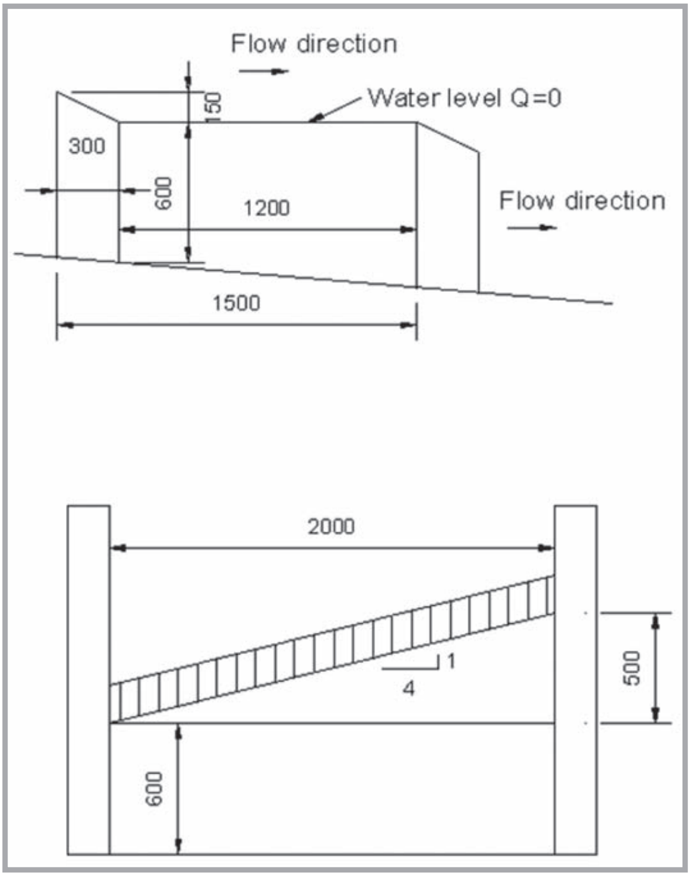


Figure 24.6: Layout of pool and weir fishway with a sloping weir.

By providing a notch in the weir (refer to previous example) the range of heads against which the fishway is operated is increased from 180-430 mm for small fish, and from 240-480 mm for larger fish. The notched fishway will also provide much easier conditions for smaller fish to negotiate it at low flows where all the flow is concentrated in the notch and low values of turbulence prevail in the pools.

24.12 Design of a sloping pool-and-weir fishway with a sloping weir

Dimensions

For comparisons with the previous two examples the width of fishway is taken at 2 m as well. DH = 150 mm, the pool depth at 600 mm, and the weir thickness T = 300 mm. The cross slope to the weir will be 1 : 4 (V : H). With a 2 m width of fishway, this will allow for a head of 500 mm before the water flows over the full width of the weir (see Figure 24.6).

Fishway discharge

The approximated formula for discharge is:

$Q = 0.267 \times Cd \times (2g)^{0.5} [\tan(\theta/2)] H_1^{2.5}$ m³ per sec. ....Eqn. 6

Where θ is the angle of the cross slope of the weir (Figure 24.7).

H_1: the head of water above the lowest point in the weir in metres

Cd: the discharge co-efficient

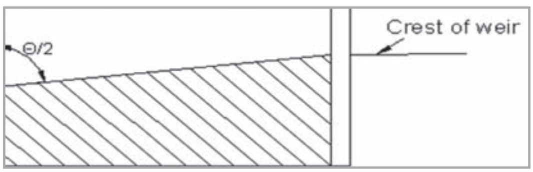


Figure 24.7: Sloping weir: definition sketch

When the water level in the pool below the weir becomes higher than the crest of the weir (H_1 > 150 mm in the example), submerged conditions occur and the discharge will be reduced as described above.

$Q_s = K \times Q_f$ m³ per sec........Eqn 4

Where $K = \{1 - \left(\frac{H_1 - DH}{H_1}\right)^{2.5}\}^{0.385}$

Turbulence

The turbulence in the pools is calculated as before:

$$\mathbf{P_v = \frac{\rho \times g \times Q \times DH}{L_e \times B \times D_e}} \text{ watts/m}^3 \text{ ....Eqn. 5}$$

Table 24.8: Summary of dimensions of the fishway

Weir components	Dimensions (m)
Channel width	2.00
Pool depth	0.60
Side slope	4.00
Cd	0.40
DH	0.15
L	1.50
Weir thickness	0.30
Longitudinal slope	1:10

Table 24.9: Comparison of head of water with flow rate and water power

H1 (m)	Qf (l/s)	K	Qs (l/s)	Pv (watts/sec)
0.05	1.1	1.000	1.1	1
0.10	6.0	1.000	6.0	6
0.15	16.5	1.000	16.5	15
0.20	33.8	0.988	33.4	28
0.25	59.1	0.960	56.7	45
0.30	93.2	0.928	86.4	64
0.35	137.0	0.897	122.8	86
0.40	191.2	0.867	165.9	110
0.45	256.7	0.841	215.8	136
0.50	334.1	0.816	272.7	163

Evaluation of fishway

The evaluation is carried out as for previous designs (Tables 24.8 and 24.9)

The sloping weir fishway has been developed to accommodate both fish and creeping/crawling species that need a wetted splash zone to negotiate the weirs. Those in the example will become submerged over their full width when H_1 = 500 mm. At this stage the discharge will be 273 l/s and the turbulence level 163 watts/m³. It is estimated that a turbulence level of 150 watts/m³ will be reached when Q = 230 l/s at H_1 = 480 mm. Similarly a turbulence level of 200 watts/m³ will be reached when Q = 300 l/s at H_1 = 550 mm.

24.13 Comparison of sloping weir with notched weir

Comparison of sloping & notched weir
The two types are compared in Table 24.10 below.

Table 24.10: Comparison of a sloping weir with a notched weir-and-pool type

P_v (watts/m³)	Sloping weir		Notched weir	
	H_1 (m)	Q (litres/s)	H_1 (m)	Q (litres/s)
150	0.48	230	0.43	250
200	0.55	300	0.48	352

The sloping weir will therefore be negotiable over a similar range of water levels and also allows for creeping and crawling species for heads up to 500 mm.

24.14 The design of a fishway for small fish only

There is often the need for a simple and cheap fishway for small fish and creeping/crawling organisms only, and this may very well be the case for many situations where WfW is involved. Here is the design for just such a facility, which will of necessity (because of the creeping/crawling organisms) be a sloping weir type.

Assume a fish length of 120 mm. Select a pool length of 350 mm (approximately 3 x fish length), and a weir thickness of 150 mm. This will give a distance between weirs (L_e) of 500 mm. Select the side slope of the weir as 1:4 and a channel width of 600 mm. This will allow for a head of 150 mm before the weirs are fully covered by water. Further select a pool depth of 400 mm at start of flow. Make the slope of the fishway 1:10 while keeping the turbulence level below 150 watts per m^3 (see Table 24.11).

If the exit (upstream end) of the fishway is built 50 mm below the spillway level of the structure it will remain functional up to a head of 100 mm above the spillway level of the structure. If a pool is made at the entrance (downstream end) where the fish can wait until the high flows have subsided, this fishway will function just as well (for the size fish involved) as the much more expensive ones previously considered.

Table 24.11: Discharge and turbulence in a small fish sloping weir fishway

H_1 (m)	Q_f (l/s)	K	Q_s (l/s)	P_v (watts/m^3)
0.01	0.0	1.00	0.0	0
0.02	0.1	1.00	0.1	2
0.03	0.3	1.00	0.3	4
0.04	0.6	1.00	0.6	8
0.05	1.1	1.00	1.1	14
0.06	1.7	1.00	1.7	21
0.07	2.5	1.00	2.5	30
0.08	3.4	1.00	3.4	41
0.09	4.6	1.00	4.6	54
0.10	6.0	1.00	6.0	69
1.10	7.6	1.00	7.6	86
0.12	9.4	1.00	9.4	104
0.13	11.5	1.00	11.5	124
0.14	13.9	0.99	13.7	146
0.15	16.5	0.99	16.2	169

24.15 Construction procedures

An under-designed fishway is a waste of money and effort, as it will not perform correctly. An over-designed fishway is also a waste of money and effort. The dimensions calculated are critical, and so, therefore, is the care with which the fishway must be constructed. Table 24.12 sets out the recommendations to ensure that the job is satisfactorily executed.

24.16 Concluding remarks

It is once more reiterated that an appropriate design can only be carried out if the needs of the species to be catered for are known. If it is important that species pass upstream during high flows, then Vertical Slot Fishways should be preferred. The designer must then refer to the bulletin by Bok *et al*. (2004).

Table 24.12: Construction procedures for the provision of a fishway

1. PROJECT PLANNING
• Ensure standard project management procedures are in place • Ensure strict adherence to specifications supplied • Any changes to design or dimensions must be authorized by the fish biologist or engineer who carried out the design, prior to implementation.
2. AUDITING DURING CONSTRUCTION
• Regular inspections undertaken by designer at critical stages in construction • Ensure any proposed changes are approved by designer beforehand • Ensure any alterations to streambed downstream of structure are taken into account in location of fishway entrance.
3. FINAL AUDIT
• Ensure all dimensions of fishway are as per approved design • Check discharge, and inspect for potential problems such as high velocities, sediment deposition and/or turbulence • Make minor alterations to improve functioning, as required • Monitor fishway to assess effectiveness in passing target species. The WRC bulletin discusses monitoring procedures.

CHAPTER 25:

FENCING

A good strong fence is a prerequisite to protect both eroded areas that are recuperating, and the structures that have been built. It should have the following features:

- A fence comprises corner posts at either end of a straight line, straining posts at set distances apart along the straight line, standards in the same straight line to hold up the wire, droppers to keep the correct spacing between wires, and wires to control animals.
- All posts and standards should stand the same height above ground level in order to follow undulations in the terrain, otherwise animals will be able to cross the fence beneath the gaps at ground level where the fence crosses depressions.
- Straining posts should be no further than 300 m apart between corner posts. Corner and straining posts are generally of 125-150 mm diameter x 1800 mm treated poles carrying the SABS mark that are planted 600-700 mm into the ground.
- Iron standards 1850 mm long with a mass of 2.5 kg per metre are the Y section standards in general use. They are usually spaced 20 m apart.
- Droppers must be so spaced that the distance between the standards is equally divided. The normal spacing is of the order of 4 m. The fencing wires must be securely tied to them at the same spacing as on the standards. A variety of dropper types is available, including creosote-treated wooden (min. dia. 30 mm), iron H-, T-, and Y-section, and Ridgeback. A two metre length of 4 or 3.15 mm dia. galvanized wire, bent in half and twisted may also be used, although they bend fairly easily and need to be straightened after a bull has had a go at it!
- Wires (preferably barbed) should be spaced parallel to one another. Five strands are required for a cattle-proof fence, at least six for sheep proofing, and a minimum of seven for goats – ten would be better. For a cattle proof fence, the lowest two strands should be 200 mm apart, and 250 mm apart the rest of the way up. As the number of strands increase, so the spacing should be reduced by 50 mm. The wires must be taut without being over-strained; if they are over-strained, the galvanizing will be burnt off that much more quickly during veld fires, and their life span considerably reduced.

Figure 25.1 illustrates more detail on the recommended construction of fences. The Engineering Section of the National Department of Agriculture (P/Bag X515, Silverton, 0127) has a bulletin entitled *Farm Fences* that more fully describes the construction of fences.

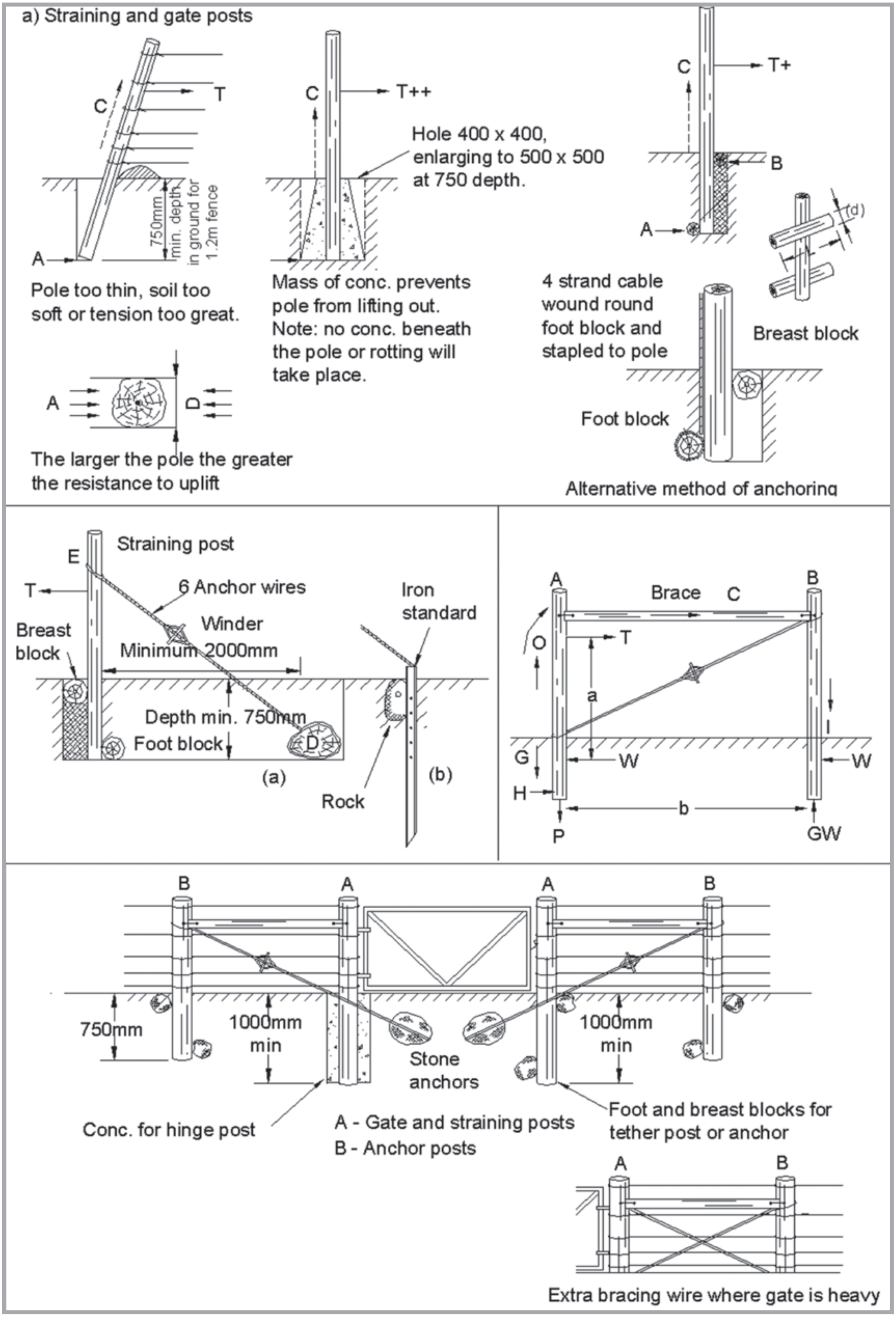


Figure 25.1: Construction of a fence

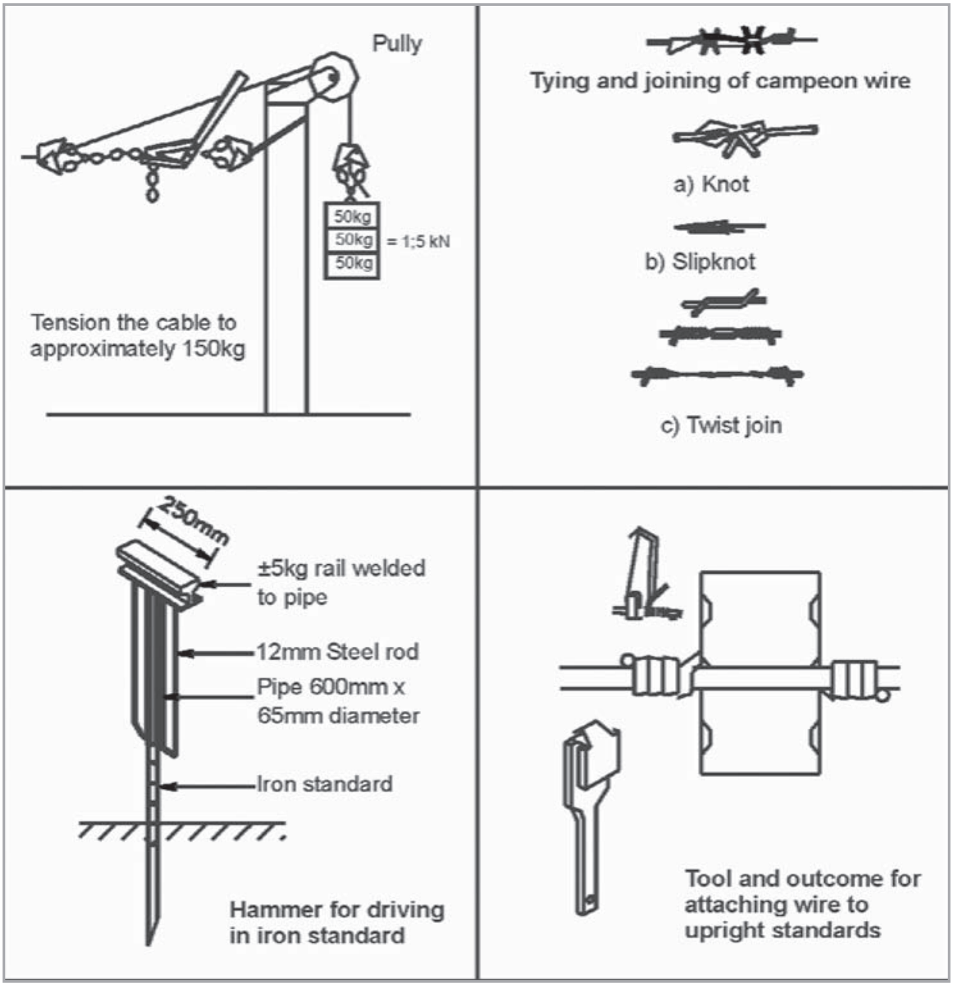


Figure 25.1: Construction of a fence (continued)

CHAPTER 26:

CONSTRUCTION TOOLS AND EQUIPMENT

The tools shown in Figure 26.1 are typical of those generally useful on a construction site, while items shown in Figures 26.2 and 26.3 are useful for relatively large earthworks.

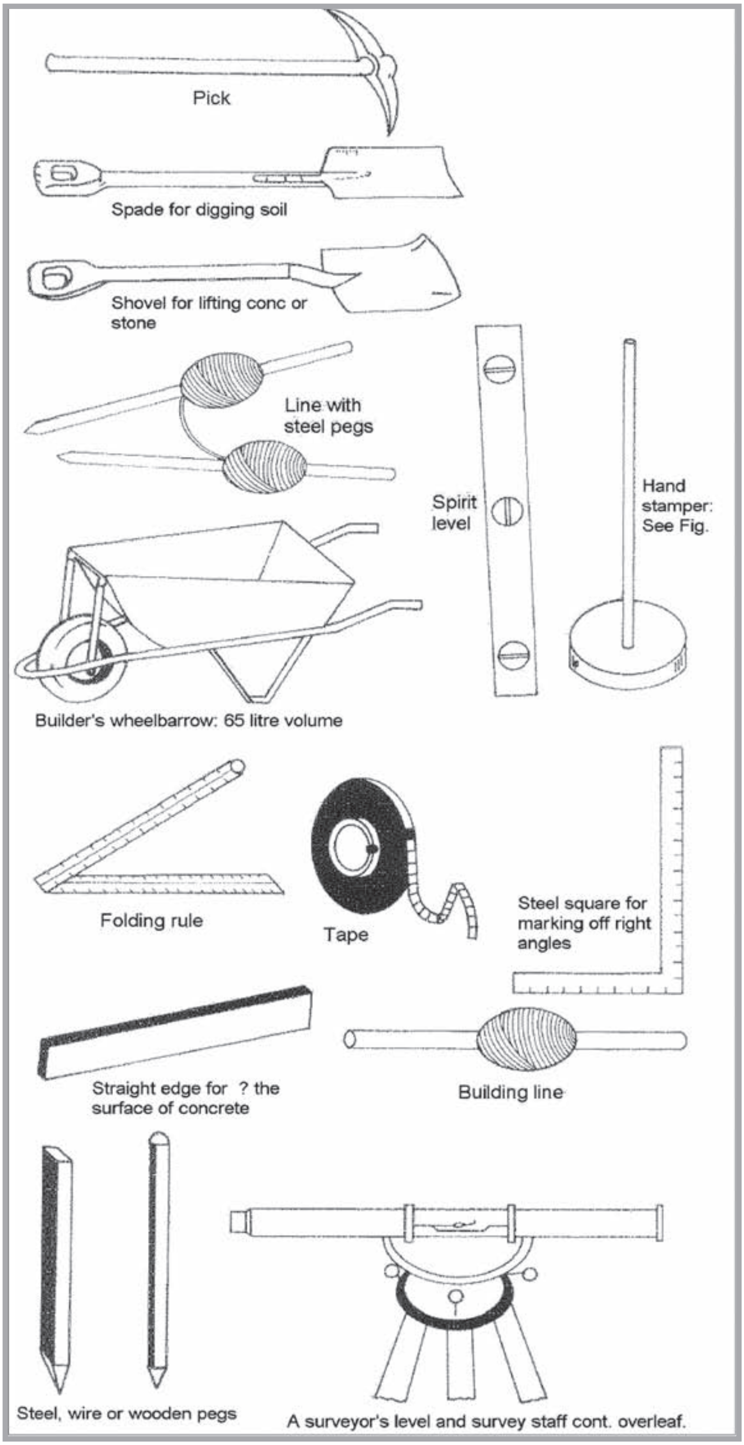


Figure 26.1: Tools used on a building site

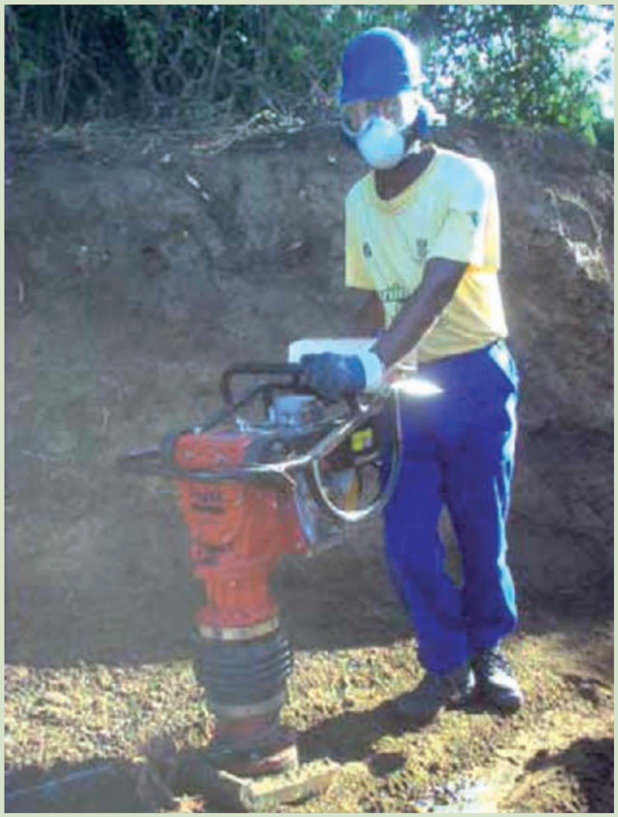


Figure 26.2: A vibration rammer is good for compacting

Figure 26.3: Where relatively large earthwork is required, a front end loader will **make hand labour more efficient**

CHAPTER 27:

CONSTRUCTION NOTES AND BILLS OF QUANTITIES

27.1 Introduction

The diagrams and dimensions are not sufficient in themselves to supply sufficient information to the contractor in order that he may carry out the job to the satisfaction of the designer. It should also be remembered that a contractor carrying out a contract must be held responsible for what he produces, and for what he does not produce. In order that this may occur, he must be given the fullest information on what is required, otherwise, if he makes a mistake, it will not be possible to hold him responsible. This is where concise construction notes come in.

27.2 Construction notes

The contractor must be given the fullest information on what is required of him. Below is a standard type list of instructions that should go a long way to specifying all that may be required in a WfW contract. As a standard list, there will always be some items that are not applicable. The idea is to just cross out those that do not apply. However, there may also be some items that are missing. These should simply be added.

Standard notes are provided as follows:

1. Check all dimensions on site and amend where necessary. For instance, in excavating the foundation it may become necessary to build the structure higher because of the need to remove some of the overburden. The designer must be consulted before any changes are made to the dimensions.
2. Excavate carefully to the final levels required, and stockpile the soil removed in a place(s) best suited for re-use. For example, when building an earthen diversion embankment, the soil excavated from a key trench can be used immediately in building up the embankment, if the excavated soil is suitable. Alternatively, and if the soil will not be needed, stockpile immediately upstream of the site of the proposed wall. It may be required for later compaction against the waterside of the completed wall. Note that the topsoil should be stockpiled separately from the subsoil, and any E-horizon material must be rejected in its entirety.
3. Where soil is to be the foundation for non-soil structures (e.g. gabions and rafted weirs), all sand deposits must be removed and the floor well compacted while the soil is at optimum moisture content for maximum dry density. The required moisture content will have been specified on the plans.
4. All earthen construction must be carried out with soil that has been moistened to the optimum condition for maximum compaction. This will mean wetting it to obtain a plasticity that, when a sample is squeezed in the closed fist the ball just holds together. The wetting should preferably be done in the borrow area, and not on the wall itself.
5. Soils unsuitable for embankments:
   - peat and soils high in organic matter
   - sands and gravel without cohesion (must be capable of forming a 3 mm diameter sausage)
   - heavy clays that cannot be worked
6. Where the addition of gypsum ($CaSO_4$) has been specified for the amelioration of a dispersive soil, this should be carried out in the borrow area. For

example, measure out an area of known size and depth (e.g. 10 m x 10 m x 0.1 m = 10 m^3). Calculate the quantity of gypsum to be mixed into 10 m^3 of soil. Mix the soil and gypsum well (preferably with a tractor drawn harrow), bring the mix up to the correct moisture content, and transport it to the construction site.

7. Build soil in horizontal layers no thicker than 150 mm when using a vibration compactor, and 50-75 mm when using hand compaction. Loosen the top layer of any soil surface that has dried out, before re-commencing construction on to it. Subject any area to a minimum of 5 passes with a vibrating compactor or 5 blows with a hand compactor and do tests to determine the required compactive effort.
8. Where soil has to be built up against vertical soil banks, those banks must be broken down to a slope no steeper than 1 : 1 to enable proper bonding between the old and the new soil. The soil that is pulled down to create the required slope may be used as part of the construction material, as long as it is suitable for the task.
9. When the final level of soil construction has been reached the topsoil should be added, and compacted, as an extra height and planted to vegetation, unless other provision for protection of the structure has been specified.
10. When backfilling soil against concrete or gabion work, extra care must be taken to ensure that a waterproof join with the structure is, as far as possible, achieved. Compact in successive layers no thicker than 150 mm (see note 7) at a time, using only **mineral** soil. Material high in organic matter must not be used for this purpose, even if it means importing soil from elsewhere. Take care not to damage the filter fabric in gabion work, and repair any tears before proceeding.
11. Ensure the correct steel reinforcing as per specifications has been delivered to site. Note carefully where the steel is to be placed within the structure, and use suitable spacers to keep the correct distances between reinforcing and outside surfaces. All steel joins must have an overlap, and the overlaps must be securely tied with at least 3 rings of 2 mm diameter mild steel wire at 150 mm spacing. Where roundbar is used the overlap must be 40 times the diameter of the bar, and weldmesh must overlap 1½ times the mesh size. Where weldmesh is to be used that has different sized bars and / or spacing of bars, it is very important to note whether the sheet of mesh must be placed along or across the gully. It should normally be placed across the gully.
12. Before placing concrete on a rock foundation, carefully chip away any loose surface layers and wash away all debris. Paint the new surface before laying the concrete with a fresh coat of cement mixed in equal volume with water.Before placing soil fill on a rock foundation chip away any protrusions and fill all racks and depressions with a 1:10 cement:sand grout to form a smooth surface to accept the first layer of fill. It is impossible to compact soil into pockets that are smaller than twice the width of the compactor being used.
13. Wet concrete is very heavy, so the shuttering that is to form the mould must be strong and well supported. If the shuttering should collapse while filling with concrete, real problems will result. The safest is to only pour one metre height of concrete in any one day. The shuttering must be well oiled on the inside before setting up. This will prevent the timber/iron from sticking to the concrete. Spacers between shuttering must be placed every one metre, both vertically and

horizontally, with a minimum of two in both directions. Ensure that the shutter oil does not get onto reinforcing steel.

14. Note that when mixing concrete it is preferable to use a full pocket of cement with each mix. Note also that there is a maximum amount of water that may be used when mixing concrete of whatever strength. The amount of sand, stone and water per pocket of cement is given in the specifications. The specified proportions may not be altered without the approval of the designer. Do not add extra water to achieve workability without adding extra cement, at the ratio of 1:1 by volume.

15. The poured concrete must be rodded to ensure complete penetration into all corners and to release any air trapped. Never add more than one metre height of concrete in any one day, and attempt to lay the concrete in even layers throughout the length of any section. Check the specifications for any requirement of expansion joints. The shuttering should be left for at least two days before stripping. Wetting it while it is curing will make for a strong construction. Keep concrete wet for at least 7 days after stripping. The same for slabs – start the wetting before the bleed water has evaporated completely. Backfilling of soil against the completed structure should only be done after a period of at least 7 days. See note number 10 above.

16. The standard procedures for the opening up and wiring together of gabion baskets and mattresses is well documented, and supplied with every delivery of the products. They must be strictly adhered to in all respects. Ensure that the lids of the final (top) baskets are always folded down and wired in a downstream direction. Consider requesting the supplier for training.

17. It is strongly recommended that, where rock-filled gabion baskets are used for the construction of keywalls, the trenches be dug wide enough so that sufficient access is available to properly backfill and compact all the way round them. It is also recommended that a soilcrete mix of 1: 10 with a plastic consistency be used as the backfill material. See note 10. Making the trench only wide enough to receive the baskets is not an acceptable practice, as water will eventually find its way around the structures and cause problems.

18. Where rock masonry is specified, use clean, unweathered rock up to 300 mm in size, 1: 4 cement: sand mortar, and cure for at least 7 days.

19. A strong barbed wire fence around the structure, to protect it from grazing animals, should be mandatory, even if it has not been specified in the plans. See Chapter 25.

27.3 The Bill of Quantities

The design and drawing up of the plans and specifications are the largest part of the overall task. Also very necessary is a complete list of all the material and labour needed to carry out the construction. This is to enable a cost estimate to be made. This is not only normal practice, but is also a requirement of the WfW Best Management Practices as documented in Appendix 4.

CHAPTER 28:

CONSTRUCTION MATERIALS

28.1 Soils

Soil in the wetland rehabilitation context comprises both the in situ material that has been degraded by erosion and needs to be repaired, as well as a possible construction material. It is a material for manipulation in bio-engineering, as well as a source of information when calculating rainfall runoff and runoff rate. It is therefore necessary to briefly discuss here some of the physical and chemical properties of soil as an introduction to the concept of soil, mainly in the engineering context.

Soil is formed when the parent rock is broken down under the influence of such soil-forming elements as air, rain, wind, temperature fluctuation, fauna, flora and topography, acting over a long period of time.

The soil-forming process comprises:

- disintegration of rocks as a result of chemical and mechanical action, forming smaller and smaller particles until the several important categories of sand, silt and clay are formed
- chemical weathering of particles to form different types of clay
- breakdown and further decomposition of plant material through bacterial action to form humus
- re-arrangement and consolidation of particles into different layers called soil horizons, such as the top- and subsoil, and several special ones
- binding of particles to give structure within the soil, known as crumb formation
- leaching of dissolved minerals, the degree of leaching being dependent upon the mean annual precipitation of the area.

The following characteristics are important in the wetland rehabilitation context, and the following are simple, generally used indications:

Colour:

- *Brown:* Decomposed organic matter stains the mineral particles – the darker the colour the higher the organic matter content.
- *Yellow:* Signifies that the soil profile is not very well drained, although not water-logged. Aeration is not sufficient to cause oxidation to red iron oxide
- *Red:* Well drained and sufficiently aerated for oxygen to cause the iron in the soil to oxidize
- *Black:* Very rich in humus (e.g. peat soils). Colour also due to black minerals which, together with poor drainage, prevents oxidation to red shades.
- *Grey:* Often associated with high clay content giving very poor drainage. This soil is often waterlogged.

Texture: this describes the relative amount of the following different sized mineral (solid) particles in the soil:

- Gravel – Larger than 2 mm in diameter Coarse sand – 2.0-0. 2 mm
- Fine sand – 0.2-0.02 mm
- Silt – 0.02-0.002 mm
- Clay – Less than 0.002 mm in diameter

The relative amounts of sand, silt and clay in a soil sample may be determined by mechanical analysis, and the textural class defined by consulting the diagram in Figure 28.1

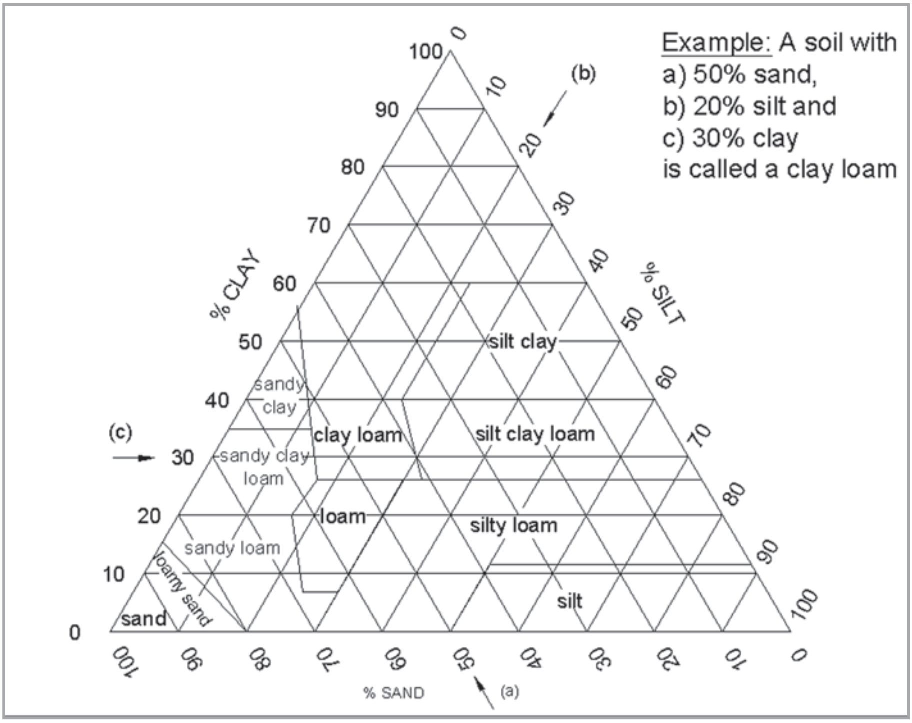


Figure 28.1: Diagram for determining the textural class of soil

Method for estimating clay content of soil Texture gives an indication of soil properties such as aeration, drainage, moisture holding capacity and permeability. In rehabilitation one is largely interested in:

- infiltration, percolation and drainage (for determining rainfall runoff intensity and hydraulic conductivity)
- optimum moisture content (for compaction purposes) which is directly related to clay content
- sand content (for excessive drainage and possible use in soilcrete)
- chemical content (for possible dispersivity problems)
- the textural class in general for determining maximum non-scouring velocity in erosion control design.

It is therefore necessary that the wetland worker be able to identify the clay content of soil at the very least. One method is as indicated above, to send a sample to a soils laboratory for a particle size analysis. The other is not quite as scientific and involves the attempt to roll a small sample (approximately two or three heaped teaspoonfuls) in the palm of the hand after it has been moistened and kneaded to bring the whole sample to the same moisture content. The diagram in Figure 28.2 will then assist in identifying its clay percentage.

When the textural class is required, one will also need the proportion of sand and silt. As the amount of silt in the soils of South Africa very seldom (if at all) exceeds 10%, it would be acceptable in the case of small-scale projects to assume that the silt content is 10%. Adding this to the estimate of the clay content will enable the percentile sand in the sample to be determined. The textural triangle may then be used to determine its texture, without the answer being significantly wrong.

A further requirement is the type of clay present, as clay material is strongly

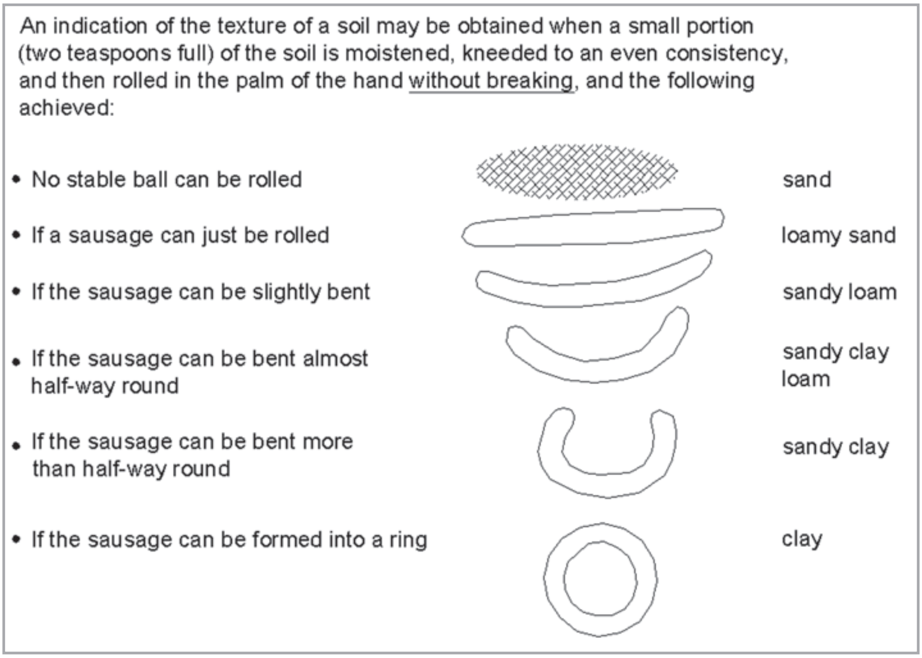


Figure 28.2: Field method for estimating the textural class of a soil

influenced by the minerals they comprise. While sand and silt comprise small to ultra small rock particles broken off from the parent material, clay is the result of *in situ* weathering. The individual particles carry an electrical charge that varies from one type of clay to another. Clay types in increasing order of problematic consequences for construction work are *kaolinite, vermiculite, smectite, illite* and *montmorillonite*. The last mentioned results in such problems as excessive shrink-swell and dispersive characteristics (see below).

The rest of the many properties of soil are of more interest to the agriculturist and will not be dealt with here. There are many books written in detail on the properties and usefulness of soils for those interested, and they should contact the Agricultural Extension Service of one of the provincial Departments of Agriculture for advice on a suitable one, if needed.

It is not expected of wetland workers that they have a detailed knowledge of the make-up of soils, especially as regards Level 1, and even to an extent, Level 2 structures (see Chapter 16). However, and wherever soil is to be used as a construction material in soil conservation work, there are a number of very important aspects regarding their limitations that must be considered, and these are as follows:

Some soils are chemically unstable, and if the problem is not remedied it could result in failure of the structure and/or severe erosion of the earthwork comprising the structure. Due mainly to an excess of sodium salts in some problem soils, the clay particles are in a dispersed state, and the soil is therefore structurally weak, especially in the presence of water. Dispersive soils (such as gley-, prisma- and pedo-cutanic, G- and E-horizon materials) are generally found in the lower rainfall areas, but also in areas where the rainfall is strongly seasonal for a part of the year and there is a substantial difference between rainfall amount and evaporation. Under natural conditions these sodic soils are usually found in low-lying areas, where the parent rock contains a high degree of soluble sodium salts, and where the rate of weathering of the parent rock is relatively rapid. They are generally soils of a fairly high to very high clay content.

A simple test to indicate whether there is a problem of this nature or not, is to take a dry clod and place it gently in a bowl of water that is as pure as possible (e.g. rain water). Dispersive soils will immediately start sending off tiny 'explosions' from their surfaces, a cloudiness will develop in the water around the clod, and, no matter how high a clay content and how strong the clod in its dry state was, it will rapidly collapse. This does not happen with soils that are non-dispersive.

Poor physical conditions in the A2 (lower topsoil) and/or B1 horizons (upper subsoil), and the development of a strong, columnar structure in the B, with an abrupt transition from the topsoil to the B-horizon, is often a strong indication of these saline conditions and solonetz-type soils. Chemical tunneling in these soils is a very real problem, and even more so in that the tunneling does not necessarily occur straight away. It can show up in an otherwise well constructed water-retaining embankment only years after the dam has filled with water.

The tunneling starts on the waterside of the embankment and proceeds towards the dry side of the wall. This is directly opposite to the case of mechanical tunneling, where excessive seepage from a poorly consolidated soil picks up velocity, leading to mechanical erosion that starts on the dry side of the embankment, working its way back towards the source of the water. Repair of damage to earthen work of this nature (i.e. tunneling in dispersive soils) is not easy, and prevention is better than cure.

These soils spell trouble wherever they occur in rehabilitation work, be it an earthen embankment or re-vegetation. The problem can be remedied to an extent by mixing a certain amount of gypsum (calcium sulphate [CaS04]) into the soil. When this is done the calcium will replace the sodium (Na) that is the root cause of the problem, and result in a more stable material. A 1 kg sample of the suspect soil must be sent to a soils laboratory for analysis and recommendations on the rate of gypsum to apply in order to displace the sodium salts.

The gypsum is incorporated and mixed in the borrow area before it is transported to the building site. An area of known size is measured out, and the depth to which the soil is to be excavated must also be known. If a tractor and plough (or harrow) is to be used (note: this is the preferred method, as hand labour will not be satisfactory), the depth of the soil to be excavated will then be to whatever the depth the plough or harrow is set. With these dimensions the volume of soil to be treated can easily be calculated. The laboratory would have recommended the application of a certain mass of gypsum in kg per cubic metre of soil to be treated. The amount of gypsum to be evenly spread out over the identified area is then a simple arithmetic calculation. A tractor-drawn harrow or plough is then used to mix the soil thoroughly before it is taken to the construction site. It is also important to apply the gypsum and to mix it in the presence of moisture. Unfortunately, and in the WfW context, hand labour does not lend itself to good mixing of gypsum with a batch of soil, especially one of a clay content in excess of 25%. The owner of the land on which rehabilitation is being carried out should be requested to assist in this regard.

An additional precaution would be to include an impermeable membrane inside the embankment during the construction process. This aspect was dealt with earlier (see Chapter 19).

It should be noted that the WfWetlands Best Management Practices document specifies that instances of dispersive soils at a site must be referred to the Technical Advisor, and this should be done before any designs are embarked upon.

Clay soils with high shrink-swell characteristics are a problem primarily on sites that are subject to regular changes in the moisture regime. They form large cracks (up to 100 mm wide) when dry, but which close up when the soil becomes wet. These soils are self-mulching and characterized by a loose, friable surface as a result of the wetting and drying cycle. They are generally very high in clay content (40-60% and higher) and this poses a particular problem. The individual clods are very hard when dry, and the soil very difficult to work when wet. There is therefore a small window of opportunity for proper compaction between the dryness of winter and the wetness of spring and summer. The embankments themselves are unstable because of this shrink-swell characteristic and must be protected with a good cover (gravel, rocks or concrete) as soon as construction is completed. Where this soil is used structurally, it must be fenced off and protected from trampling by animals. Concrete structures are preferred, although there is the danger of the soil pulling away from the concrete surfaces as the soil dries out. This danger may be overcome to an extent by importing better, more stable soil to use in the immediate vicinity of, and up against the structure.

Peat and Vertic topsoils: It should be noted that peat is not a mineral soil. It is composed predominantly of organic matter. It is therefore unstable, not easily compacted, and therefore not suitable for civil engineering. Any earthen structure that may be planned within a peat area, therefore, must be constructed with mineral soil brought into the wetland from outside of it. Alternatively the type of material that should be used must be changed to something more suitable than soil (e.g. concrete or gabion work). The earthen structure may also not be constructed on top of any layer of peat. The peat will have to be removed down to the subsoil and the structure built up from there. In soil classification a so-called organic topsoil is, in fact, very close to peat in its composition.

To be on the safe side with soil as a building material, it is best practice not to use any topsoil in a structure at all, but to use it as a final covering after the design dimensions have been reached. The organic matter, roots and seeds contained in topsoil will assist in stabilizing the outer skin of the structure with vegetation.

Soils with a clay content in excess of 70% should also preferably not be used, especially when using hand labour to compact it. The high clay content makes for a material that is very hard and difficult to work when dry, and also extremely difficult to work when wet. The window of opportunity to compact it to a dense mass is very small. When it has a high dispersivity as well, it is a recipe for disaster. If a structure has to be built in an area comprising this high clay content, the recommendation is for a concrete structure. The backfill material used in the trenches around the keywalls, etc. should be a more suitable soil brought in from elsewhere. An alternative would be to use soilcrete, a sandy material mixed with cement in the ratio of 1 part cement to 10 parts sand and moistened to optimum as for ordinary fill. Whichever is used, the material must be very firmly compacted in the trench.

The exception is when a waterproof core is required in an earth structure. The core can be constructed of puddled clay where the very clayey soil is placed considerably wet of optimum soil content (OMC) at the consistency of firm mud and compacted by foot tramping or ramming with a wooden pole or pick handle. A puddle clay core must be prevented from drying out by a thick cover of well compacted stronger soil.

Soils with a clay content of 10% and less should also be avoided. Although they compact to a favourable density (approximately 1600 kg/m^3) they absorb water easily, become unstable when saturated, and degenerate over a short period of time.

Irrespective of the clay content in the soil that is used in water-retaining structures that are not properly compacted, the structures will be severely infiltrated by the water they control, and they will collapse through saturation or just plain settlement. For soils to be properly compacted, they must be as free as possible of organic matter, contain a certain amount of water when undergoing compaction, and must be compacted in thin layers (not more than 150 mm thick) with suitable compacting machinery. A mechanical plate compactor should be the minimum requirement. Rubber-wheeled tractors are even better. The greatest pressure intensity possible must be used in the compaction process, and even then, a 10% extra height should be added to the structure as a settlement allowance.

When hand compaction is used, the stamper should weigh ± 5 kg (concrete filled 5 litre paint tin with suitable handle) and the layers should be no more than 50 mm. Five blows of the hand rammer is the minimum requirement.

The optimum moisture content (OMC) for maximum dry density is dependent largely upon texture of the soil and the type of clay. In order to ascertain the correct optimum moisture content for maximum dry density, samples of the soil should be sent to a soils laboratory for analysis, and this is strongly recommended for earthen

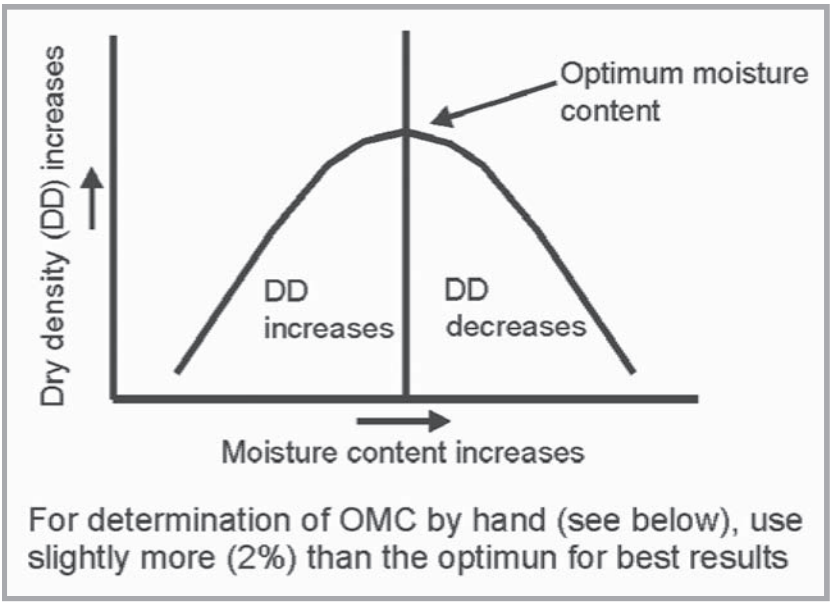


Figure 28.3: The influence of moisture on the compactibility of soil

embankments that are to be built higher than 3 metres. See Figure 28.3 for an explanation of the way in which moisture content affects compaction.

Bringing the soil moisture up to optimum for maximum compaction is carried out in a manner similar to that described in the paragraphs dealing with the mixing of gypsum into the soil (earlier in this section). This must be done in the borrow area.

If the proposed structure is small the following rule of thumb field method can be resorted to. Basically, if the soil is moist enough for a stable ball to be formed when a sample is squeezed in the fist, the soil is approximately at OMC. Similarly, the OMC is approximately the water status when making clay oxen!

Compacted soil fill that is to stand aboveground must be protected by suitable vegetation at the earliest opportunity, and fenced off from grazing animals. In the drier areas of the country vegetation does not establish as easily, especially when the material used is subsoil, and heavy rainstorms can cause serious damage to the structure. In this instance a 200 mm thick blanket of gravel or road quarry material would be a better option. See Figure 28.4 for a photo showing the effect of a gravel blanket versus an unprotected slope.

Figure 28.4: Effect of a gravel blanket on an earthen berm in an arid climate. The upper half is covered in rip-rap, is colonized by vegetation and is stable. Whereas the lower half is not covered with rip-rap. The soil is bare and is being eroded and washed away.

28.2 Rock masonry

Rock masonry is the building method, similar to brickwork, whereby individual rocks, instead of bricks, are used to build a solid structure with a mixture of cement and sand as the bonding mortar between them. Its benefit lies in the fact that no shuttering is needed during construction, and the process does not require great skill. While this might result in a saving on cost of wetland rehabilitation, the skill in the use of this technique is not widely required in the market place. Building can, however, be carried out with little training and little supervision once the technique is mastered.

Both rock masonry and gabion work require the same type of rock, which must be clean, hard, dense and non-absorbent. Fine-grained granite, dolerite, basalt, norite and quartzite are suitable geological materials; slate, shale, sandstone and limestone are most decidedly not. The latter are generally too soft, light in weight and subject to weathering. If there is any doubt have the rock tested by an engineering soil laboratory. Smaller rock must be mortared in to fill the large interstices between the larger rocks, in order to save on mortar.

While rock masonry work can be a very suitable building material in wetland rehabilitation, care must be taken when deciding upon the source of the material. It is not always the best practice to rely on local building material. It is often very irregular in shape and size, leading to excessive use of mortar, and the gathering of the rock can be very time-consuming. Locally gathered rocks are often ‘dirty’, with a skin of soil adhering to them, making for a weak bond within the structure unless the rocks are washed. The collection of natural rock is also damaging to the environment, and any proposal to make use of it on WfW projects must first be cleared with the relevant Technical Advisor, as per instruction in the WfW BMP (Appendix 4).

Rocks for masonry work must not have a skin of weathered material. They may be of any handy size, but not be so heavy that they sink through the under-lying mortar into the rocks below. Too large and heavy, and they will also be difficult to place for best effect. The shape is important. As the technique is similar to brick-laying, preference should be given to those rocks with a flattish, longitudinal shape. From an economic point of view, the more irregular they are in shape the more mortar will be needed between individual rocks, and therefore the more expensive (and lighter in mass) the structure. The mortar is lighter than the rock recommended, so the more mortar that is used the lighter the final structure will be, and its stability may then be problematic, unless this has been taken into account at the design stage.

The mortar is a mixture of cement, sand and water. The mortar should be no thicker than 15 mm on average, and the sand should preferably be clean river sand. See Figure 28.5 for a picture of a typical rock masonry weir.

The mix should be 1:5 cement : sand. The sand must be suitable for use as building sand as opposed to plaster or river sand as these latter materials will require excessive water content to achieve a suitable mortar, with resulting poor adhesion, bleeding, shrinkage and cracking.

A very good structure can be built economically if the outer faces are built by skilled workmen using selected stones while the core is constructed by less skilled people using more uneven stone that has been rejected from the face construction. For best results wipe the joints with an old hessian bag as soon as the mortar has set and clean off the exposed faces of the stones before the mortar has hardened.


Figure 28.5: Rock masonry weir

It is difficult to calculate in advance how long it will take to collect the rock, and controlling the efficiency of collection is another problem. On the other hand, although fairly expensive, quarried handstone will be of the recommended rock type, and its cost of procurement on site is easily calculated. Calculation of the amount of sand and cement required is difficult and liable to be at fault. It is heavily dependent upon the size and shape of rock. One third of the total volume of the structure is generally taken as the volume of mortar required for purpose of the calculations for the Bill of Quantities.

28.3 Concrete bricks

There may be a need for a brick-type structure in the rehabilitation situation. They can be used:

- for small weirs (i.e. less than 1 m in height)
- as permanent shuttering in the construction of an arch-type weir
- as fill material for gabion baskets if the concrete mix used results in the brick having a density of approximately 2600 kg/m^3
- for the quick lifting (by a small height – no more than 250 mm) of the height of an existing concrete structure.

Concrete bricks, unlike burnt clay ones, lend themselves to a wet environment, as in a wetland. Where clay bricks tend to disintegrate in water, concrete only gets harder. A further benefit to their use is in the teaching of a skill that can be used later in the construction business. Sand-cement and concrete bricks can be made virtually anywhere and with little capital, unlike clay bricks. They are in great demand for home building, although, whereas hollow ones will suffice for house construction, the need in water control structures is for dense, solid ones. Excellent concrete bricks with a density of ±2300 kg/m^3 were made on a site near Dundee using a mix of I packet cement, to 100 litres of sand to 100 litres of 9.5 mm stone.

All the aspects of manufacture of concrete bricks will be dealt with in the following section of this chapter. All that should be emphasized at this point is that they should be made to a uniformly standard size, and that they should always be laid in the manner similar to that in clay brick walls. Where they are to be used in wetland rehabilitation, they should not be placed in a tension-stressed situation, as concrete (especially mortar-bonded bricks) is relatively weak under tension but very strong under compressive stresses.

28.4 Concrete

Concrete is a mixture made up of (in this instance) Portland cement, sand, crushed stone or gravel, and water. The word 'Portland' is not a trade name but a particular type of cement, made from certain specific materials, by means of a specific manufacturing process. After mixing it sets firmly and then hardens with time to great strength and durability. While concrete work requires a degree of skill and care in procedures, the result will be a structure with a life span of at least 50 years. This is more than can be said for any other building material in general use for wetland rehabilitation. Unlike soil it cannot be trample-damaged by grazing animals and unlike gabions it does not rust in time and collapse when high velocities are exerted on them. Its inherent strength results in a structure that is a lot thinner than gabion work, and where transport of material comprises a large segment of the total cost of a structure, concrete should out-compete the latter type structure cost-wise. See Table 21.3 for a comparison of costs. Taken altogether, concrete should be the building material of choice with most types of structures (including soil plugs!), in spite of the more intricate procedures involved.

There are other types of cement on the market, but in wetland rehabilitation only Portland cement strength class 32.5N is used. Masonry cement is to be avoided at all costs. The time taken to set and then to harden will depend on the amount of water used and, very importantly, on the ambient temperature. Both excessive heat and icy cold temperatures will result in poor quality concrete. Poor quality means lower strength and lower durability. Where it is to be used, therefore, the timing of mixing when working in winter is sometimes critical. On the Highveld it is recommended that no more mixing be carried out after 14h00 in winter. The placed concrete should then be covered with veld hay as soon as it has set, in order to keep its temperature above freezing. On the other hand, in summer when rainstorms are imminent freshly placed concrete must be covered with polyethylene film in order to protect it from the action of pummeling raindrops. This will loosen the weak bond that is still developing between the aggregates, and will cause the cement to 'bleed' out of the mixture, resulting in a concrete which is weaker than that which was designed.

The quality of the various constituents, and the proportion of cement to sand to stone to water, and especially the ratio of cement to water, can be manipulated to give a large variation in strength and durability. In order to meet even greater strength requirements, and also to reduce the thickness of the concrete, it is sometimes reinforced with steel reinforcing rods. The manner in which concrete is allowed to harden will also influence final strength. For quality concrete therefore, the following aspects of the constituent materials need to be followed:

Portland Cement is the binding agent that holds together the sand and aggregates (stone chips and gravel). When water is mixed with it much of the water combines chemically with the constituent compounds by a process called hydration, which in turn makes the mixture harden. It is sold in pockets with a mass of 50kg, and a volume of 33 litres. As it is poured out loosely into a container, the same 33 litres will fluff out to approximately 38 litres. *For this reason, and to ensure a quality concrete product, all mix proportions should be made in the ratio of multiples of whole pockets of* *cement.* For small amounts of concrete, of course, this will not apply, but then an extra 15% cement should be added. For the larger, expensive structures in civil engineering the mix is weigh-batched to give the most accurate measure. This will not apply to wetland rehabilitation at the scale that WfW presently operates.

Cement in paper pockets is liable to absorb moisture from the atmosphere or any other dampness. It forms lumps, loses strength, and is then not reliable. It in fact loses strength at the rate of 5-10% for every month after manufacture, depending on climatic conditions. For this reason it should be purchased for a project in stages so that it is kept no longer than six weeks without being used. *Cement must be stored prior to use in a sheltered, dry place, the bottom layer being on wooden pallets and not directly on the floor, and never on the bare ground.* In the field immediately prior to use, the pockets should be laid on polyethylene film and covered with the same in such a way that no moisture can reach them. Never leave any pockets of cement out at night.

Sand for concrete must be clean, free from dust, silt, clay, salt and organic material. To test the suitability of sand, fill a half litre fruit jar one quarter with the sand, and fill it three quarters with water. Shake the bottle well and leave to stand for 24 hours. If a sediment layer more than 3 mm deep forms on the surface of the sand it is unfit for building purposes and should either be discarded or washed until it meets the standard recommended.

Very fine sand should be avoided as this does not result in a quality concrete. The best type is coarse sand interspersed with a small amount of medium grade particles, i.e. a clean river sand (0.1-5 mm dia.).

Crusher dust from quarries (aka. quarry dust) may be partly suitable and half the price of purchased sand. It is often used for mass gravity components that are more than 500 mm thick. If the sand on site (i.e. sediment) tends to be too fine, a 50-50 mix with crusher dust may be possible, and result in a better quality material at a reduced cost. The only problem with crusher dust by itself is that if it is not carefully worked the water, with cement in suspension, tends to bleed out fairly quickly, resulting in a weaker concrete. For this reason it is preferable to use the finer of the two grades of quarry dust available.

The quality of the sand will determine the amount of water required to make the mix workable. This water demand will, in turn, determine how much cement is required to achieve the required design strength. The quality of the sand will therefore have a major effect on the cost of the structure, so the sand should be chosen with care.

Stone for concrete consists of crushed stone ranging in size generally from 5 mm to 75 mm. More specifically, the standard nominal sizes generally sold by quarries are 9.5 mm, 13.2 mm, 19.0 mm, 26.5 mm and 37.5 mm. These are the maximum sizes in a mix with smaller stones. The smaller stones fit into the interstices between the larger ones, making for a denser product. Together with the graded sand used, the final mixture should be one of a very dense medium of individual particles closely packed and 'glued' together by the cement particles covering all surface areas. In this way a conglomerate mix with a density of approximately 2600 kg/m^3 will be achieved.

From an economic point of view the largest size stone possible should be used, provided that it is not larger than one fifth of the smallest dimension of the concrete to be cast. For example, if the section required to be cast is 75 x 200 x 500 mm, the maximum size of stone that should be used will be 75 / 5 = 15 mm. The standard size 13 mm stone would therefore be the correct stone to use in this situation. A further condition as regards reinforced concrete is that the largest stone must be able to fit between two adjacent reinforcement rods with at least 5 mm to spare.

Water for concrete should be pure enough to drink. The more water that is used the weaker will be the resulting concrete, irrespective of the strength of the cement: sand ratio. Only sufficient water to make the mix workable should be used. The actual quantity necessary will depend on the nature of the sand and stone, the quantities of the ingredients, and whether they are moist or dry. Standard tables normally give the volume of water required per pocket of cement, and for dry sand. It is preferable, for ease of mixing, to use sand that is as dry as possible. If wet sand is used its moisture content must be determined using a mass of sand of known volume; and subtracting that water from the recommended amount.

Mass (wet) - Mass (dry) ÷ Mass dry = Amount of water per volume measured (Note 1 litre water weighs 1 kg).

If for example, a sample of wet sand was found to weigh 5 kg, was dried and then found to be 4 kg in mass, the amount of water in the sand would be 1/5 × 100 = 20%. If one was using 100 litres of this sand, and the mix required 27 litres of water, 27 × 100 – 20 / 100 = 21½ litres would be the amended amount added.

If additional water is required as specified in Table 28.2 in order to improve workability, it must be added together with extra cement in the following amounts:

Table 28.1 Litres cement required per litre of water

Strength class of concrete	**Litres cement per litre** water added
A (10)	0.9
B (15)	1.1
C (20)	1.2
D (25)	1.4
E (30)	1.5

Concrete mixes: This term relates to the relative proportions of the various ingredients that go to make up a concrete mix. Different applications require different mixes. A mass gravity structure that relies on its total mass for stability, for instance, will require a much leaner (weaker) mix than will a buttress weir where some of the structure is under slight tension. Using the same mix for both would therefore result in either a more expensive mass gravity weir, or a weaker buttress weir, or vice versa. The different mixes relate therefore to the design of structures and to the efficiency of compacting. Tables 28.2 and 28.3 contain the recommendations for the smaller structures classed as Levels 1 and 2.

Table 28.2: Concrete mixes recommended for wetland rehabilitation: quantities of materials provided as a volume (litres)

Type	**Mix code/** strength (Mpa)	Nominal stone size (mm)	**Mix ratios per pocket of cement**			**Small batch ratios:** cement: sand: stone
			Materials in litres			
			Sand	**Stone**	Water	
Mass filling	A (10)	37	160	200	34	1:5¼:4½
		26-19	170	145	34	
		13-9	175	95	33	
Mass gravity weirs	B (15)	37	136	170	29	1:3¾:3½
		26-19	125	120	30	
		13-9	130	80	29	
Buttress weirs	C (20)	37	115	155	26	1:2¾:3
		26-19	95	100	27	
		13-9	100	70	26	
Reinforced Concrete raft foundations	D (25)*	37	100	135	23	1:2½:2¾
		26-19	80	90	24	
		13-9	85	60	23	
	E (30)	37	85	120	21	1:2:2½
		26-19	65	85	21	
		13-9	70	55	21	

*Rafted weir: slab and heel

Table 28.3: Concrete mixes recommended for wetland rehabilitation: materials required per cubic metre of concrete

Mix code and strength (Mpa)	Nominal stone size	Materials required per cubic metre of concrete			
		Pockets of cement	**Sand (m3)**	**Stone (m3)**	**Aprox. Water*** (litres)
A (10)	37	4.4	0.71	0.87	
	26-19	4.5	0.76	0.66	155
	13-9	5.0	0.88	0.47	
B(15)	37	5.1	0.68	0.87	
	26-19	5.6	0.70	0.68	168
	13-9	6.3	0.82	0.50	
C(20)	37	5.7	0.66	0.87	
	26-19	6.8	0.65	0.70	184
	13-9	7.5	0.76	0.51	
D (25)	37	6.5	0.63	0.87	
	26-19	7.7	0.61	0.71	185
	13-9	8.5	0.72	0.53	
E (30)	37	7.2	0.60	0.87	
	26-19	8.6	0.57	0.73	185
	13-9	9.5	0.67	0.54	

*Nett amount for dry sand: If sand is wet, reduce water added by a like amount

Rock ‘plums’ in concrete are solid, unweathered, igneous rocks not more than 250 mm in size that may be incorporated into a mass gravity structure while it is being built. This should bring about a saving on both cost of materials and labour time, especially if the plums are available near site. The size is related to the requirement that they are not so heavy as to sink further into the concrete (before it sets and starts hardening) and come to rest against the lower-lying ones. If this does happen, cavities will develop in the concrete, from whence the rocks moved, and weaken it. Generally, plums should not be more than 300 mm in size, and a maximum of 30% of the total volume of the structure may be made up of them, unless the design has called for something else.

Mixing of concrete in small quantities is best done in a wheelbarrow. For larger quantities it should be done on a piece of sheet iron or on a concrete floor. For still larger quantities it should be done using a concrete mixer that is sized according to the size of the job.

Hand mixing: The literature describing the method of hand mixing stresses the need to mix the cement, sand and stone together in one operation, and then to apply the water. The experience of the writer is that it is easier (but still as effective) to mix the cement and dry sand first, then to mix in most (± 80%) of the water thoroughly, and finally to add and mix the stone, the latter having been wetted while still in the wheelbarrow.

Mechanical mixing: Mixing with a concrete mixer calls for a slightly different procedure. The water is poured into the barrel of the mixer first, the cement second, and the aggregates (sand and stone) last. The materials must be close at hand and a plentiful supply of water must be available at all times, preferably in open drums to allow swift filling of the buckets.

On the average sized projects run by WfW, it is suggested that the mixer have at least a four to five wheelbarrow capacity. A concrete wheelbarrow has a 65 litre capacity when filled level to the rim. Allowing for a margin to save on spillage, a 250 litre capacity concrete mixer should therefore be the minimum size for a smooth operation. Having a larger one would speed up progress even more, but transport to and from site could be a problem.

For smooth and efficient mixing and transporting it is imperative that each worker has his/her specific task, and that all the materials are close to hand. It is suggested that when mixing mechanically, two workers filling and pouring buckets of sand and stone, one pouring water and cement, and one operating the mixer, should be able to keep four workers transporting concrete in an almost continuous operation. This will of course be dependent on the distance the concrete has to be transported and the condition of the path they have to traverse. Such a team of eight, with a 250 litre capacity mixer, should be capable of a rate of production rate of just on one cubic metre of concrete per hour, depending on the transportation distance. A mixer with a mechanical feeder will assist in mixing even faster. This estimate is based on another two workers being available for receiving the concrete, placing and rodding it to fill corners and evacuate airpockets. In an 8 hour day, therefore, one should expect something of the order of 0.50-0.75 m^3 per man day.

With hand mixing, but with the same conditions as set out above, progress should be approximately 25% slower or ¾ m^3 per hour; a norm of 0.25-0.50 m^3 per man day.

With poverty-relief workers and their lack of a suitable diet, and with learner contractors, the operations may take an extra 25% longer to execute, or ½ m^3 per team hour. This relates to 4 m^3 per 8-hr team day.

The order of operating and filling the mixer should be as follows:

- Switch the mixer on and the drum will start rotating.
- Pour in the required amount of water, and while the drum is rotating,
- Add the cement at a rate that allows a thorough mix with the water.
- Add the stone and continue rotating until a smooth paste has formed around the stone.
- Finally add the sand, and rotate until all the stone is coated with the cement-sand paste.

The concrete is now ready to transport to site and to place. Water from the concrete mixing process or from washing of tools and containers must be contained and not allowed to escape into the wetland.

Placing of concrete:

- Concrete should be placed within one hour of having been mixed. Never re-work or use concrete that has already set and started hardening.
- Before placing concrete against a soil surface or existing concrete that may absorb water from the fresh concrete, moisten the surfaces thoroughly without leaving free water to dilute the concrete.
- If shuttering (formwork) is being used to shape the structure, paint the surfaces of the shuttering that will be in contact with the new concrete with old motorcar oil, to prevent the shuttering from sticking to the concrete.
- Avoid excessive shaking of the concrete while transporting it, to prevent segregation of the ingredients. The pathway from mixing area to casting site should be regularly smoothed to speed up the construction process and make for better work efficiency.
- Place concrete in layers of 150 mm and agitate with spade or rods to eliminate air voids, especially at the sides and corners of the shuttering and around reinforcing bars. Important work should be agitated with a concrete vibrator.
- Try to complete the work in one operation. If this is not possible leave the concrete surface in a rough condition – suitable rocks half submerged into the wet concrete is a common practice to provide a rough surface on which new concrete can bind. Before continuing, clean the surface of loose particles to expose a fresh aggregate face. Be sure to clean off the shiny film left by the drying out of the bleed water. Just before starting to place the new concrete, moisten it and paint it with a 1: 1 cement: water cream.

Curing of concrete. In order for the concrete to harden properly, it must be kept moist for 7 to 10 days after placing and allowing it to set. There are various options:

- Cover the surfaces with sand, soil, straw or hessian which is then regularly watered
- Sprinkle continuously with water
- Dam up water over the surface
- Cover the surfaces with a polyethylene film so that the water within the concrete cannot evaporate
- Paint the surface with a commercially available curing compound in accordance with the manufacturers instructions
- Continue the curing treatment for a 50% longer period during freezing weather.

Formwork (shuttering) used in concrete construction : In order to build vertically with concrete it is necessary that some form of temporary double wall be erected wherein concrete can be placed while it sets and hardens. The formwork may comprise:

- Concrete bricks that have been built in the form of a cavity wall. Ensure first that no spilt water or old mortar remains at the bottom of the cavity.

The cavity is filled with concrete once the mortar between the bricks has hardened. For this technique not to be a very expensive operation the initial design must have taken the cavity wall into reckoning in the calculation of the total strength required so that the concrete bricks and the concrete filling are both part and parcel of the structure.

- Do-it-yourself timber shuttering: Here sawn timber or shutterboard is made into the necessary shape to receive and hold the concrete until it has set and hardened sufficiently. The shuttering is then stripped and used elsewhere. For smaller structures (up to two metres in height) stripping time can be as little as two days. The method of construction is dealt with in detail in Chapter 28.
- Rented or purchased steel formwork. This is similar to the timber method, but with a host of different shaped panels to suit all aspects of concrete work (Chapter 29). The panels are designed for quick joining using special couplings. This type is recommended for larger structures and where speed of operation is essential. Preparation of the panel surfaces with oil is all important.

28.5 Some synthetic materials used in soil conservation engineering

Geotextiles are a range of both woven and non-woven continuous filament needle-punched membranes. They are manufactured out of polypropylene and polyester fibres. While polyester is reasonably resistant to the ultra violet rays of the sun, polypropylene is definitely not. It is strongly recommended that, irrespective of the type of polymer material, they always be placed in a protected environment when stored for later use, when temporarily stored at the construction site, and when placed in position in or on the structure. The material is subject to damage when roughly handled, walked on by animal hooves, and even sharp-billed birds such as herons and cranes.

Geotextiles are used as:

- *drainage filter material* to allow moisture to seep out of soils and other *in situ* material without the parent material moving through the cloth along with the moisture. An example is the universal use of the cloth as a separation lining between all gabion – soil interfaces. In general, needle punched polyester fabrics have a greater opening ratio and are therefore less susceptible to blocking by fines from the soil than are woven fabrics. Needle pointed 'Bidim' should be used in preference to woven fabrics for gabion backing
- *a soil-reinforcing membrane* where berms/embankments need to be built with side slopes steeper than the natural angle of repose of the soil involved. Suppliers will assist with identifying the correct fabric for the job
- *an impermeable membrane* for water retention when treated with bitumen emulsion – this could be used for temporary water storage on site. Useful where relatively large summer water volumes are stored on site for construction use in winter, or to seal off a wildlife pond that is to form part of the planned rehabilitation
- *a separation membrane* between ground surfaces and road-building material when constructing a road across unstable surfaces. This could have important application where roads are required to traverse wetland conditions. Suppliers will design a weave, taking account of the strength of the foundation and the rolling pressure of the expected traffic.

The geotextile material is sold in standard rolls of 5 m x 150 m and with various thicknesses/strengths for the various applications required. It is best to consult with the manufacturer with respect to the

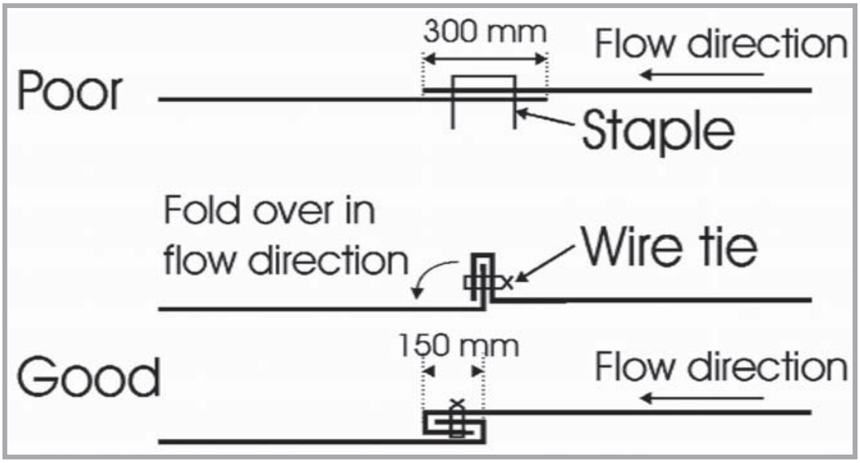


Figure 28.6: The types of joins that can be used when working with geofabric

correct thickness of material to be used. One well-known brand is manufactured in South Africa by Kaymac Industries and distributed by Messrs KayTech, Maccaferri and Land Rehabilitation Systems under the trade name Bidim. They have service centres in Johannesburg, Cape Town and Durban. There are a host of different materials available for a very wide range of applications, and the reader is therefore referred to one of these firms dealing with them for the most suitable membrane for his particular problem.

Joints in geofabric should be made with an overlap of at least 300 mm or a 150 mm double fold over and tied with galvanized wire staples at 300 mm intervals. The joint must always lap away from the direction of flow, otherwise the joint will open (Figure 28.6).

Geoliners

This is a thin, flexible, waterproof film made of polyethylene, polypropylene, PVC or butyl rubber to suit various requirements. Each has its own special application, but polyethylene is the most suitable of these materials for wetland work. In the wetland rehabilitation scenario it would be typically used to separate erodible soil from fast flowing water, such as underneath a gabion chute or gabion apron below a weir. In order to protect the material from puncturing by sharp pointed rocks, it would have to be protected with a covering layer of geotextile – see above.

Another application would be to stop water moving through the upstream face of a gabion weir in order to create a dam of water. Again, the film would need to be protected by a geotextile film placed between it and the gabion basket material, and also upstream by a blanket of soil (Figure 28.7).

Geomembrane tends to be very slippery and will not support soil cover or anything else lying on it at a slope steeper than 1:10. It has to be anchored at the top of the slope if the latter is more than 1:10. Mattresses lying on it must also be anchored. Soil cover must be placed and compacted from the bottom up, and not simply tipped down the slope. Geomembranes are in great demand for informal housing and hence very vulnerable to theft.

The film has been used to good effect by the national Department of Agriculture as a vertical separation membrane through the middle of earthen embankments used to dam up water where the soil is highly dispersive or permeable. The film is laid in a vertical zig-zag manner as soil is built up in successive layers on either side of the

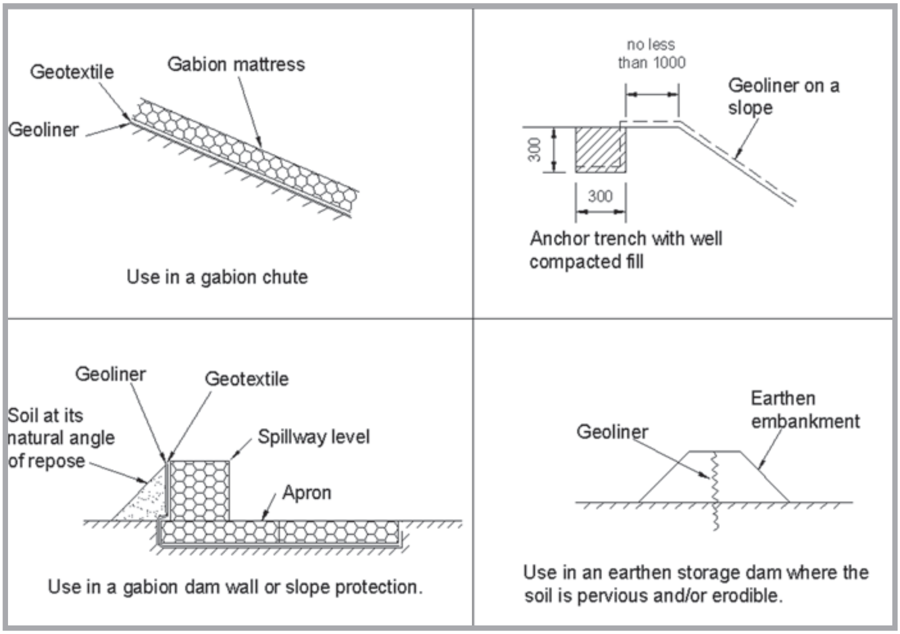


Figure 28.7: Use of geoliners and geotextile in erosion control

film. It also improves the seal between the compacted soil and the film.

These geoliners are available in rolls of approximately 5 m wide x 50-100 m long. A minimum thickness of 500 micron is recommended. Under harsh conditions (e.g. rough, stony terrain) a thicker film should be used. There is no known glue capable of permanently bonding polyethylene sheets. Joints have to be made by thermal welding either in the supplier's yard or on site. This is a specialized procedure usually carried out by the supplier. It is quite quickly performed and can be economical if long lengths of joints are required, but as the set up charge is high, the making of small lengths of joints or repairing damage can be very costly.

The various materials have different levels of resistance to deterioration when exposed to sunlight, but in all cases except with the thickest polyethylene it is quite rapid. All geomembranes should be protected from exposure by sunlight by at least 150 mm of soil or 300 mm of water. Use geocells to hold soil in place.

Geo-cells

These are systems of regular cells that have been formed by the alternate fastening of strips of polyethylene material in order to form a system of square cells when the finished product is stretched out sideways. See Figure 28.8. The cells are filled with either soil, gravel or concrete, in order to either:

- stabilize steep slopes, when soil (planted to suitable vegetation) or gravel/crushed rock is used
- line chute spillways or storm water drains, when concrete is used
- protect foundations from the force of falling water below weirs, when concrete is used
- protect earthen berms from trampling by animals, when crushed rock or concrete is used
- stabilize roadway stream crossings, when concrete is used
- hold soil in place over geomembranes to permit slopes steeper than 1:10 but not steeper than 1:5.

The advantages in using this technology

Figure 28.8: Geo-cell System: various applications

include the lightweight of the material, its flexibility in use, ease of installation, and application to both labour-intensive as well as mechanical methods of filling. The product is formed out of woven polypropylene slit film tape, an impregnated, porous, acrylic non-woven geotextile, or a polyethylene material depending on the manufacturer. It is sold in panels of roughly 10 m x 5 m, and heights/depths that range from 100 mm upwards. The sizes of individual pockets range from 100 mm to 250 mm. Especially where concrete is used as the filler, the cellular system results in the very suitable formation of inter-locking blocks, and allows for seepage between adjacent blocks.

The following commercial firms advise on, and market these and other similar products under different brand names. Their telephone numbers should be accessed from the telephone directory.

- African Gabions (Durban, Johannesburg and Cape Town)
- Hyson Cells (Muldersdrift)
- Kaytech (Durban, Cape Town and Johannesburg)
- Land Rehabilitation Systems (Randpark Ridge)
- Aquatan (Johannesburg and Cape Town).

Geojute or hessian

Cloth of woven jute is known in the trade as Geo-jute, Soil saver, etc. It is probably more cost effective to purchase it as plain hessian. Laid on bare soil as a cover to both hold soil in place, reduce the energy of falling raindrops, and to retain moisture on and in the soil, hessian is a useful product to encourage the quick germination and growth of vegetation that has been seeded, especially on sloping land.

It is therefore used to provide quick protection to earthen berms, storm drains, etc. Its life span is, by its very nature, short, and where termites are a problem should not be contemplated at all. Preparation of the soil with the incorporated agricultural lime (in acid soils), gypsum (in dispersive soils) and appropriate fertilizers, will greatly speed up the growth of the vegetation. This type of vegetation establishment should preferably take place in autumn when temperatures are still fairly high, the soil moist, and when rainfall intensities are reduced.

On steeper slopes it should be used double thickness, anchored at the top by burying 250 mm into the soil, and anchored with short wooden pegs at 1.5-2.0 metres centre to centre down the slope. The cloth is sold in widths of 1.2-1.8 m.

28.6 Concrete cellular mattresses

Marketed as Armorflex, these inter-locking, pre-cast blocks are manufactured by Messrs. Concor Technicrete Building Products with offices throughout Gauteng, Limpopo and Mpumalanga, and under license by Messrs Infraset of New Germany, Durban.

Armorflex mattresses consist of concrete blocks that are machine-pressed to a special inter-locking shape. They inter-lock with each other transversely across the width of the mat. The blocks have a partial taper to the sides that allow the system to articulate freely without disjointing. The taper encourages the ingress of fine granular particles into the joints between the blocks. Where the mats are required to protect the underlying soil from high velocities, they can be wired together, across the direction of flow, to provide extra stability (see Figure 28.9). While they can be delivered to site and laid in mats 6.2 x 2.4 m in size, they lend themselves to hand placing and wiring as well. A further

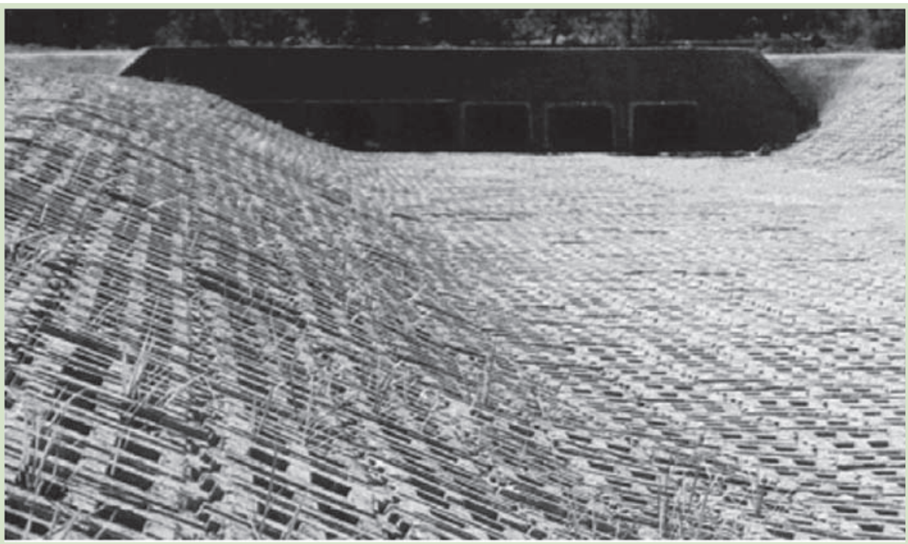


Figure 28.9: Concrete cellular mattresses used to line an eroding ditch (photo courtesy of Messers Infraset, New Germany, KZN)

advantage is that they can be laid under water. The suppliers will provide onsite training on request.

When properly designed and laid Armorflex can provide protection against quite fast flowing water. The velocity that the lining can tolerate is a function of the geometry of the channel and the characteristics of the underlying soil.

28.7 Gabions

Gabion work is the technique of building with dry handstone sized rocks packed into specially manufactured wire baskets and mattresses of various standard sizes. The baskets and mattresses are laced together as they are filled, in the construction of, usually, mass gravity weirs, although chutes can also be constructed with them. The design of gabion work requires that the fill material be of a certain density as the structure relies on its mass for resistance to overturning and/or sliding. Most of what was said of rock for rock masonry work applies equally to that for gabion work. Adhering therefore to the type of rock mentioned, i.e. using only high density, quarried igneous rock, will ensure that the cross section dimensions of the structure are the minimum for a given height of structure and depth of overflow.

The advantages of gabions are that they:

- do not require a solid rock foundation and can flex to take up a certain amount of settlement
- are relatively simple to construct
- can be built in a wet environment
- do not require a drained surround for stability.

The prescribed method of construction of gabion work is adequately illustrated in the supplier's leaflets (see Figure 29.8 in the next chapter), who will also provide on-site training in the correct method, should the project manager so require it.

The disadvantages of gabion structures are:

- As long as a rock foundation is available, the amount of building material necessary for a gabion structure is a fair amount more than for a concrete design. This is because of the fact that, because of the voids in the packing of the rock the mass per unit volume of a gabion structure is usually less than that of concrete, by 30% and more. For the same final design mass of structure (for stability) the gabion will require more rock than will one made of concrete. The cost of concrete chips is similar to that of handstone, so that where transport of material forms a large portion of the project cost, gabion work could cost considerably more than concrete structures.
- If they are to hold back water for the duration of their expected lifespan they must be rendered impermeable, especially where the adjacent soil is dispersive. Use is then made of both geotextile and geoliner material as described above, adding further to the cost.
- The simplest way to key the gabion structure into the walls of the gully is to construct the keywall as a gabion work. This is completely in contradiction to the requirements of a keywall, which need not be as wide as one metre (the width of a gabion basket), and must be impervious. The keywall must therefore be lined with a polyethylene and geotextile film on both sides and underneath the waterside as well, adding further to the cost. The underground keywall surface is an uneven one because of the projecting rocks, and compacting the backfill soil securely around the many protuberances is problematic. This is a very real problem in dispersive soils. Alternatively the key wall and waterproof diaphragm can be constructed as a relatively thin (0.3 to 0.5 m) reinforced concrete wall and the gabions used for stability and bank protection.

- The rock must be very carefully packed to create as dense a structure as possible. Some gabion work has been carried out in the past using reject burnt brick as filler. Brick is much lighter than the recommended rock, and in the normal course of events will therefore require a larger cross section dimension in order to resist sliding and overturning. This could result in a higher overall cost in spite of a lower tariff for the fill material. Further, it must be pointed out that burnt clay brick is water soluble in the medium term and most unsuited for gabion work in a wet environment. Concrete bricks, however, if the correct concrete mix is used to create the required mass, will result in a material very much more suited to packing in gabions. The closer packing that can be achieved with uniform bricks could result in even smaller cross section dimensions than those required for quarried rock. This may help to overcome an increased cost of manufacturing the bricks instead of using quarried rock.
- Unfortunately, and while gabion weirs are probably the easiest structures to erect, they should be considered as medium term solutions only. This is especially the case where the water flowing through and over the structures is highly acidic. The wire has, in most cases, and according to the manufacturer's information brochures, been double galvanized. The fact remains that there is a fair amount of evidence to show that rust can be a problem. Added to this are the high temperatures generated when wildfires sweep through wetlands in winter. Aggravating the situation is the large amount of combustible vegetation that develops in wetlands. These fires can result in the gradual burning off of the galvanizing, and acidic water will attack the wire and cause it to rust and break. The structure itself is then liable to break up. It is therefore recommended that gabion work be limited to splash protection components and overflow structures no more than one metre in height. In the latter instance vegetation that has taken hold should have a fair chance of maintaining the shape of the structure, especially if the catchment size (and Q) is small and velocities low.
- It has been found that the wire baskets are attractive to the local population desirous of rearing chickens. Instances have arisen where gabion work has been interfered with in order to use them for caging these birds.

The WfWetlands organisation requires that wherever gabion work is proposed, samples of the water in the wetland be analyzed for corrosive properties, and the results discussed with the relevant Technical Advisor before any design work is carried out. This is mandatory – see the Best Management Practices document in Appendix 4. *The sample(s) should preferably be taken during low flows only.* The problem of corrosivity is considered to be particularly problematic in wetlands that have pine plantations, suburbia and/ or industrial complexes in their catchment areas. Coal-mined areas are an exceptional hazard.

The procedure is to take a one litre sample of the water during low flow, and send it to a laboratory that can do the test for corrosivity. There are two complementary tests that need to be undertaken, both of which require information on Total Dissolved Solids, expected water temperature (in wetlands approximately 15-20 ^{0}C), alkalinity ($CaCO_3$ in mg per litre), Calcium content, and pH of the sample. These tests have been devised for use in the industrial water-conditioning situation to protect boiler and heat exchanger systems, but the procedure should also be applicable to the problem of gabions in wetland rehabilitation.

The Langlier Saturation Index (LSI)

The Langelier Saturation Index (LSI) is a method of evaluating water quality in order to determine whether the sample has either a corrosive or a scale-forming tendency. The formula is:

$LSI = pH_a - pH_s$

where pH_a is the actual pH of the water, and

pH_s is the pH of the same water, but when saturated with Calcium Carbonate.

A negative value of the LSI is indicative of unsaturated $CaCo_3$ (i.e. soft water) and therefore aggressive towards iron. A positive answer on the other hand intimates that the reverse is the case – the water (i.e. hard water) tends to deposit, among other elements, Calcium, and therefore does not corrode. The actual values one way or the other indicates the degree of corrosiveness or otherwise, without indicating just how bad the situation is. In fact, two different water samples may have vastly different pH values but still have the same LSI. A further calculation is therefore necessary:

Ryzner Stability Index (RSI)

The Ryzner Stability Index (RSI) was developed to distinguish between the two waters having different pH but having the same LSI. The form of this formula is:

$$RSI = 2(pH_s - pH_a)$$

The calculations are involved, but any laboratory serving the boiler treatment industry will be able to conduct the tests and to advise on the corrosivity of the water. Table 28.4 below gives a suggested guide for when gabion work should be safe against corrosion. The introduction of a structure height limitation related to degrees of corrosivity is considered necessary by the author as the higher the structure is to be, the greater the damage and cost of repair should corrosion cause the collapse of the structure.

Recommended reading on this matter is the book by Hamer, on *Industrial Water Treatment.* A supplier's instructions on gabion construction for various applications are supplied in Figure 29.8 in the following Chapter.

It will be noticed that there has been no mention made up to this point on the use of PVC coated gabions. The reasons are twofold:

- The PVC coated gabions are very expensive.
- The PVC coating will be burnt off over time, either by the ultra-violet rays of the sun, or by wildfires that occur in wetlands where the very structures themselves have resulted in a vigorous growth of vegetation.

The use of these gabions is therefore not recommended, unless approved by the relevant Technical Advisor. The actual design of these structures is dealt with in Chapter 21.

Table 28.4: Recommendations regarding the use of rock-filled gabions as weirs or chutes in wetland rehabilitation, in the presence of corrosive water.

Numerical value		Degree of corrosion	**Maximum height ofstructure(m)**	**Gabions**
Langelier Index	**Ryznar Index**			
-1.0 to -4.0	10-14	High	Any	No
-0.3 to -1.0	8.5-10	Moderate	1.0	Yes
-0.3 to +0.3	7.5-8.5	Neutral	3.0	Yes
above +0.3	above 8.5	Alkaline	3.0	Yes

CHAPTER 29:

WORKING ON SITE

29.1 Setting up a construction site

For purposes of this discussion the construction site encompasses both the specific position where the structure will be erected and the best site for the off-loading and stockpiling of any imported material such as rock, sand, cement, gabion material, timber shuttering, tools etc. The source area for any local building material that may be used, such as sand, soil and water, is also included. Finally this section should be considered as complementary to the Best Management Practices (BMP) document drawn up by Working for Wetlands, and which is mandatory in respect of their programme. Their BMP document is reproduced in full in Appendix 4.

This discussion is deemed necessary in order to ensure that the site, being in a wetland that needs rehabilitation, will not suffer further damage as a result of poor planning for the execution of the work. It is also necessary to ensure that the clean-up afterwards is carried out with the minimum of effort. The effort of cleaning up after the completion of the project is very necessary, but results in what may be termed non-productive expenditure. Planning the set-up carefully in advance should result in the minimum of fruitless expenditure at the end of the job. The project manager and contractor are urged to picture in their minds the progress of the entire project. What will be the order of successive tasks? What tasks can be carried out simultaneously? What type of problems could arise during the construction work?

The area(s) chosen for the stockpiling of imported (purchased) building materials should be demarcated, and notices put up declaring what must be stockpiled where. The project manager may not be on site when the truck delivering the material arrives. Labour for the shifting of tonnes of stone and sand that have been dumped where excavation has still to take place shows lack of planning and forethought, and results in wasted effort.

The source area for items such as soil for embankments (i.e. the borrow area or borrow pit) must also be identified, and access to both it and the stockpiles of imported materials smoothed, drained and hardened if possible. Nothing can be more disheartening and energy sapping if workers have to push/pull heavily laden wheelbarrows through saturated areas. The topsoil must be stripped off of the borrow pit and also stockpiled in a suitable place, ready for re-use. Experience has shown that without proper and constant supervision the untrained workers will very easily source soil from an area that, in terms of the rehabilitation, should never have been disturbed in the first place! And they will use the topsoil where it is not supposed to be used!

Very important is the setting up of a garbage drum and a temporary fuel storage site if any motorized equipment is to be used. The fuel storage area must be bunded and waterproofed to ensure that no spilled fuel soaks into the soil or runs off into the wetland. Any soil contaminated by fuel (oil, hydraulic fluid or any other hydrocarbon) must be dug up and transported off site for safe disposal.

The siting and erection of toilet facilities must be carefully considered. There are fairly explicit Best Management Practices set out in respect of toilet facilities, and these must be adhered to in the finest detail. An extra suggestion is that a well-drained site (both internally as well as surface-wise) be chosen, well away from the wetland edge and with due regard to privacy and wind direction. A bucket-type system would always be preferable, but practicalities may dictate otherwise. If the toilet is to be of the 'long-drop' type, then a deep red soil is indicative of a well-drained soil profile and must take preference.

Sufficient toilet paper and some sort of hand-washing facility should be provided. Needless to say, the hole for the long drop must be properly filled in afterwards and re-vegetated. A couple of poles and some shade cloth will make an inexpensive, re-useable site for resting and eating away from the sun.

Cooking fires should not be permitted in wetland areas. If fires are to be made, a formal fire place should be built on a bed of mineral soil that can be removed on completion of the work. Even braziers should be stood on a mineral soil bed. Hot coals must not be tipped in the wetland area, especially in the dry season when the danger of fires both above and below ground is high.

Workers must be properly instructed in the proper care of the environment, especially with respect to poaching, disturbance of nesting and roosting areas, disposal of human waste , garbage etc.

29.2 Access to the site

Bearing in mind that a lot of traffic is going to occur between the edge of the wetland and the chosen site of the structure, the access route across the wetland must be carefully chosen with due regard to flood flow patterns. Vulnerable areas, valuable plant and animal species such as Wattled Crane nests must be avoided. Once the route has been decided upon, it should be marked off with barrier tape, and ensured that the workers understand that movement outside of the areas so demarcated is prohibited. Where a Crane nest is close to the work site consideration should be given to masking the inter-visibility by the use of a shade cloth covered screen. This is especially necessary where winter-breeders such as the rare Wattled Crane is concerned.

It may be necessary for vehicular movement through the wetland to the site in order to dump building material, however unfortunate that may be. This must be done in as sensitive as manner as possible. It is a simple arithmetic exercise to calculate the cost of the road construction (and its removal after the project has been completed) against the cost of manhandling building material to the site. For example, two workers walking one behind the other, with a 2.4 m x 50-75 mm diameter wooden pole slung between them and resting on their shoulders, should be able to carry a 50 kg load slung over the pole. A walking pace of at least 2 km per hour should not overly stress them. The return trip must of course also be taken into account in the calculation. In this manner it may be possible for 2 workers to move 1.0 to 1.5 tonnes of building material per seven-hour working day over a 250 m long access route!

In this context, and especially where concrete structures are to be built in peat wetlands, it is recommended that serious consideration be given to mixing the concrete on hard ground outside the wetland and manhandling it to site. On the downside however, this will mean that the workers have to carry the added mass of water. Alternatively, shutterboard should be used on which to mix the concrete in the wetland. The relationship between concrete structures and peat wetlands is purposely mentioned as peat can not be used as a building material, and under the same hydrological conditions a concrete structure will always require less material than will gabion ones. The latter type structure will therefore require far more manhandling of material than will the former. Furthermore, water from washing of tools and containers must not be allowed to escape into the environment as it is highly alkaline and toxic to most organisms.

The most innovative method of transporting material across a wetland must, however, be the scheme devised by Doug Woods, implementer for the Northern Eastern Cape area. See Figure 29.1. In this way they moved 130 m^3 of concrete 150 m in one month.

Figure 29.1: An innovative and effective method of transferring materials across a wetland using a cableway with a wheelbarrow suspended from it.

29.3 Setting out the structure

The area(s) to be excavated must be precisely demarcated, preferably with barrier tape tied between sturdy stakes (e.g. yellow painted 8 mm round bar) that have been hammered well into the ground at each corner of the excavation. This should preferably be done just before the work is to commence. If marked out too far in advance one will run the risk of having to re-do the staking out because of vandalism, wildfire (wooden pegs) or trampling by grazing animals. The specifications may call for a specific height of the structure in relation to something else (e.g. a dimension above or below original ground surface, or a structure at a lower elevation than another upstream).

A Bench Mark peg (also termed a Reference Peg) will then have to be inserted well away from the excavation in order to guide the builders as to final height of construction when the topography has possibly changed through the disturbances caused by construction work. See Appendix 2 for a fuller explanation of the benchmark and how to set both it and the various types of structures out.

Exceedingly important too is to mark out precisely where the excavated soil must be placed. If it is to be re-used in the trenches after construction it should be stockpiled close at hand without the risk of it falling back into the trench. If it is to be used in any other earthwork, then it should be excavated, transported, placed and compacted as a once-off operation, if at all possible. Double handling of building material is a complete waste of time, effort and money.

With regard to water and the construction process, and especially where earthen and concrete structures are to be erected, a sufficient supply of good quality water will be needed. This should be considered even at the preliminary investigation stage, and provision made for it. If the wetland is normally dry during the winter construction period plans must be made to find the closest source of suitable water. Pumping water a distance into a small portable on-site reservoir may be the only option, or riding drums of water to site on the back of an LDV as an alternative, are the two obvious options to be considered. In actual fact, and especially in the climatically drier areas of the country, a flexi-tank that can be carried on the back of an LDV should be standard equipment, as should a pump, for any persons involved in any type of wetland rehabilitation caused by soil erosion. The importance of water for both concrete and earthen work can not be over-emphasized, and the reader is referred back to Chapter 28 in this regard.

29.4 Storing building equipment and materials

Borrowing or renting a weatherproof and lockable shed in the yard of the landowner will be the preferred option, as long as the daily effort to get the equipment to site is not too time-consuming. This option should prove to be fairly safe from a theft point of view. The alternative would be to buy a secondhand shipping container and place it near the dwelling closest to the site. A very sturdy lock and some form of compensation to the owner of the dwelling for supplying security would then be necessary. All tools, fuel, equipment and cement should be stored in a safe place. More pertaining to the storage of cement has been given in Chapter 28.

29.5 Controlling water during construction

Working in a saturated environment is very difficult, and when placing concrete or compacting soil under very wet conditions, is not a good construction practice. Even building gabion structures in a watery environment can lead to problems, to say nothing of the danger of diseases such as bilharzia to the workers. It is not easy to excavate a level base under water, nor is it possible to compact the soil base in a pool of the same before laying the gabion mattress. It is important to dry the site out to a fair degree before construction commences, although, as indicated in the section above, some water will be needed thereafter for most of the construction methods to be dealt with.

Controlling natural water at the construction site is achieved by a variety of methods, sometimes requiring a combination of two or more. The following are the methods in general use:

- Excavate a trench on a gradient of not less than 1:100 from upstream of the site, leading the water well away from building activities. It may be necessary to pack bags, filled with soil or sand (see note on sandbags below), in the channel where the trench starts in order to lead the water into the trench. The trench must be properly closed off on completion of the work.

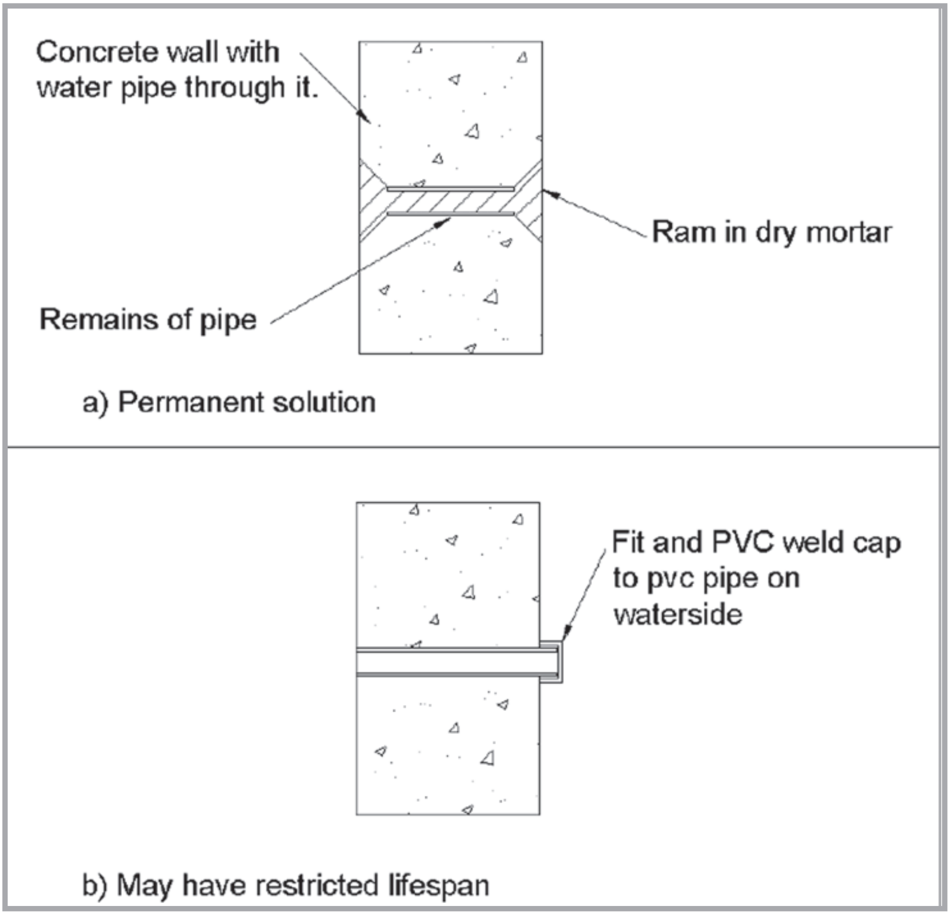


Figure 29.2: Methods of permanently blocking a water or spacer pipe.

- Where the gully or artificial ditch is fairly wide and the water flow strong it may be possible to build a diversion of soil or sandbags just upstream on the one side of the gully. The flowing water is then diverted to the other side while construction takes place in the protected area. Having inserted a large enough pipe or sluice through the first section of wall, it is a simple matter to now divert the water through the pipe while completing the second section of the structure. It is sometimes necessary to carry out repair work where floodwater has cut a channel around the side of a weir. In order to work in the breach it will be necessary to build a temporary 'cofferdam' out of sandbags around the damaged area. The flowing water is forced to build up behind the cofferdam to the height of the spillway, and then to flow through the spillway while repair work progresses.

  Note on sandbag cofferdams:
  Extreme care must be taken in building a secure and stable structure. There is a tendency to build them too slender, and failure can be hazardous to workers and catastrophic to works under construction.
- Block the channel with a small soil berm and pump the collected water out and away from the site. The delivery of the pump used will have to be chosen to fit the rate of flow being experienced, or the small dam made large enough to store sufficient flow, and then to pump it out every couple of hours. This method is particularly suited to slow flowing seepage water.
- Block the channel as before and fit a pipe (in most instances a PVC pipe would be quite in order) with a large enough diameter to lead the water through the workings, discharging into the channel below the site. Although this method is more complex, requiring that one then build around the pipe, it would be the chosen option in the scenario with a fairly high flow rate and where the water flows within a fairly deep channel. The pipe could be built into the structure and then closed off with a stop-end on the upstream end once the work is completed. A more permanent closure would be to chop the pipe back 50 mm into either end of the wall and ram the void full of a dry–mix mortar. See Figure 29.2. If the mortar is too wet it will slump and not fill the pipe completely.

29.6 Construction techniques

Shuttering for concrete work

Shuttering can be made of wooden planks or steel plates.

Timber shuttering

The former is a 'Do-it-Yourself' operation where shutterboard is normally used. It is typically used on structures up to 3 m in height. Shutterboard is a strong plywood 19 mm thick, and available from timber merchants as sheets 1.2 x 2.4 m in size. The sheets are cut to suit the dimensions of the required structure, and spacers and ties of 15 mm PVC piping cut to the required thickness of the wall. Iron rods through these pipes hold the shuttering the required distance apart fitted to separate the two walls. SA pine timber lengths with dimensions 50 x 75 mm are normally used to fasten separate sheets together (see Figure 29.3 for details). The board must be oiled on the inside to stop it sticking to the concrete. When stripping the shuttering, the threadbar is removed to be used again. The PVC piping however remains in the concrete. The holes can be closed by forcing epoxy into the pipes, or as illustrated in Figure 29.2. An alternative to the thread bar (which is expensive and will not remain useable with rough handling) special clamps can be used to clamp onto ordinary 8 mm diameter roundbar, see Figure 29.3.

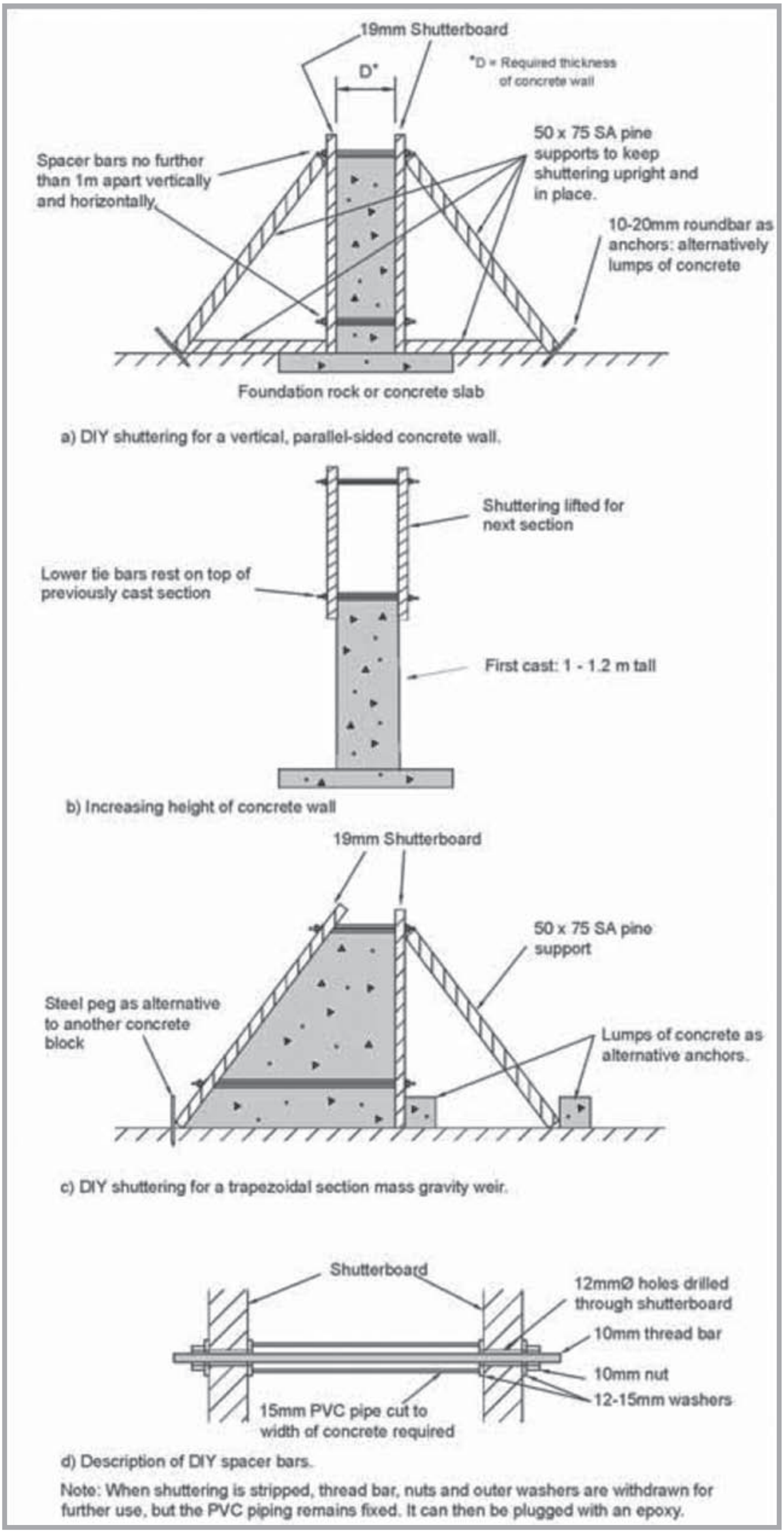


Figure 29.3: DIY timber shuttering for concrete weirs

On the more sophisticated side is steel shuttering of various shapes and sizes to suit specific dimensions, sold or rented out by a number of private companies. Find them in the Yellow Pages under the heading ‘Scaffolding’. The panels are held together by steel clamps and are very easy to erect and to strip afterwards. From the same companies a large variety of extra items such as corners, props, tubes and fittings, ties, etc. are available. The firms will draw up a list of equipment needed for the project, based on the engineering plan for the structure. The panels must also be oiled before use. See Figure 29.4 for examples of their wares.

Ties are available in two fashions. The crimp tie remains in the concrete wall, although the steel cones can be removed for re-use. This is not recommended for weir construction. The round bar tie set is used, as in the D-I-Y method, in conjunction with non-recoverable PVC spacer tubing, allowing the round bar to be removed and re-used. The advantage of this tie bar is also that the bar has a fast run-out thread, and clogging by concrete splash is not a problem. They can also be used with timber shuttering.

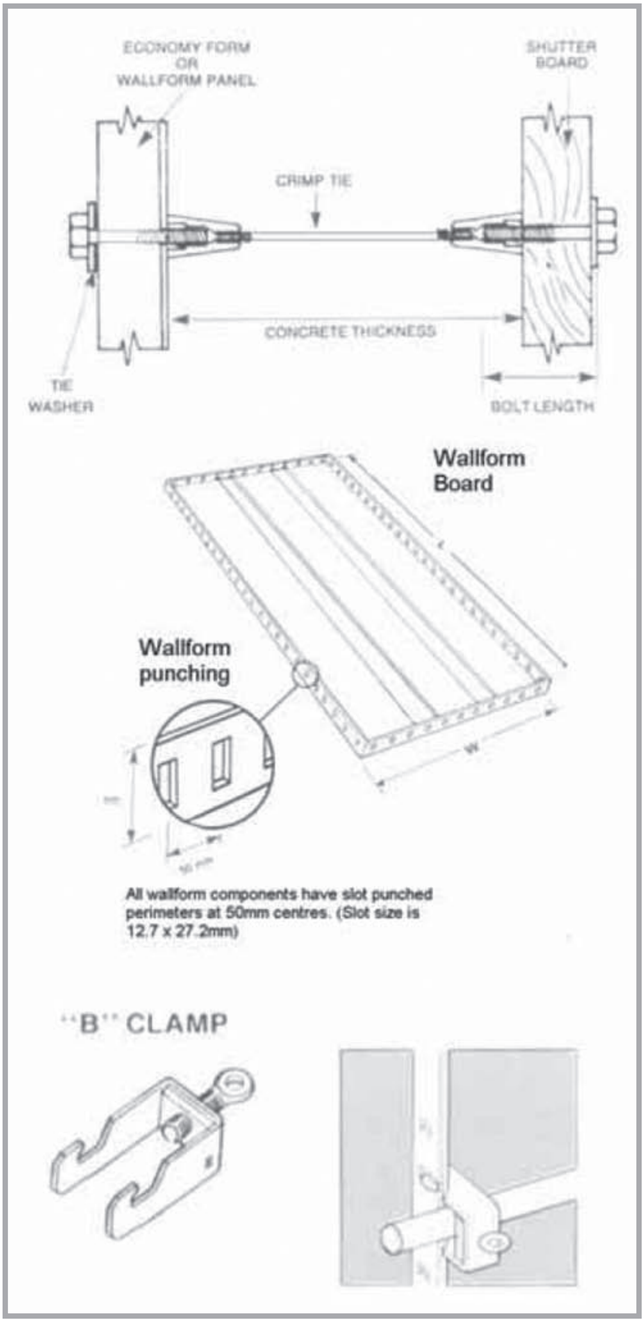


Figure 29.4: Commercially available shuttering panels and accessories

Building to a specified slope

A mass gravity concrete weir has a trapezium-shaped cross shape with a vertical face on the waterside and a slope to the downstream face. There are a number of ways of ensuring the correct angle of slope.

- Possibly the simplest is to build it in steps as shown in Figure 29.5. The negative aspects to this method are that it will require slightly more concrete, and it will take longer to build due to having a necessary delay required before stripping off the shuttering step by step. On the other hand there is less shuttering required, and because of the 'staircase' effect the result will be lower velocities on the downstream side of the weir due to the constant energy loss as the falling water hits each step in turn. *Splash protection on the sides of the gully via shoulder walls is very important with this method.*
- Using full shuttering, the downstream face of the shutterboard must be sloped to the required angle according to the specifications and fastened with long spacer bars. The problem with this method is that of getting the concrete into the furthermost corners of the encasement (see Figure 29.3(c)). The sloping shuttering is also subject to vertical forces and may lift if not properly tied down (Figure 29.3(c)). Never pour concrete a vertical distance more than 1.2 m, otherwise the aggregates will separate and result in a poor distribution of the mix. This distance also fits the shorter side of a standard sized shutterboard sheet (1.2 m x 2.4 m).
- When rock masonry weirs are built, the sloping downstream face is regularly checked using a triangle and spirit level. The triangle may be made of wood or round bar. Make sure that the contractor knows which side to place the spirit level (see Figure 29.6).
- An earthen embankment is always built to certain standard side slopes (discussed in Chapter 19), and the higher the embankment, the more difficult is the task of ensuring that the correct side slopes are maintained. Figure 29.7 shows some of the different ways in which the side slope angles can be determined during construction.

Gabion work

The leaflet on handling, fixing and filling gabion boxes and mattresses is self-explanatory (Figure 29.8). There are a couple of issues that are not dealt with, however.

- Contrary to the present practice amongst some implementers in constructing gabion weirs in wetlands, it is NOT correct to excavate to the exact dimensions of the structure. Excavation should be approximately 500 mm wider, and the boxes/mattresses placed squarely in the middle. This allows a space 250 mm wide around the structure. Once the first layer of baskets/mattresses have been filled and the filter fabric affixed, the surrounding space must be carefully backfilled with good clay soil at optimum moisture content and well compacted. If the soil is unsuitable, soilcrete (1:10, cement: sand mix wetted to a plastic consistency) must be used instead.
- The next layer of baskets are then placed, being careful to align them, not as in staggered brickwork, but one on top of the next so that all edges and diaphragms line up. These empty units are then wired up along all adjacent edges both horizontally and vertically, and including the diaphragms. Only once the empty baskets are properly wired, may filling this next layer commence.

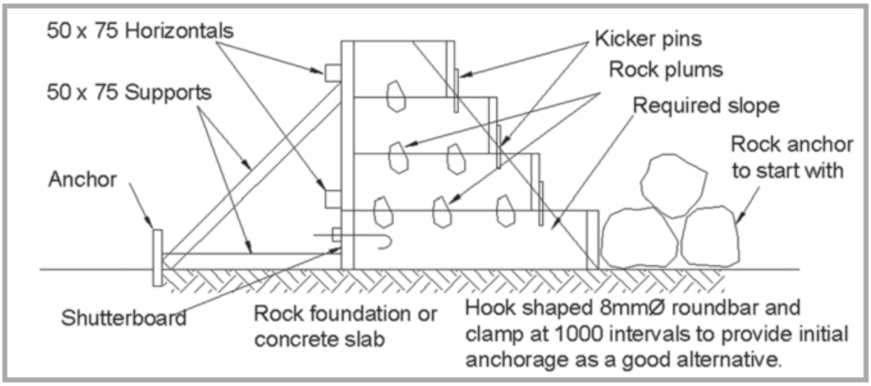


Figure 29.5: Stepwise method of construction of a mass gravity concrete weir

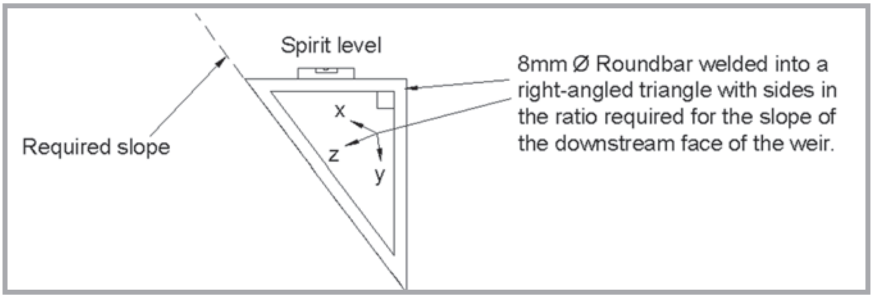


Figure 29.6: Triangle for checking downstream slope on mass gravity weirs

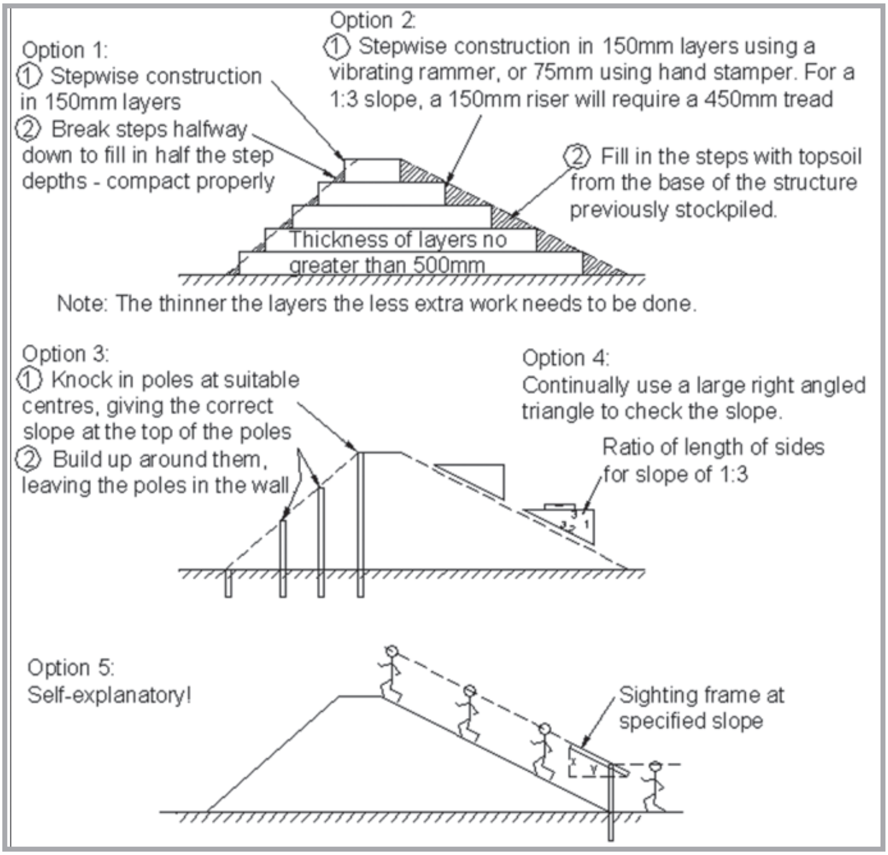


Figure 29.7: Various methods of ensuring the correct slope of an earthen embankment

Figure 29.8: Assembly of gabions (pp 243-247)

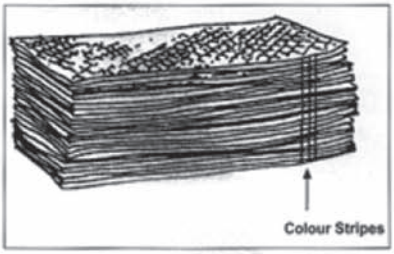
GENERAL INFORMATION

Box Gabions and Reno Mattress units are easily and quickly assembled by unskilled labour after the minimum of instruction. The information in this leaflet will help to ensure that a well packed, structurally sound, durable and attractive structure is obtained.

Packing *See Fig. 1*

The units are delivered to site folded flat and compressed into bundles weighing approximately 800kgs. The type and size of unit determines the number in each bundle. Box Gabions are usually wired together in bundles, whereas Reno Mattress bases and lids are usually packed in separate bundles. For easy identification, bundles are spray painted with coloured stripes to identify the different sizes.

Fig. 1

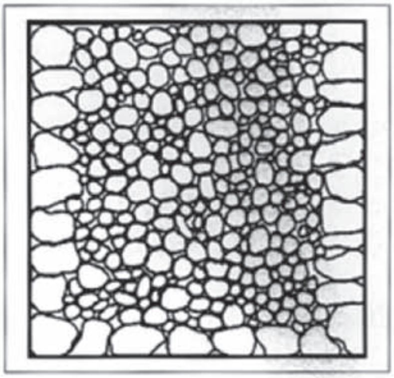


Stone Fill *See Fig. 2*

The stone used as filling for gabions should be clean, hard unweathered boulders or rock fragments. The rock fragments should not exceed the grading size given below:

Unit Type	Grading
All box gabions	100 - 250mm
170mm deep mattresses 230mm deep mattresses 300mm deep mattresses	100 - 125mm 100 - 125mm 100 - 200mm

Fig. 2

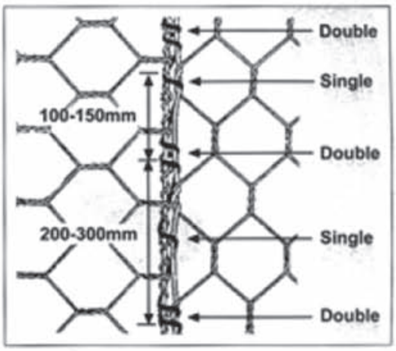


Wiring

Manual lacing is carried out in a continuous wiring operation, not with individual ties or twists. *See Fig. 3.*
Single and double twists are required alternately at approximately 100 to 150mm spacing.

A manageable length of binding wire is one complete turn from the coil as supplied.

Fig. 3



Bracing Wires

To speed up and improve job site operations, bracing wires are readily available from African Gabions, in 3.9mm pre-formed shapes.

Tests show that no other manual lacing method gives the necessary strength!

Tools *See Fig. 4*

We recommend the use of 200mm long nose pliers to aid in the assembly and wiring of the units, using the binding wire supplied with the gabions. Suitable pliers, a special lid-closing tool and Spenax tools and rings, for improved productivity, can be purchased from African Gabions (Pty) Ltd.

Foundation Preparation

The founding surface on which the gabion and mattress are to be laid should be levelled so as to present an even surface. If necessary, cavities between rock protrusions can be filled with a layer of stone under the box gabion or mattress structure. The founding surface may also be prepared with a slope to facilitate the construction of a battered wall.

Formwork *See Fig. 5*

African Gabions strongly recommends the use of a formwork as a means of bracing the front face of the gabion to assist in providing an aesthetically pleasing finish.

Hand-filling

Hand selected stone of the specified size should be filled in layers to prevent bulging, and should be filled just below the level of the bracing wire, after which the braces should be twisted to provide tension on the front face. Care must be taken to ensure that each layer of gabions are level and ready to receive the next course.

Mattresses used for revetments and aprons should be filled using random stones in the first layer and selected stones for the top layer, to form a stone surface which stands slightly proud of the mattress base. The lid has to therefore, be fitted using the assistance of the closing tool.

Non-rectangular Shapes

Gabion units are flexible enough to conform to bends down to a radius of 20 – 25m without mitreing: first wire a number of units together and offer them up to the curve set out previously, holding them in position during filling.

Other shapes, bevels and mitres can be easily formed by cutting and folding the panels to the required angles. *See Figs. 6 and 7.*

Fig. 4

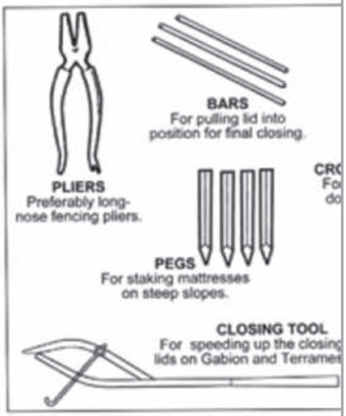


Fig. 5

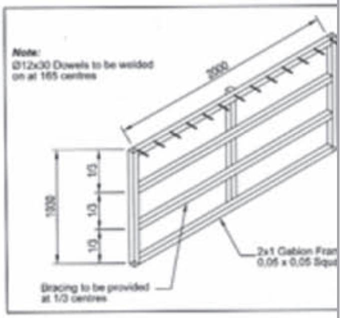


Fig. 6

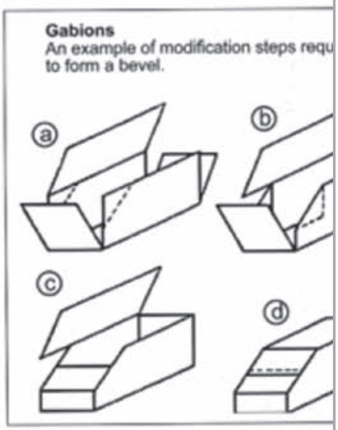
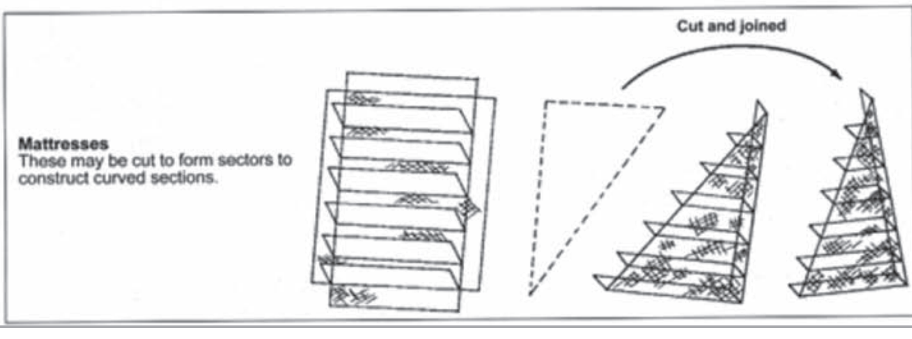


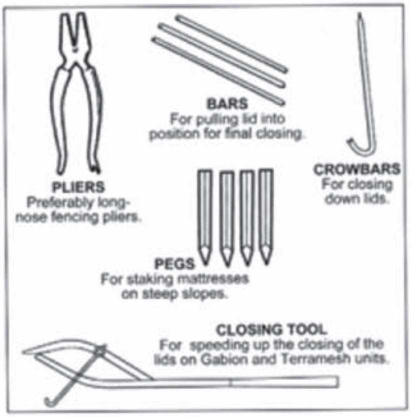
Fig. 7



Tools *See Fig. 4*

We recommend the use of 200mm long nose pliers to aid in the assembly and wiring of the units, using the binding wire supplied with the gabions. Suitable pliers, a special lid-closing tool and Spenax tools and rings, for improved productivity, can be purchased from African Gabions (Pty) Ltd.

Fig. 4



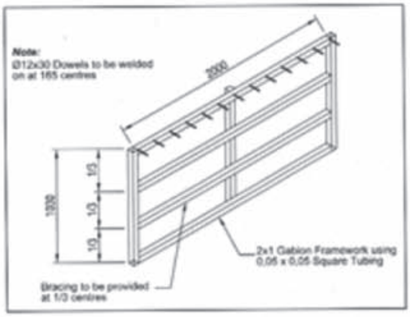
Foundation Preparation

The founding surface on which the gabion and mattress are to be laid should be levelled so as to present an even surface. If necessary, cavities between rock protrusions can be filled with a layer of stone under the box gabion or mattress structure. The founding surface may also be prepared with a slope to facilitate the construction of a battered wall.

Formwork *See Fig. 5*

African Gabions strongly recommends the use of a formwork as a means of bracing the front face of the gabion to assist in providing an aesthetically pleasing finish.

Fig. 5

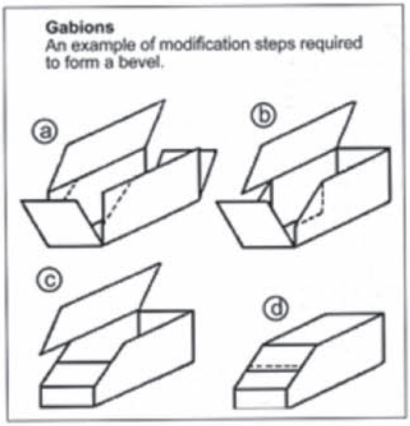


Hand-filling

Hand selected stone of the specified size should be filled in layers to prevent bulging, and should be filled just below the level of the bracing wire, after which the braces should be twisted to provide tension on the front face. Care must be taken to ensure that each layer of gabions are level and ready to receive the next course.

Mattresses used for revetments and aprons should be filled using random stones in the first layer and selected stones for the top layer, to form a stone surface which stands slightly proud of the mattress base. The lid has to therefore, be fitted using the assistance of the closing tool.

Fig. 6

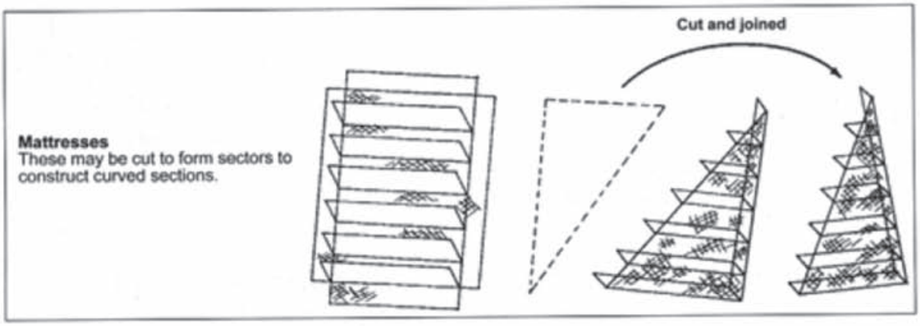


Non-rectangular Shapes

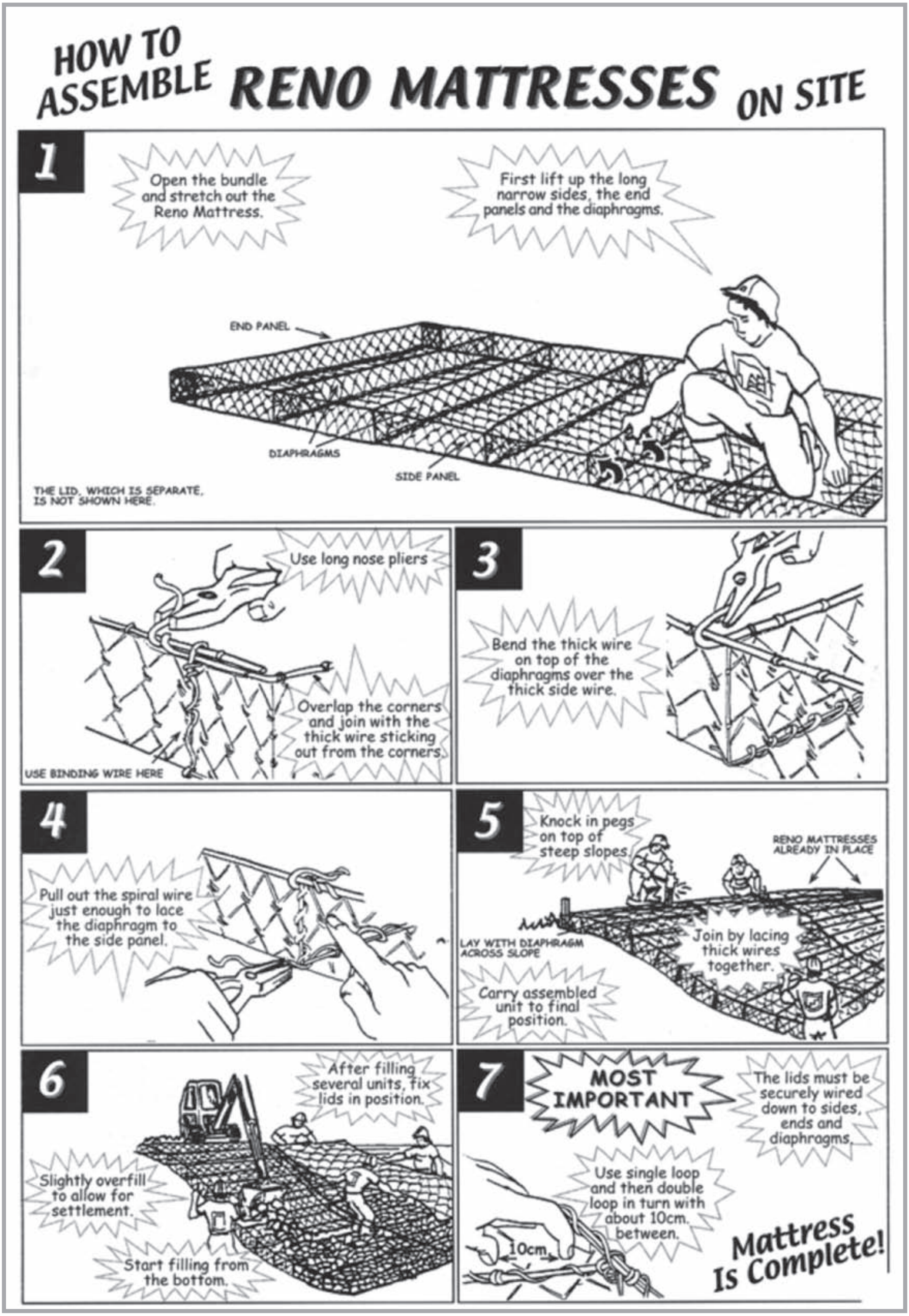
Gabion units are flexible enough to conform to bends down to a radius of 20 – 25m without mitreing: first wire a number of units together and offer them up to the curve set out previously, holding them in position during filling.

Other shapes, bevels and mitres can be easily formed by cutting and folding the panels to the required angles. *See Figs. 6 and 7.*

Fig. 7




HOW TO ASSEMBLE
BOX GABIONS
ON SITE
1
Make sure the gabion is really flat!
Unfold each gabion on a hard, flat surface. Stretch it out and stamp out any kinks.
CRUMP!
CRUMP!
END
LID
BACK
FRONT
END
2
10" FENCING PLIERS
Fold the side and end panels to make a box.
Join the top corners together with the thick wire sticking out from the corners.
3
10cm
Secure the binding wire at the top corners of the panels. Lace the edges with single loops and double loops in turn, with 10cm. between them.
4
Wire several gabions together into groups. Carry over to gabions already in place, and join.
OTHER GABIONS IN POSITION
5
MOST IMPORTANT
1-2-3-...
OLD ROAD PINS
After joining section to gabions already in position, stretch empty gabions using a winch or similar.
HEAVE !
6
HOW TO FIX BRACING WIRES
Lay wires flat across filling
Bracing wires are fixed inside when gabion is 1/3 and 2/3 full.
Stone to stop untwisting
Loop through mesh and tighten by twisting
6-1
FILLING.. ..IN 3 STAGES
Fill the gabions only 1/3 full first, with level surface on top.
6-2
Fix bracing wires and fill 2/3 full with level surface on top.
6-3
Fix bracing wires again and finish filling.
IMPORTANT
Filling should be 2.5cm to 5cm above the level of wire sides.
7
Lever down lids and lace up.
Gabion Is Complete!


HOW TO ASSEMBLE RENO MATTRESSES ON SITE
1
Open the bundle and stretch out the Reno Mattress.
First lift up the long narrow sides, the end panels and the diaphragms.
END PANEL
DIAPHRAGMS
SIDE PANEL
THE LID, WHICH IS SEPARATE, IS NOT SHOWN HERE.
2
Use long nose pliers
Overlap the corners and join with the thick wire sticking out from the corners.
USE BINDING WIRE HERE
3
Bend the thick wire on top of the diaphragms over the thick side wire.
4
Pull out the spiral wire just enough to lace the diaphragm to the side panel.
5
Knock in pegs on top of steep slopes.
RENO MATTRESSES ALREADY IN PLACE
LAY WITH DIAPHRAGM ACROSS SLOPE
Join by lacing thick wires together.
Carry assembled unit to final position.
6
After filling several units, fix lids in position.
Slightly overfill to allow for settlement.
Start filling from the bottom.
7
MOST IMPORTANT
The lids must be securely wired down to sides, ends and diaphragms.
Use single loop and then double loop in turn with about 10cm. between.
10cm
Mattress Is Complete!

29.7 Efficient management of workers

One of the problems with learner contractors appears to be the manner in which they plan the most efficient use of their staff. The experience of the writer is that there tends to be unnecessary standing around while a few of the workers are used to complete a small task. There are normally a number of different tasks that can be done simultaneously, as long as the work programme is properly planned. A simple example would be that of constructing a gabion weir. While some of the workers are excavating the site, others could be assembling the baskets, while others are excavating and setting up the toilet facilities, and still one or two others are building a shade port for their meal and rest periods.

In another example concerning the construction of a concrete weir, while site clearing and excavation is proceeding, others could be measuring and cutting up the shutterboards and reinforcing mesh, diverting water, wetting the soil prior to backfilling and compacting, etc. The project manager should look to teaching the contractor to work his team efficiently.

It is sometimes considered more cost-effective to use local material for building purposes, such as suitable rocks lying around the construction site; the argument being that the most important aspect of the project is to give people work so that they may be paid a wage. This is particularly the case where a quarry may be a great distance away and transport costs high. A caution is offered here. The workers may spend many days sorting out, picking up, and having to walk long distances carrying the local rocks to site or to a truck/trailer for building a gabion or rock masonry structure. A better and more cost-effective alternative could possibly be found at the design stage. A buttress or arch weir (Chapter 21) may suit the situation just as well but require much less in the way of building material – albeit higher quality purchased material. In this way transport costs would be lowered. At the same time the workers will be taught how to work with concrete and shuttering – a skill they could use later on in the market place.

29.8 Safety measures on site

See Appendix 4 for reference to the Occupational Health and Safety Act.

Here follows notes on specific problems that could endanger workers on site.

- **Manual lifting of construction material:**
  The problem of manual lifting of construction material such as concrete or rock (into gabion baskets) to a height greater than 1.5 metres can pose problems. The contractor should plan well ahead for this situation, and provide for a sufficient number of empty 200 litre drums and scaffold planking to enable an easier working situation. With higher structures it would be safer to hire proper scaffolding. Temporary chutes made out of corrugated iron sheeting, if correctly placed, can help in pouring concrete into shuttering with the minimum of exertion. The reader is referred to Figure 29.1 for an idea in making the transport of materials less exhausting. The purchase of sufficient of these items should be included in the Bill of Quantities at the design stage. A Bill of Quantities is a complete list of all the materials and equipment that will be needed to complete the job.
  If the workers involved in wetland r*ehabilitation are to be taught a skill, they must be taught how to carry out that skill with efficiency.*
- **Safety from fire:**
  Most wetlands have a high fuel load in winter when rehabilitation work normally is at its busiest. High winds are also fairly frequent at this time. The fire hazard is therefore of concern. See item 5.2.1 in the WfW Best Management Practices document

(Appendix 4). Included should be the need for a firebreak to be burnt around the site to protect the workers from fire danger, if not for the entire site area to be burnt off. The firebreak should, however, preferably be burnt under the personal supervision of the landowner/user or his authorized manager, and strictly in accordance with the local Fire Management Committee regulations embodied in the Forestry Act.

- **Safety from flooding:**
  Item 5.3 of the Best Management Practices document says it all.
- **Safety from excavation collapse:**
  The WfW Best Management Practices document specifies the requirement for excavated depths. It is suggested that instead of shoring up vertical excavations, and depending upon the stability of the in situ soil, the face of excavations deeper than 1.5 m should rather be sloped to an angle of at least 1:1½, depending on the soil type and the possibility of the soil profile becoming wet at any stage of construction. Wet soil has a flatter angle of repose. Where this is required the Bill of Quantities must take account of the extra work that will be required in both excavation and backfilling. These narrow excavations are generally required for the construction of keywalls. Considering that the keywalls must be completely sealed off from seepage that could cause failure of the structure, these excavations should be made wide enough for workers to stand inside the trench, and on either side of the keywall, in order to properly compact the backfill.
- **Safety from structure collapse:**
  Any structure made of concrete, rock masonry or gabions over 1.5 m in height must have stable and effective scaffolding erected around it to enable workers to work in complete safety and to carry out the job properly. This may consist either of empty 200 litre drums and scaffold planking, or proper steel scaffolding rented or purchased from a reputable firm. During construction of vertical walls a spirit level must be used to confirm that vertical walls are vertical. The spirit level must be checked daily. The simple check is illustrated in the box below. Further checks entail the testing of the stability of the foundations. If a structure is to be built on a soil foundation, that foundation must have been compacted at optimum moisture content – see Chapter 28. Before placing the first layer of building material, check the density and stability of the under-lying foundation with a suitable probe (e.g. garden fork, spade or roundbar). With a concrete wall, the shuttering must be very well supported at 1m intervals for at least two days until the shuttering is due to be stripped. Never lay more than a 1-1.2 m high section of concrete in one day. It is preferable to lay a wall across the gully in even, horizontal layers, and with suitable construction joint features see Figure 29.3. Never fill any one portion of a continuous length of shuttering more than 500 mm above any adjacent, newly laid, portion of concrete.

29.9 Protection of structures

Of all the types of structures erected for wetland rehabilitation, those most liable to deterioration are the earthen embankments, whether they are large diversions, smaller soil plugs, or merely sloping of gully walls. These structures are of great interest to humans and domestic animals alike, but the latter are the most damaging, and will steadily trample the soil structures down, damaging any protective vegetation in the process as well. The problem is especially serious in drier climatic areas, where neither the soil nor the vegetation is very suited to construction work. The action of the raindrop hitting a bare, sloping soil surface is a problem, but usually a good mat of actively growing vegetation (or a gravel blanket) is sufficient, as long as the animals are kept out. Some form of cover on the

Checking the correctness of the spirit level:

Take a wheelbarrow, set it so that the rim of the bucket is completely level. Fill it with water so that excess water just spills over the entire circumference of the rim – this will assist in ensuring that the rim is level.

- **Checking the horizontal bubble:** Hold the spirit level just on the water surface and check that the bubble is in the middle of its run.
- **Checking the vertical bubble:** Place a straight edge across the width of the barrow. Hold a builders set square on the straight edge with its longer arm pointing upwards. Hold the level against this truly vertical edge and check that the bubble is in the middle of its run.

If either bubble is not in the middle of its run the spirit level should be discarded. Check any newly purchased level in the same way.

ground surface, as well as a sturdy fence should therefore be sufficient.

A barbed wire fence (see Chapter 25), kept in good condition, is probably the best first line of defense in protecting degraded areas. It should be mandatory for a fence to be erected around the structure itself, and another around the entire sphere of influence of the structure. The fence should encompass the entire eroded area and beyond, so that rehabilitation can proceed as rapidly as possible. Only once rehabilitation can be seen to be taking place, may animals be allowed into the area for restricted grazing periods. At this stage the Technical Advisor should be approached for a written grazing management plan that can be served on the land user. The first fence mentioned will then still protect the structure(s) itself, while the animals can utilize some of the grazing within the sphere of influence of the structure without damaging it.

Certainly in the wetter regions of the country, and if the soil berm is on the larger size, kikuyu grass will prove the best, the need for indigenous biodiversity notwithstanding. For small structures along drainage ditches, the indigenous wetland vegetation should be suitable.

In the dry areas (MAP < 650 mm) vegetation will struggle on sloped berms, especially if they comprise largely subsoil. A 200 mm layer of gravel or weathered dolerite or shale, such as used to stabilize road surfaces, will provide the extra protection that vegetation will not (see Figure 28.4).

Structures that dam up water will attract domestic animals, and the farmers will be keen to use the water for their stock. It will be preferable to fence the entire area off and include a pipeline and drinking trough in the structure design, rather than allowing the animals free access to the site of the structure. The trough should be built away from the wetland, if possible, and on an erosion resistant site.

29.10 Cleaning up the site on completion

In accordance with the Environmental Management Plan (see Appendix 4, Best Management Practices document, item 4.2), all litter, building rubble, etc. must be removed and disposed of at an appropriate site. Any areas that were cleared of topsoil must be rehabilitated, and the site left in an environmentally friendly condition. The toilet facility must be removed and its site cleaned up. An effort must also be made to rehabilitate, as far as possible, the roads and

CHAPTER 30:

AFTERCARE OF STRUCTURES

Earthen structure maintrenance

Generally the first structures to show signs of deterioration will be those made of soil, especially if there are grazing animals in the neighborhood and a fence around the structure is either non-existent or in a bad state of repair. No matter how well the soil was moistened and compacted, and especially if it had been compacted by hand, the berm or plug will settle with time. The cattle trampling effect would have hastened its settlement. A 10% settlement in height is not untoward and should have been included in the original specifications as an extra safety factor. This will mean that the freeboard is no longer sufficient, and the structure could overtop in time.

The obvious thing to do is to bring in more soil to bring the height back up to specification. The surface of the structure must first be roughened, and any vegetation removed before adding soil. Planting of suitable vegetation should take place thereafter.If the soil is dispersive one must look for signs of excessive erosion of the bank and tunneling pipes through the bank. The damaged areas must be opened up and fresh soil mixed with gypsum and water, and firmly tamped into place.

Fence repairs

The second item that will be in need of repair will be the fence that protects the structure. Where fences show signs of sagging the wires must be loosened, the corner posts replanted and anchored if they are loose, and the wires tightened and re-wired. Replace any wire and/or droppers that have been removed.

Chute fill-ins

Signs of under-cutting by water are bad news. This problem may require fairly large-scale excavations to replace the soil lost. Sections of the concrete or gabion work may have to be broken up and replaced after the soil has been replaced. Debris may have collected around the baffles, if these were included, and this must be removed. Check for signs that splash has damaged the earthen sidewalls, and repair where necessary.

Check spreader canals

Check that the stockpiled berms are well covered with vegetation, and are not sliding into the canals. Look for signs that the lip of the canals are not eroding to the extent that water is concentrating too much at isolated points, leading to erosion occurring downslope as a result of the increased velocity. Check also that vigorous growth of vegetation is not blocking the free flow of water along the canals, and remove it if necessary.

Gabion work replacements

Check for signs that the wire is rusting. A painting of rust converter (obtainable in any hardware store) may help. Make a note in this case to check more frequently on the structure. Look for signs that water velocity has moved the encased rock to such an extent that the structure is no longer performing the function it was built to carry out. One sometimes comes across a sink hole in the sediment just back of the wall indicating either ineffective packing of the rocks or a hole in the geotextile. If so, the baskets/mattresses must be opened and the rocks re-packed.

Check on the continued efficiency of the geotextile backing the structure. If it has deteriorated it may have to be replaced.

Concrete cracks

Check for signs of the concrete cracking. If this has occurred the cracks must be chipped open and filled with a mortar mix of 1 pocket cement to 100 litres sand after the opened surfaces have been painted with a 1:1 cement: water mix. If the cracks continue to show movement, clean them out again and plug with bitumen. Make a note to check on the structure more frequently.

General

Whatever structure is in place, the following general observations should be made:

- Look for signs that the structure is leaking, and repair.
- Look for indications that water is moving round the sides of the structure and take action to stop it.
- Check on the stability of the aprons/ stilling basins and take corrective action timeously.
- If runoff is obviously bypassing the structure, or if it is returning to the gully/drain too quickly, check on the wingwalls and repair/extend where necessary.
- Look for any signs of erosion of soil from under channel linings of Reno mattrasses or Armoflex.
- If a flood event has overtopped the structure spillway showing possible under-design, make an effort to obtain the rainfall figures that caused the flood event: rainfall depth and period of event to calculate intensity. Check on antecedent rainfall as well. Was the soil thoroughly saturated immediately prior to the time of the event? Attempt, with the use of Mannings Formula (Chapter 17), to determine the floodpeak. This type of investigation is very useful if the estimating of Q values is to improve. Relate actual I and Q to the design values and find out where things went wrong.

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GLOSSARY OF TERMS

Aka.	Shorthand version of 'Also known as' ….
Apron	In this context a pavement, either of concrete, or a rock-filled gabion mattress, laid down immediately below a weir, to protect the foundation of the structure from damage by the water falling on it. High velocities will tend to displace the rock in a mattress and concrete is therefore preferable.
Basal flow	The minimum discharge in a stream or river that occurs as a result of deep percolation of water; not through surface runoff (also known as perennial flow)
Berm	A mound or bank of earth used as a barrier against flooding of land
Bill of quantities	A list of all the various materials needed to complete a task, together with the amounts/ number of the items, the equipment needed and the number of man-days necessary.
Bio-Engineering	The use of suitable vegetation as an intervention, with or without the addition of structures, to bring about an improvement in the damage to a degraded site.
Bitumen	A semi-solid inflammable mixture of hydrocarbons formed as a residue in the petroleum industry. When mixed with sand or gravel is called asphalt or macadam and is used to surface roads. Purchased at any hardware store.
Borrow area	In civil engineering, the area adjacent to a building site that provides a source of material suitable for the construction of dams and berms.
Catchment	All the land area from mountaintop to seashore which is drained by a single river and its tributaries. Each catchment in South Africa has been sub-divided into secondary catchments, which in turn have been divided into tertiary. Finally, all tertiary catchments have been divided into interconnected quaternary catchments. A total of 1946 quaternary catchments have been identified for South Africa. These sub-divided catchments provide the main basis on which catchments are sub-divided for integrated catchment planning and management (consult DWAF [1994]).
Chute	A channel-type, sloping structure used to convey runoff from a higher elevation to a lower one. It is used either as the spillway for an earthen storage dam, or to counteract the erosive energy of water falling over a gully head cut.
Conservation tillage	Any one of a number of tillage operations, the purpose of which is to reduce the extent of soil and water losses from a cultivated field. Its practice usually requires a reduced amount of tillage and the leaving of a mulch cover of vegetative residue on the soil surface in order to reduce the energy of falling raindrops. The types of conservation tillage recognized include stubble mulch tillage, strip till, ridge till, and no till.
Contour banks	A system of canal/banks that are constructed at intervals down the slope of cultivated fields in order to reduce accelerated soil loss from them. Although termed 'contour' they are in fact given a slight gradient in order to remove the excess runoff generated by high intensity storms that causes erosion.
Corrosive water	Corrosion is the slow destruction of materials, particularly metals, by chemical agents. In the gabion context it is the rusting of iron, which is caused by the formation of iron oxide. Corrosion occurs in the presence of acidic water and oxygen.
Culvert	An artificial, covered channel for water to allow it to pass underneath a road or railway line.
Cut-off sill	A horizontal member of a structure, in this context of concrete, buried in the ground, in order to stop water under-mining the structure.
Discharge	The quantity of water flowing in a stream per unit time, typically in units of cubic meters per second ("cumecs")
Drop Inlet	A pipe spillway that receives water from the upstream section of an earthen embankment, conveys it underneath the structure, and discharges it on the downstream side.
Dry freeboard	The extra height above the wet freeboard given the spillway of a water-control structure as a safety measure to cater for wave action, damage by animals and/or natural settlement of the structure material.
Erodibility	The ease with which particles or aggregations of particles, can be removed from their in situ position by a fluid such as water flowing across the surface of the soil. Erodibility of soil is influenced by its organic matter content, the texture of the soil, its chemistry, structure and permeability.

Erosivity The potential ability of falling rain, flowing water and blowing wind to cause erosion of soil. This is basically as a result of the kinetic energy (i.e. the energy resulting from movement) of the falling rain/flowing water/blowing wind, and the mass of the moving body of rain/water/wind.

Flood peak The highest discharges that occur in streams following a rainfall event

Gabion Specially constructed wire baskets that are filled with rock and used to stabilize a potential erosion problem. Gabions are made to standard dimensions 1 x 1 m in cross section, and in lengths of 2, 3, and 4 m.

Gabion mattress A thin section wire basket, filled with rock, that is used to protect soil from erosion caused by the velocity of flowing water. The thickness usually varies from 150 mm to 300 mm. The thickness used is dependent on the velocity of the water and the erodibility of the soil.

Gypsum Calcium Sulphate, a by-product of the fertilizer manufacturing industry, and used, among other things, for ameliorating soils that are high in sodium salts.

Harrow An agricultural implement, drawn by a tractor, and used for loosening the top 150 to 200 mm of soil.

Head cut The upper-most entrance into an erosion gully. The point where the headward extension of a gully is actively eroding into undisturbed soil.

Hessian A roughly woven, open textile made of jute. Used previously for making potato pockets. Nowadays used for curtaining and temporary screens.

Hydraulic Pertaining to the movement of water and the force exerted by it.

Hydraulic conductivity A measure of the rate at which water can move through a permeable. medium such as soil or rock.

Hydraulic jump The phenomenon that occurs to a flow of water when its velocity changes from a super critical state to a sub critical one. The latter causes a build up of water due to the lower velocity. The turbulence that is caused at the change–over can cause damage when dam spillways are involved.

Hydrograph A graph depicting the rise and fall in height, of a flood peak, with time. Together with a knowledge of the stream cross sectional dimensions and the velocity of flow, the hydrograph will enable the determination of the rate of flow of the flood, as it changes with time.

Hydrophyte Any plant that grows in water or on a sub-stratum that is at least periodically deficient in oxygen as a result of soil saturation or flooding; plants typically found in wet habitats.

Infiltration The slow passage of water through a filtering medium (n this case the soil).

Intervention In the wetland rehabilitation context means the introduction of an action to improve the situation.

Key trench A trench or ditch excavated along the centre line of a proposed earthen embankment to be built specifically for the holding back, either permanently of temporarily, of water. The purpose of the trench is to cut through any permeable layers and roots of trees under-lying the proposed bank, and to block off any possible subsurface tunnels that could result in leaks and potential destruction of the dam wall. It is normally back-filled with suitable clay type soil to form a water-proof seal.

Key wall An extension of the overflow portion of a weir. It is built into the adjacent earthen banks of the stream or gully in which the weir is built. Its purpose is to stop any subsurface water bypassing the structure at the soil – weir interface.

Lateral cut A head cut eroding laterally from a main one.

Line of latitude Distance on the earth's surface northward or southward from the equator, measured in degrees of the meridian. See line of longitude and meridian.

Line of longitude Distance east or west on the earth's surface, measured by the angle which the meridian through a place makes with the Greenwich meridian and which is designated 0°.

Line of saturation The upper line of the water table that develops in an earthen embankment when water collects behind it. Due to the inherent porosity of soil and the action of gravity tending to pull it down, as the moisture moves through the soil so it tends to slope downward, the further it percolates. The degree of slope is dependent on soil type and the amount of compaction. The soil below this line is unstable due to the saturated condition.

Maximum non-scouring velocities Velocities slow enough not to cause soil erosion. The actual velocities are soil specific and depend on the erodibility of the soils, and the degree to which they are covered and protected by vegetation.

Meridian A great circle drawn from any point on the earth's surface and passing through both poles. A meridian is therefore a.k.a. a line of longitude.

Optimum moisture content (OMC) In the context of compaction of soil, the amount of moisture in the soil that will allow of the greatest dry density under a given compacting force. As moisture content rises, so better compaction results, until a maximum, after which further additions result in a decrease in dry density. OMC is strongly influenced by soil particle size. The sandier the soil the less water required, the higher the clay content the more water required.

Percolation The act of rainfall filtering down through the soil profile after it has infiltrated the soil surface. The rate of percolation varies according to soil type and the **presence of limiting layers within the profile**.

Rehabilitation The process of assisting in the recovery of a wetland that has been degraded or of maintaining a wetland that is in the process of degrading so as to improve the wetland's capacity for providing services to society.

Reno mattress The trade name for a gabion mattress

Restoration The aim of creating an environment conducive to the re-establishment of the composition, structure and function of an original system.

Return period The time period in years that a given rainstorm or flood event of a given size will be repeated. It is expressed in terms of one event in every 2, 5, 10, etc. years, and is recognized through long-term observation and measurement.

Rhizome Horizontal stems of certain plants that occur on the soil surface and produce roots from their underside and vertical stems and leaves from their upper surface.

Rill erosion Erosion in the form of minor channels that are so small that they can be eliminated by normal ploughing. Rills will therefore be no wider than 250 mm and with a depth not exceeding 150 mm.

Rip-rap Rock well packed to protect a structure or situation otherwise subject to erosion.

Rodding The agitation of newly laid concrete using a pole or length of pipe in an up-and-down motion to clear the mix of air pockets, and to ensure that the concrete is forced into all corners of the form into which it has been placed. It also attempts to ensure that there is an even spread of concrete stone throughout the ultimate structure.

Runoff Total water yield from a catchment including surface and sub-surface flow.

Runoff control planning The planned siting of structures to reduce the velocity of artificially accelerated runoff, stabilize watercourses, and stop accelerated soil erosion, ensuring simultaneously that the runoff still follows the natural flow path as closely as possible.

Sediment Solid material transported by moving water, which typically comprises sand, silt and clay sized particles.

Sheet erosion Erosion of such a nature that the soil is removed in thin sheets. It is a serious form of erosion in that, while not being very noticeable, it nevertheless removes valuable topsoil and fertility.

Shoulder wall A wall or walls that lie connected but at right angles to the overflow section of a weir. The purpose of shoulder walls is to hold the soil on the adjacent stream banks in place and to protect same from splash action of the runoff discharging over the overflow section.

Shuttering In civil engineering, the temporary timber or steel panels that are used to form and hold newly mixed, semi-liquid concrete in position until it has set and hardened.

Sill In this context, a horizontal member of a structure whose purpose is to either stop under-mining of the structure by water (see Cut-off sill above), to spread water, or to protect another, less stable component of the structure.

Soil	A mixture of very small weathered rock particles (<2 mm in size), minerals, humus, specialised soil insects and animals. The individual particles range in size from 0.005 to 2 mm, the smallest being termed clay, the medium sized silt and the largest sizes sand. The humus is formed from the breakdown of vegetation, insects and animals. Differences in soil types arise as a result of differences in geology, climate and topography. An example would be the fairly heavy clay type soils derived from shales, as opposed to the sandy soils derived from sandstone.
Soil dispersivity	The property of a soil (usually of a fairly high to high clay content) that causes the soil structure to collapse in the presence of unpolluted water. This is, in turn, caused by the presence of at least 15% of the cations on the clay colloids having been replaced (in a natural way) by sodium cations. The Na cations tend to keep the clay particles separated, and when water is added to the soil the Na goes into solution and the clay particles separate. See Solonetz soils.
Solonetz soils	Those soils of the drier areas that contain an unusually large amount of sodium in the B-horizon, resulting in a soil that is highly erodible and liable to chemical tunneling when used in water storage situations unless treated with gypsum.
Spillway	A passageway underneath, around the side, or over the top, of a dam wall in order for surplus water from the reservoir to escape without damage to the wall.
Spreader canal	An artificial canal excavated on the contour in order to receive runoff in a concentrated form (e.g. as from a gully) and to spread it over a wide area when the water in it fills and over-tops the canal.
Stabilisation	In this context, the action of instituting measures that will ensure that no further degradation takes place. An example would be the establishment of vegetation in an area that was eroding badly, and because of the protective action of the vegetation, erosion no longer takes place, although the signs of the original erosion may still be visible.
Stolon	Horizontal underground creeping stem typically found in grasses and sedges.
Thalweg	The natural profile across a valley undisturbed by gully erosion. Similar to the catenary, or the shape taken up by a rope or string held at either end so that the middle loops round in a smooth but continually changing curve.
Time of concentration	The time taken for runoff, originating in the hydrologically most distant part of a catchment area, to reach an observation point. The significance of this value is in the calculation of the size of flood peaks. Design floods are assumed to occur when a storm, having a duration equal to the time of concentration, and for a given (chosen) return period, causes high intensity rains to fall.
Topography	The physical features of a region or area, including slopes and landform. A topographic map is therefore a map that uses contour lines to describe the physical features of an area.
Watershed	A natural topographic boundary identifying the border along which runoff from rainfall will split and flow in distinctly different directions.
Waterways	In the soil conservation context, specially prepared canals excavated down the slope in order to receive and convey runoff water from cultivated fields into natural watercourses. They are typically lined with vegetation or concrete.
Weigh-batching	Measuring sand and stone for the making of concrete by weighing it.
Weir	A structure placed in a stream or gully in order to lift the water level and or to catch up sediment. It is usually of concrete, rock masonry or rock-filled gabions. Unless it is used solely as a diversion structure, it differs from an earthen structure by the fact that the entire section in the stream is used simultaneously as a spillway. The earthen dam wall generally has a specially designed spillway, either over-the-top or bypass, and its design procedure differs radically from that of the weir.
Wet freeboard	The calculated depth of flow through a spillway caused by the maximum rate of runoff for which the spillway has been designed. To this depth is added dry freeboard.
Wind-rowing	The action of moving recently cut vegetative material into long lines for the purpose of picking it up in an efficient manner.

APPENDIX 1:

MAPS: ACCESSING, READING AND DRAWING

1.1 Introduction to maps and map reading

This is a very brief introduction to maps, describing the different types that may be useful in wetland rehabilitation, how to read them, and where one may obtain them.

An accurate map is a representation on paper of what is on the ground. It is drawn to a scale, and it uses lines, symbols, photographic images and/or words to explain where objects such as trees, houses, roads, etc. are positioned in correct relation to each other (see Figure A1.1).

Because a map is drawn to scale, one may measure the distance between objects on the map using a ruler, and apply the scale of the map, in order to determine the actual, but direct, distance between them (Figure A1.1). The size of an area can also be determined from a map.

If they are topographic maps, the symbols will include spot heights and contours, making it possible to measure both height differences between points, their distances between, and to calculate the average slope of a particular area as well (see Figure A1.1). This is very useful in wetland rehabilitation projects.

Maps are therefore very useful tools in carrying out any type of resource planning, including the planning and design of erosion control measures and structures in wetlands.

All maps must have a north sign in order to allow orientation of the map when reading it, a legend that allows the reader to interpret the meaning of the symbols used, a title, the scale, the vertical interval (if it has contour lines), and an accession code.

1.2 Types of maps

Maps that can be used for wetland rehabilitation planning purposes include the following:

Aerial photographs

Aerial photos form the basis of most maps nowadays. Before government publishes a new set of maps, an aerial photographic survey is carried out, and from these the final cartography is done, after photographic inaccuracies have been corrected. It must be pointed out that aerial photos themselves are not very accurate, and have to be processed before use, removing various forms of distortion that result in inaccuracies, before they are totally acceptable. This distortion arises because of:

- taking flat surface pictures of the curved surface of the Earth
- the distortion that arises when the airplane carrying the camera is tilted to one side by wind gusts or changes, and/or
- the errors that arise in hilly countryside through steep undulations in the topography.

Aerial photos are produced in the first instance as a square of 230 mm x 230 mm, which is the size of the negative. This size is therefore called a contact photo, because it is the same size as the negative. Contact photos can be enlarged, but more on that later. See Figure A1.2 for an example of an aerial photo.

A contact photo always has a scale given it, but this is an approximate scale only, and if one needs to do any work on an aerial photo that requires the reading of distances, areas, etc., the scale of that

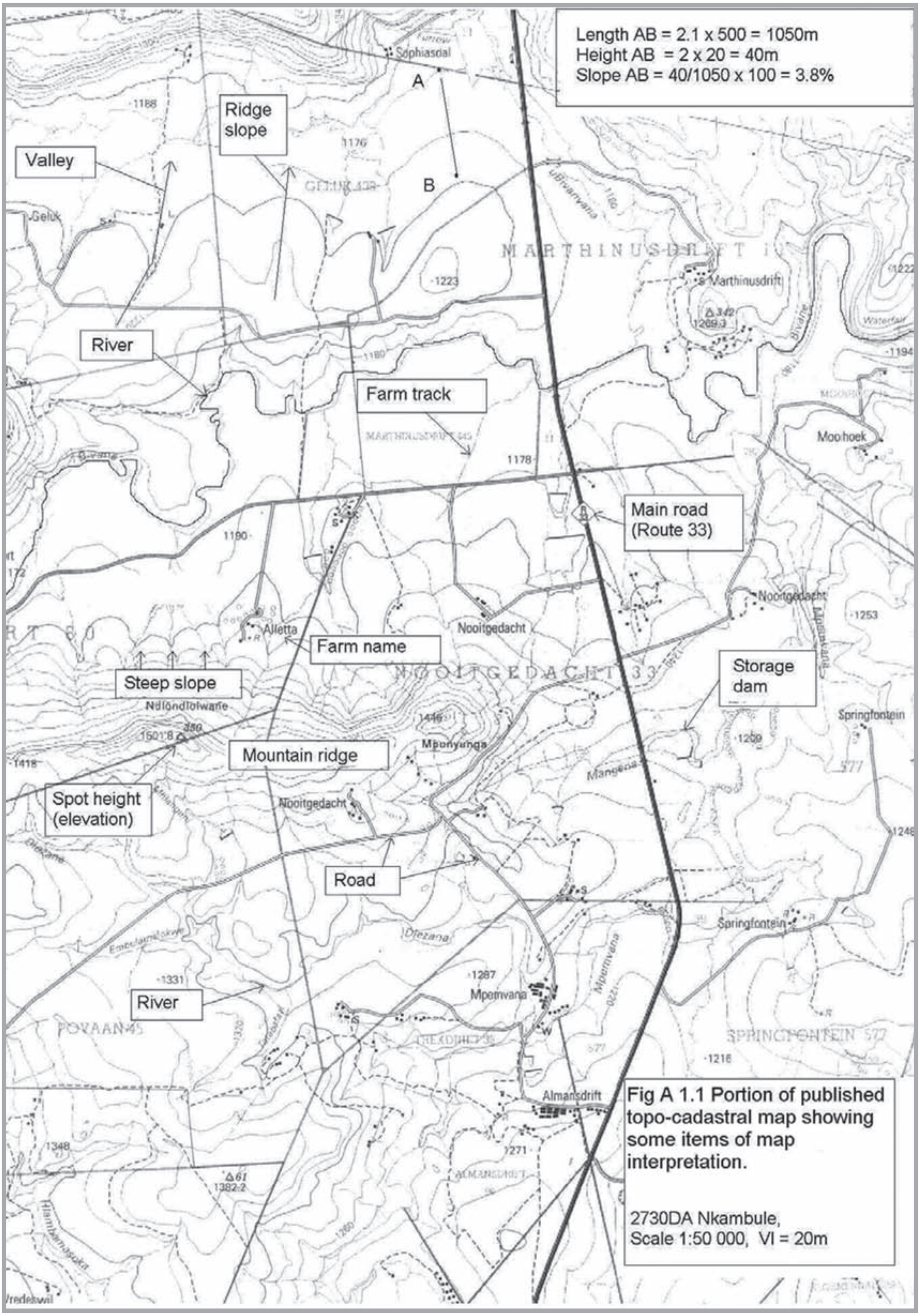

Figure A1.1: Portion of topo-cadastral map showing some items of map interpretation

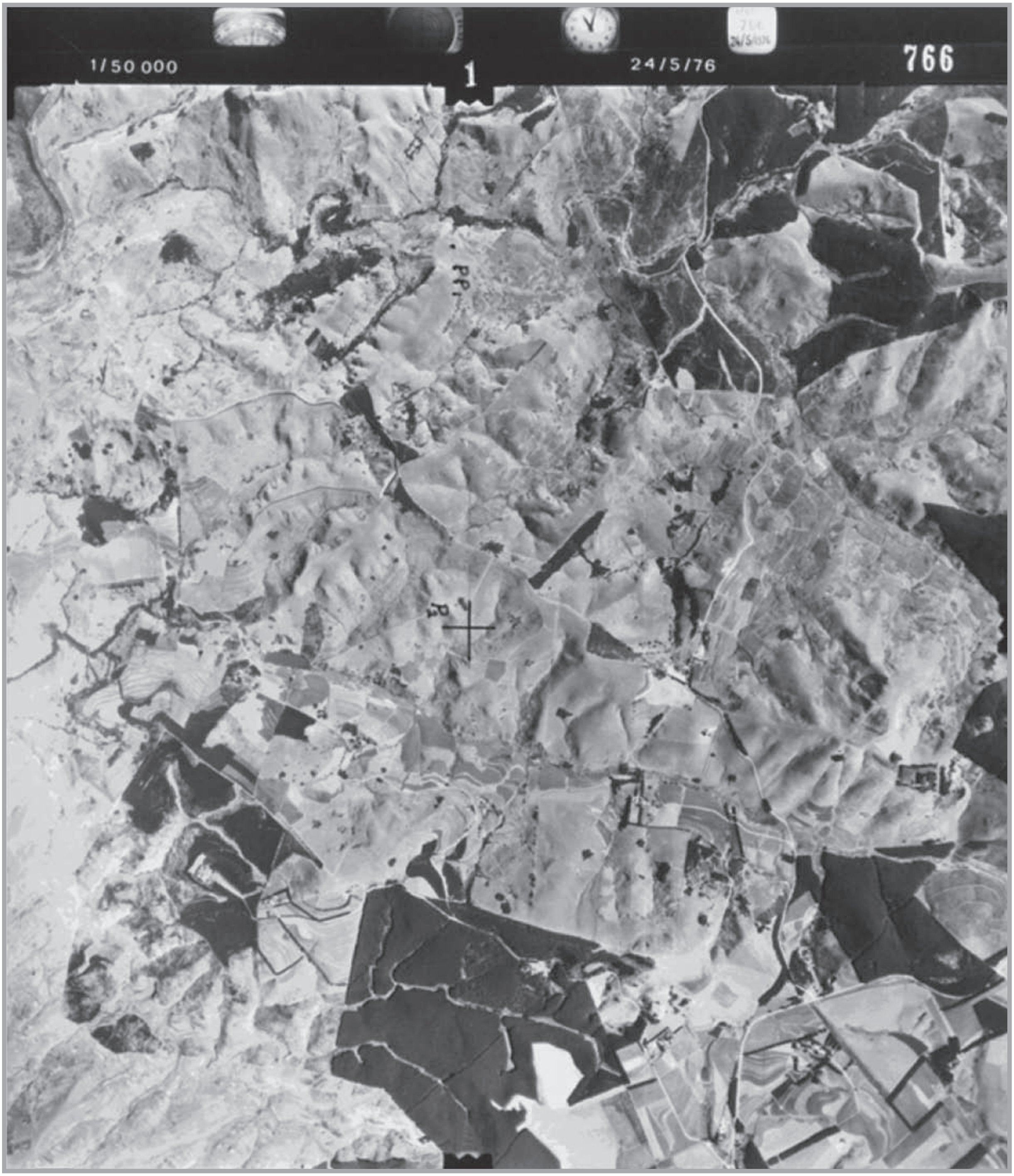

Figure A1.2: A contact aerial photo showing (L to R) approximate scale, strip no., date of photograph, photo no., and in the middle the Principle Point y.

particular portion of the photo must be calculated. See section 1.4 below on how to determine the scale of a map.

Aerial photos are not very suitable as maps, for the reason that they are not reproducible in a satisfactory format (they are rather dark) and even scanning them into a PC does not provide the ideal print of an area. However, if one wishes to obtain an overall picture of an area, aerial photos, and especially so-called stereo pairs (i.e. two adjacent photos), are invaluable for overall planning purposes.

For example, one of the most reliable means of determining whether a gully head-cut is active or not, and it's rate of headward extension, is by comparing the position of a head-cut on aerial photo's taken at different times (e.g. 10 years apart). In order to do this as accurately as possible, it will be necessary to determine the scale of that portion of the photo on which the gully head appears. It will also be necessary to measure the length of the gully, or at least a part thereof, on both photos, relative to some fixed point such as an identifiable tree, building, etc. Both photos will need to be treated in this way in order to make a proper comparison. Only in this way will the investigator know how far the gully head has moved over the period between the taking of the older and the newer photos. An example of this exercise is given later in section 1.4 under the heading 'Using map scales'.

Aerial photos are taken using a camera on board an aeroplane flying in, as far as possible, parallel flight paths or strips across the countryside, usually, but not always, in a latitudinal direction. They are taken in a regular sequence so that there is an overlap of approximately 60% between successive photos in the strip, and a 30% overlap between the strips. This is done purposely, in order that one may then use two adjacent photos (a stereo pair) under an instrument called a stereoscope (Figure A1.3). This four-legged tabletop instrument is supplied with special lenses and binoculars allowing three-dimensional viewing with up to a six-time enlargement. When the stereo pair is placed side by side beneath the stereoscope the three-dimensional image of the terrain allows the worker to consider rehabilitation

Figure A1.3: Using a stereoscope to study aerial photography in 3-D options before going into the field. This is a timesaving exercise, as it indicates in advance to the investigator where suitable rehabilitation sites may be expected.

Stereo pairs can give information other than a 3D view of the ground surface. Areas of similar colour and texture indicate areas on the ground of similar characteristics, e.g. soil type, vegetation, etc.

Setting up a stereo pair for use under a stereoscope

It is important to set up the stereo pair correctly, otherwise three-dimensional images will not be apparent, or eyestrain will occur with prolonged use. The steps involved in setting up the photos and the stereoscope are as follows:

1. Tape an A3 sized sheet of blank paper to the desk or tabletop.
2. Draw an horizontal line, approximately 300 mm long, on the paper.
3. Place the stereoscope over the paper parallel to the line just drawn, and with the line inscribed immediately below the eyepiece lenses. Pivot the stereoscope by holding the left back leg and moving the right hand legs backwards and forwards. It will be noticed that, when looking through the eyepieces, the line breaks as the ‘scope is moved. When the line is observed as unbroken or continuous, the ‘scope is correctly placed in relation to the straight line previously drawn.
4. Close the right eye and, looking through the left eyepiece only, mark a point A on the line directly in the observed centre of vision.
5. With both eyes open, look through both eyepieces simultaneously. Move the pencil point to the right along the line until the pencil point appears to be superimposed on point A. Mark this second point and label it B. Repeat the exercise, moving the pencil point now from the right hand edge of the paper, and along the drawn line. Confirm that there is only one point B on the paper.
6. Measure the distance AB. It should be approximately 230 mm, but will vary slightly according to the instrument used. Record this distance, which is specific to the observers’ eyes, and for the particular stereoscope in use.
7. Now mark the centre point of each of the photographs using a ruler and soft chinagraph pencil. These are called the Principle Points, and are found by the intersection of the lines joining the opposite corner crosses (called Fiducial Marks), or by joining the centre marks of opposite sides (called Collimation Marks). (See Figure A1.2). Number them PP_1 on the left-hand photo and PP_2 on the right-hand photo respectively.
8. Locate the point on the right-hand photo that corresponds to the Principle Point of the left-hand photo and call it P_1, and similarly locate and mark P_2 on the left-hand photo, which is the same point as PP_2 on the right-hand photo.
9. Once again, using a Chinagraph pencil (never use ink or any other indelible marker on aerial photos), join the points PP_1 and P_2, as well as PP_2 and P_1, extending the respective lines to the edges of the photos. These lines represent the line of flight of the aeroplane carrying the camera.
10. Fix the left-hand photo on to the table with PP_1 directly over A. Do the same with PP_2 and mark B. Then line up the flight lines of both photos with a ruler – i.e. PP_1 to P_2 and PP_2 to P_1 must be parallel to the edge of the ruler. Fasten the photos in position with masking tape. See Figure A 1.3.
11. Position the stereoscope over the photographs and twist it until both flight paths line up in a straight line. Stereovision should be immediately apparent on looking through the lenses of the instrument. The stereoscope may be

moved away from the reader or towards him/her in order to view the area under investigation, and even sideways, and as long as the instrument remains parallel to the flight lines stereo vision will be apparent. Note that some people due to problems with vision are unable to see the exaggerated 3-D effect.

Table model stereoscopes are very expensive but with the 6 times magnification a very detailed picture of a site under investigation can be obtained. They are extremely useful for obtaining a birds' eye view of a situation. Pocket stereoscopes are a lot cheaper. Although they do not give as satisfactory a result as the table model (they have only one enlargement factor) they can give a fairly good overall aerial view of the site one is studying. Neither model is imperative for use in soil conservation work, but they are of great help if available.

Topographic maps

These are maps with the addition of contour lines marked on them. Contour lines are lines on the map representing points of equal height above a given datum (i.e. a fixed point) on the ground. Mean Sea Level (MSL) is generally used as the datum on most published maps, although when local surveys are carried out an *ad hoc* benchmark can serve as the datum for that survey. Contour lines are drawn a set height difference between successive ones, and this is called the vertical interval (VI) between them. For example, the latest issue of the 1:50 000 topo-cadastral map has a vertical interval of 20 m. The older issues had them at 50 feet, and they are still in use, so the worker must always check the scales and VI values of every map he/she uses.

Different maps have different values for the vertical interval (VI) between contour lines, but whenever they are present on a map the standard value of the VI between contour lines will be given at the bottom of the sheet. Along with other important information, an explanation of the symbols used in the map is given. The value of each contour line is identified at various points on each individual line, and the odd spot height as well. This enables the reader to determine height differences between identified points on the map.

Each contour line has a value that represents the height of that line above the datum, and in RSA the unit value of contour lines is the metre. The experienced map-reader can therefore read the direction of the slope of the land off the map by noticing the change in contour line value. If the value increases in the direction the reader wants to take, then this indicates a rise. If it decreases, it indicates a fall in the terrain. One can also trace out the line of a valley or a ridge merely by understanding what the contour lines indicate. For instance, if a series of adjacent contour lines bend back on themselves, and in so doing 'point' in a direction up the slope of the land, they indicate the presence of a valley. If the same thing happens but they 'point' down the direction of the slope, they indicate a ridge. This feature allows one to demarcate watersheds, and assists in the calculation of runoff intensity (flood peaks) for the design of soil conservation works, a procedure that will be discussed later.

The distance between successive contour lines also indicates the steepness of the terrain – the closer they are together the steeper is the terrain. The actual slope steepness may be calculated by dividing the height between two points (as indicated by the number of contour lines between them), multiplied by the value of the contour interval, and divided by the linear distance between those same two points. An example is given on the map in Figure A1.1.

Cadastral maps

These are maps that indicate the boundaries of properties (both ownership and political), roads, buildings, etc., but without contour lines. They are not of much use in wetland rehabilitation as one cannot determine the topographic parameters.

Topo-Cadastral maps (see Figure A1.1)

As the name implies, these comprise a combination of contour lines (indicating the shape of the terrain), as well as streams, roads, property boundaries, etc. (see Figure A1.1). Typical scales of these maps are 1:50 000 and 1:250 000. The 1:10 000 orthophoto maps need special mention. With a large scale of 1 cm representing 100 m, and 1 square centimetre representing 1 ha, they are almost perfect for wetland work in general. The problem with them is that they are only available in high potential growth points, and large areas of RSA are presently without this cover. See Section 1.3 below for identifying which maps are available.

Aerial Photo Mosaics (APM's)

These are maps, generally fairly large scale, prepared from aerial photos where the scale distortion has been corrected and with a uniform scale over the entire map. They are therefore completely photo-based, without any line drawings on them until the user draws them in. Inasmuch as they are normally a composition of more than one aerial photo, they are called aerial photo 'mosaics'. The office of the Chief Director of Surveys and Mapping produce them on transparent material (at a price) that allows the worker to ink in important detail, and then prints of the map can be produced using a plan printing machine. One of the problems with them is that they do not have contour lines on them and so topographic parameters cannot be identified. The process of transferring contour lines onto these APMs is not a simple operation, but it can be done.

Resource distribution maps

Maps can be used to indicate the distribution of all types of resources (soils, geology, etc.), climatic parameters, natural resources such as soil types or wetlands, and production statistics. Use is made of either symbols (e.g. dot maps), shadings and colours (e.g. soils and vegetation maps) or iso-lines (e.g. contour lines), isobars (lines joining points of equal atmospheric pressure), isohyets (lines joining points of equal mean annual rainfall), etc.

Maps typically used for wetland rehabilitation

- The **Locality Map** (i.e. the map that indicates the position of the farm within the district in which the wetland is situated, and which shows public access roads, farm boundaries, etc.) is generally the 1:250 000 topo-cadastral map, although for a small site the 1:50 000 may be better. Superimposed on this should be the boundary of the farm(s) or area that is involved.
- The **Site Map** can either be the 1:50 000 topo-cadastral map or, even more suitable if the wetland is relatively small, the 1:10 000 ortho-photo map. This will ideally indicate the site(s) of structures as well as the relevant watersheds of the catchment areas.

It may be necessary, if the site is very small, for a local survey to be carried out and a site specific map drawn to a scale larger than 1:10 000. Aerial photo mosaics can also be used for site maps.

Internet (Google Earth)

Fairly high quality aerial images of any part of the country can be easily viewed on Google Earth (www.earth.google.com). The resolution of these images is good enough to define land features such as erosion gullies and the photography is comparatively recent and frequently updated.

1.3 Locating and purchasing maps in RSA

Important sources of maps

These published maps, aerial photos and APMs mentioned above are all compiled, drawn, and sold to the public by the office of the Chief Directorate: Surveys and Mapping (CDSM) of the Department of Land Affairs. There are offices of this Chief Directorate where one may purchase them, either over the counter or through the post:

- Bloemfontein (P/Bag X 20634, 9300)
- Pietermaritzburg (P O Box 396, 3200)
- Pretoria (P/Bag X291, 0001), and
- Head Office is at van der Stel Building, Rhodes Avenue, Mowbray. The postal address is P/Bag X10, Mowbray, 7705

Price lists and an index to the maps that are available are obtainable gratis from these offices. Included in the material available at a price are:

- Contact photos, at scales ranging from 1:20 000 to 1:150 000 depending on the original purpose for which the photography was carried out, some (but very few) of which have been photographed in colour. They have an archive of photo's dating back to the 1930s, also available to the public
- Enlargements of whole contact photos up to three times the original size
- Enlargements of portions of contact photos up to six times, restricted to a size no larger than 680 mm square (black and white only)
- Flight Plans of all the aerial photo jobs
- A comprehensive range of maps from the very useful 1:10 000 ortho-photo, through the well known 1:50 000 maps, down to 1:1 000 000 scale cadastral maps and smaller
- Aerial photo mosaics to a scale that may not be of an enlargement greater than six times the original contact photo, and a paper size no larger than 680 mm square.

The various Provincial Departments of Agriculture, as well as the National Department of Agriculture and the Agricultural Research Council (ARC), prepare more specific maps for their own planning purposes. They may also be accessed, but via the local Agricultural Extension Office of the relevant Department or the ARC head office in Pretoria. These maps include those indicating soil types, veld types, veld burning guidelines, bio-climatic regions, bio-resource units, veld grazing capacities, runoff control planning, farm planning, etc.

Indexing of maps

Indexing of maps is carried out in order to make it as simple as possible to find the map(s) required, and the explanation below is in respect of the method followed by the CDSM. Private mapping companies may or may not follow suit.

For **aerial photos**, a Flight Plan for the specific aerial photo Job is generally superimposed onto a 1:250 000 topo-cadastral map, and has the position of every strip (numbered), and every fifth photo (numbered), drawn on it. To identify the photo(s) needed, one merely identifies on the Flight Plan the farm on which the wetland is situated, and chooses the nearest two photos that will cover the area concerned. The photos are identified according to Job Number, Strip Number and Photo Number.

For all the **other published maps** from the CDSM, use is made of the grid system devised for use in the Latitude/Longitude geographical positioning system. RSA is divided up into more-or-less squares bounded by one degree of latitude and one degree of longitude. The Lat/Long lines intersecting in the top lefthand corner of each square (block) give the identification code to that one-degree grid block. So, for instance, the one degree grid block 2930 is that covering the Pietermaritzburg-Greytown area. See Figure A 1.4.

For the **1:250 000 scale topographical map**, two whole degree blocks (generally horizontally connected, but not always) are used. The Durban sheet, for example, extends from 29°S 30°E in the top left hand corner to 29°S 32°E in the top right hand corner, and is indexed as 2930 Durban. A portion of this type of map would generally be useful for indicating the route from a known town or city to the farm on which the wetland is situated, as required by the WfW Rehabilitation Plan.

The one-degree block is subdivided into four equal sized blocks, and numbered A, B, C and D left to right, top to bottom as a basis for further subdividing.

For the **1:50 000 scale topo-cadastral map series**, each of these blocks mentioned above is further subdivided into four equally sized sub-blocks, and once again numbered A to D. See Figure A1.4. A typical code for one of these maps is 2930 CD. This map type is useful for indicating the wetland boundary as well as the watershed of the catchment above the wetland. This is the second map required by the WfW Rehabilitation Plan. It has also to be used, in an enlarged form, for the rehabilitation map when the 1:10 000 orthophoto map is not available.

For the **1:10 000 Orthophoto maps** each of the 1:50 000 sub-blocks are divided into 25 smaller blocks and numbered 1-25, five blocks across and 5 blocks down. See Figure A1.4. The easiest method of finding the orthophoto map required is to access the 1:50 000 topo-cadastral map and divide it up into a grid of 5 equal blocks horizontally and 5 equal blocks

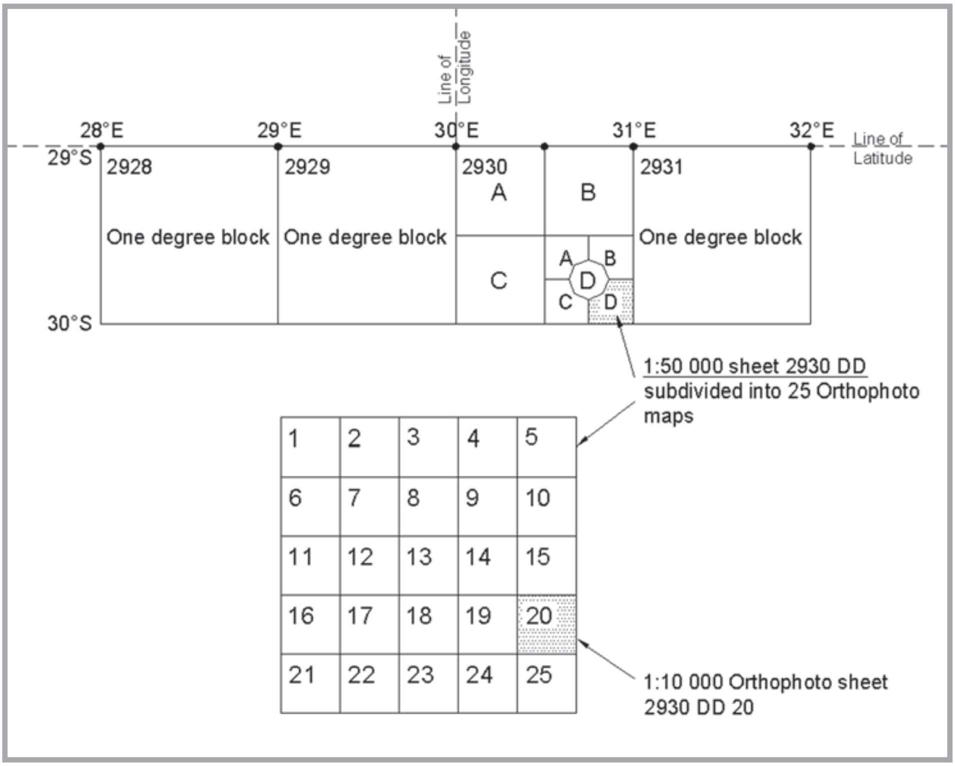

Figure A1.4 : The method of indexing the 1:50 000 topo-cadastral and 1: 10 000 orthophoto maps vertically. The area of interest is easily found on the 1:50 000 map, and using the numbering system mentioned above, one may now determine the code for the map covering the exact area that is of interest. A typical way in which the code is structured would be 2930 CD 23.

This map type is usually ideal for describing, in the Rehabilitation Plan, the placing of the group of structures that are recommended for construction. There is unfortunately insufficient coverage of this particular map in RSA. The coverage available is obtainable from the Chief Directorate, Survey and Mapping.

1.4 Using map scales for accurate measurement

All true maps have been drawn to a scale, to enable the reader to determine the distance, between points of interest, size of areas, slope of land, lines of intervisibility, etc. There are various ways in which the scale of a map is represented.

Representative Fraction (RF)

Inasmuch as the map represents a ratio of the distance between objects on the map to the distance between those same objects on the ground, that ratio is nothing more than the scale of the map.

So, for example, a scale of 1:10 000 means that one unit of measure on the map represents 10 000 units of the same measure on the ground. The RF is also written as a fraction, e.g. 1/10 000.

A small-scale map is therefore one where the fraction is very small, and a large scale is one where the fraction is larger.

The unit of measure may be anything – millimetres, centimetres, metres, kilometres, feet, inches, etc. When using the scale in practice, however, it is useful to change the form of expression as follows :

If 1 cm on the map represents (or =) 10 000 cm on the ground,

1 cm on the map represents (or =) 100 m on the ground (because there are 100 cm in a metre).

It is useful to dispense with the word 'represents' in practice, and simply to use the '=' sign, although this is not, of course, entirely correct. The distance between two objects is measured on the map using a ruler, and that measurement is then multiplied by the scale to arrive at the correct ground distance. So, if the distance between X and Y is measured on the map as 5.3 cm, and the scale of the map is 1:10 000 (or 1 cm = 100 m), the distance between points X and Y on the ground is

Distance XY on the ground = 5.3 x 100 = 530 m

The disadvantage of using this type of scale is that, should the map be enlarged or reduced in size, the scale of the image changes, and the new scale must be inserted on the map, otherwise incorrect calculations regarding distances will be made. See the following section for the method of finding the correct scale after enlargement/reduction.

Graphic Representation

The scale is sometimes indicated graphically by means of a measured line showing the map lengths of ground distances (see Figure A 1.5). It is called a bar scale. This makes it possible to measure the distance between two points on the map by marking them on the edge of a piece of paper and placing it against the graphic scale in order to determine the ground distance. This method has the added benefit of allowing the enlargement or reduction in size of the map without having to alter the value of the scale on the hard copy.

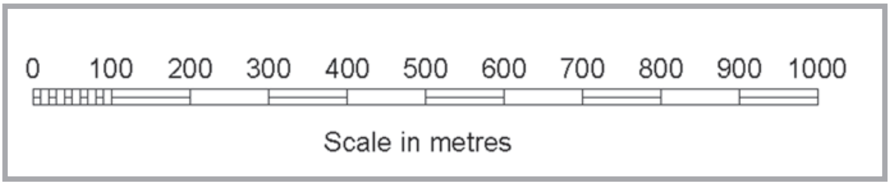

Figure A 1.5: Graphic method of scale representation using a bar scale

Engineering scales

This is simply expressing the scale in the form of suitable units on the map (or engineering diagram) representing suitable units on the ground, e.g. 1 cm = 250 metres. This has the same problem when enlarging or reducing the size of the original document as indicated in the paragraph above when discussing the RF.

Determining the new scale after enlarging or reducing the size of the map or engineering diagram:

Suppose the original scale of the drawing is

1 cm = 500 m (or 1:50 000 as a RF), and it is to be enlarged four times.

Remembering that the scale is in the form of a fraction, the new scale will then be four times as large, or

1 cm = 500 ¸ 4 =125 m (or 1:12 500 as a RF).

In enlarging the size of the drawing (i.e. reducing the size of the RF), one simply divides the right hand side of the equation by the size of the enlargement factor, and multiplies it by the size of the reduction factor when reducing it.

Finding the scale of a map

Sometimes, as with aerial photos, the scale of a map is not always apparent. One needs then to determine what the scale is (as pointed out in sub-chapter 1.1 of this Appendix). To find the true scale of an aerial photo (or any other map that does not have it displayed), two points on the photo that are easily identifiable must be marked and the distance measured, usually in centimetres. Another map (e.g. a published 1:10 000 or 1:50 000 scale topo-cadastral) must then be consulted and the same two points also identified on it. Using the known scale of this map, and having measured the map distance on it, the true ground distance can be determined. It is then merely a matter of relating the map distance as measured on the first map to the true distance on the ground.

Example:

Suppose the distance between two points A and B on an aerial photo is measured as 2.35 cm. The map distance between the same two points A and B on a 1:50 000 scale map is measured as 1.6 cm. Find the scale of the aerial photo.

Solution:

Ground distance AB according to the 1:50 000 scale map (1 cm = 500 m) is

1.6 x 500 = 800 m.

On the aerial photo the distance was measured as 2.35 cm. According to the photo therefore,

AB = 2.35 cm (map) = 800 m (ground)

The scale of the photo over the section AB is therefore

1 cm = 800 m¸ 2.35 cm = 340 m, or 1:34 000 (RF).

Determining area using scales

Very few maps indicate what the equivalent scale is for calculating the size of areas on them. Just as distances on a map are in a scale or proportional relationship to the ground distances they represent, so likewise are the areas on a map. The relationship between map area and ground area is simple: the area scale will be in the ratio of 1 (note that 12 = 1) to the square of the denominator of the Representative Fraction. For example, if the linear scale of a map is 1:50 000, then one square unit on the map will represent 50 000 square units on the ground. Finding the map area in hectares is carried out as follows:

If the linear scale is 1 : 50 000, and therefore

1 cm (map distance) = 500 m (ground distance),

then 1 cm² (map area) $= \frac{500 \times 500}{10\ 000}$

= 25 ha (ground area)

(note that there are 10 000 square metres in a hectare)

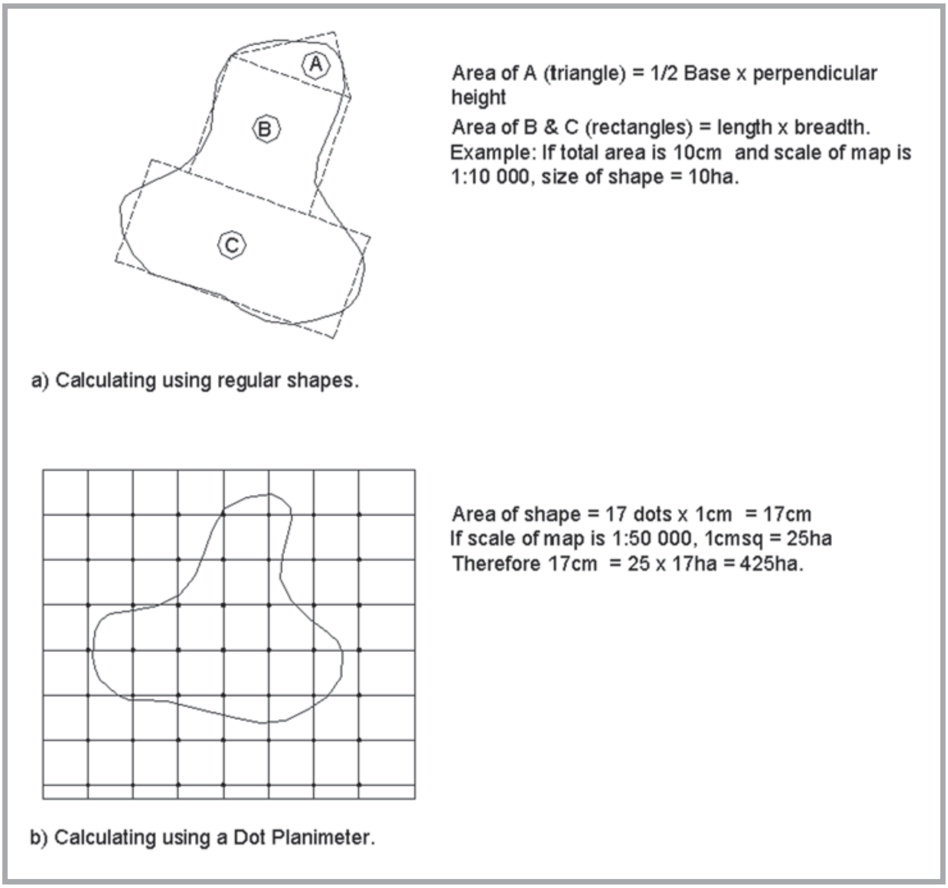

Figure A1.6: Calculating the size or irregular shapes on maps

Measuring the irregular shapes of catchment and wetland areas on a map

There are a number of methods of measuring the size of irregular shapes on a map. Only two will be mentioned here.

- Making use of regular shapes: The irregular shape is broken up into a system of regular shapes that approximate as closely as possible to the original. Knowing the formulae for calculating the area of the regular shapes, these are calculated and the sum of the individual areas is the total in square centimetres. Apply the scale formula for square centimetres. See Figure A1.6(a).
- Making use of a dot planimeter: Make up a grid, on transparent material, of equally spaced dots one centimetre apart vertically and horizontally. Place this on the map and count the number of dots that fall within the irregular shape. Apply the scale formula for square centimeters. See Figure A 1.6(b). Note that with small map areas one may have to resort to a grid of dots 0.5 mm (or smaller still) apart in order to achieve greater accuracy.

Calculating Ground Slope

Choose an upper and a lower contour line that together encapsulate the section for which the steepness of slope is required, and subtract the smaller value from the larger. This gives the height difference between the two points chosen.

Measure the distance with a ruler between two chosen lines and determine the distance between them as explained previously:

Then % slope =

$$\frac{\text{Height difference between contourlines chosen} \times 100\ \%}{\text{Ground distance between them}}$$

For example, from a map with a scale of 1:10 000, and having the vertical interval between contourlines 20 m, find the slope between two points measured 4.5 cm apart between two adjacent contourlines:

Height difference between two contourlines
= 1000 – 980 = 20 metres

The distance between them is given as
= 4.5cm x 100 = 450 metres

The percentage slope therefore is

$$S = \frac{20 \times 100}{450} = 4.4\%$$

1.5 Copying maps

It is sometimes necessary to copy a map for a given purpose, but the worker does not require all of the data present on the map he wishes to copy. He may also wish to enlarge (reduce) the map at the same time. There are a number of methods:

- If the facilities are available, scan it electronically and scrub the data not required.
- Draw a rectangular grid on the map to be copied, using the same dimensions (i.e. scale) both vertically and horizontally. Note the scale of the map. On a separate piece of blank paper, draw another, similar grid, but with the sides of the squares larger (if a larger scale is required, or smaller if a smaller scale is required). If one started out with the grid on the map (e.g. with a scale of 1:10 000) having squares 1 cm x 1 cm, and one wished to draw the new map to a scale of, say 1:3 000, the new grid would have to have grid squares 3 cm x 3 cm. Now, using the grid lines as guides, transfer whatever data is needed from the old to the new map by marking the latter wherever the lines on the old map cross the grid lines. See Figure A1.7.
- Transfer the required data using an instrument called a pantograph. Space and time does unfortunately not allow an explanation of the technique here. It was the usual method prior to the electronic age, and is still used occasionally today.

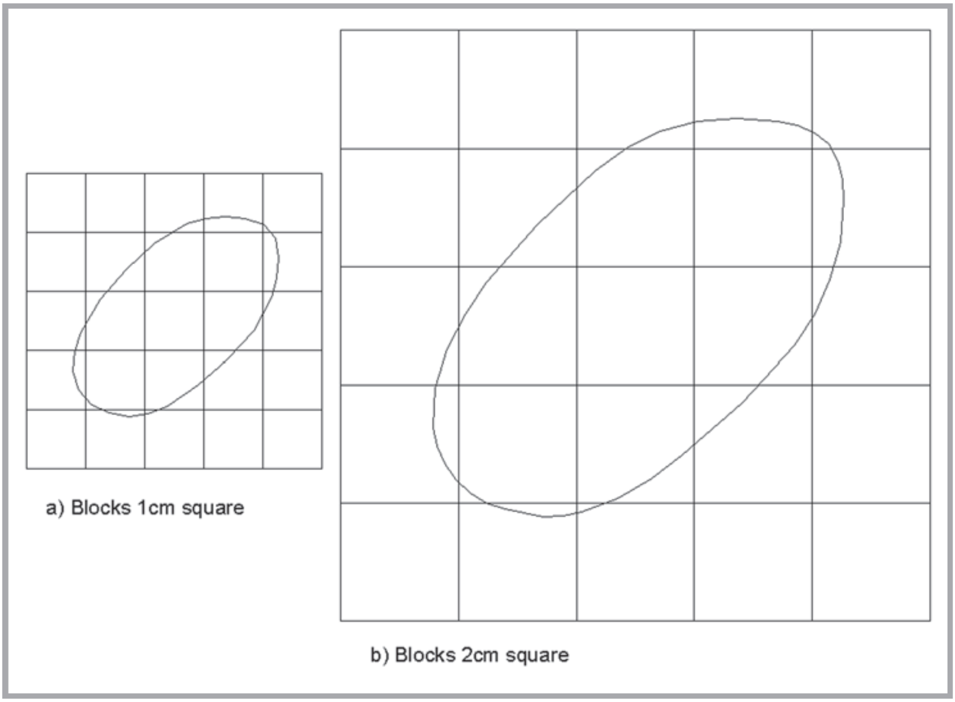

Figure A 1.7: An example of using two sets of different sized grid squares to enlarge or reduce images

1.6 Catchment delineation

Water flows downhill perpendicular to contour lines. Initially water may flow overland until it reaches a small watercourse or stream. These streams join progressively larger water courses (tributaries) until they ultimately reach the ocean. Each tributary has its own catchment, as do the progressively larger rivers, until the entire river system, including all its tributaries, can have its own defined catchment. A catchment is therefore considered to be the area of land that naturally drains into a tributary or river system.

You can make out the drainage patterns and direction of flow on the landscape, as well as delineate the catchment, by examining the contours of a particular river system. As a general rule the contours 'point' upstream, so you can work out the direction of flow and where the highest point on the landscape is above a stream – this is the head of the stream as well as the edge of the catchment. If you go beyond this point, the land slopes away towards another catchment. If you join all the highest points around a particular river or stream you would delineate the catchment boundary (Figure A 1.8). A good reference for reading topographic maps and delineating catchments is that produced by the US Dept of Agriculture (Natural Resources Conservation Service, no date). Burton and Pitt (1993) is also an excellent South African resource for information on reading topographic maps.

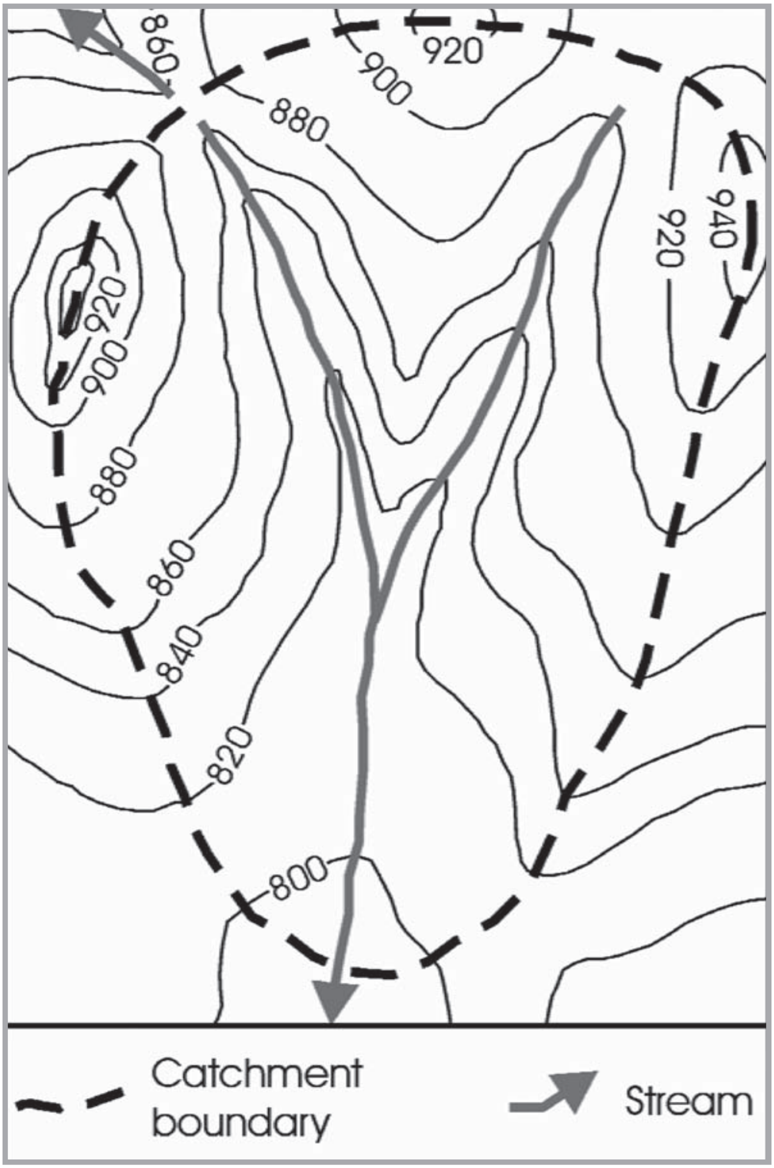

Figure A1.8: Map showing a delineated catchment based on contour information (adapted from Natural Resources Conservation Service, no date)

1.7 Bibliography

Burton, M & Pitt, I (1993) *South African Mapcraft*, Shuter & Shooter, PMB.

Chief Directorate: Surveys and Mapping, Department of Land Affairs RSA (2003). *Mapping South Africa*.

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Gijsbertsen, BG (1997) *Map Work Course Manual*, Natural Resources Section, KZN Department of Agriculture.

Natural Resource Conservation Service, no date. *How to read a topographic map and delineate a watershed.* United States Department of Agriculture. [On line] www.nh.nrcs.usda.gov Access

APPENDIX 2:

SIMPLE TOPOGRAPHIC SURVEYS AND SETTING OUT STRUCTURES

2.1 Simple topographic surveys

From what has been stated throughout the body of the manual, it should be obvious that a certain amount of topographic survey will be required in order to properly plan and site the positions of structures. Without going into great detail regarding the different types of survey instruments, their use and care, an attempt will be made to explain the basic principles of level surveys, and how to use the simplest ones.

Leveling simply means the determination of heights between different points on the ground. The instrument common to most surveys is the survey staff. It is normally 4 m or 5 m in length but can be telescopically reduced or folded (depending on the make) to 1.25 m for ease of carrying. The numbering system on the face is divided up into lengths of one metre by background colour, and into 10 mm divisions by small blocks and colour of the individual markings. When reading it, the staff must be held in a truly vertical position. See Figure A 2.1 for an explanation of its make-up and how it is read.

The staff can be imagined as a monster tape measure that is used in the vertical position. It is used to determine heights of points relative to each other. In order to do this one needs an horizontal line of sight (See Figure A 2.2).

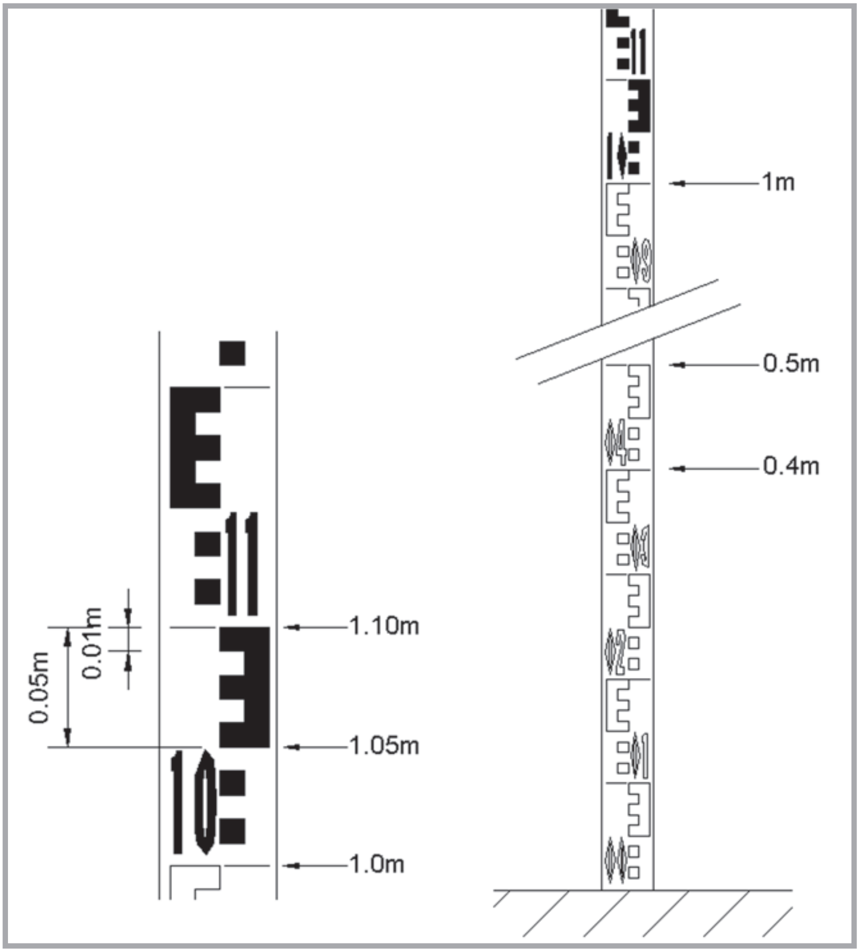


Figure A 2.1: Survey staff

The horizontal line of sight can be obtained by using either an instrument called a dumpy level (Figure A 2.3), a hand level (Figure A 2.4) or a spirit level. Everyone reading this should know what a spirit level looks like, but the one referred to here needs to be large, and this is accomplished by using a line level (purchased from any hardware store) hooked on to a piece of fish line (Figs A 2.5).

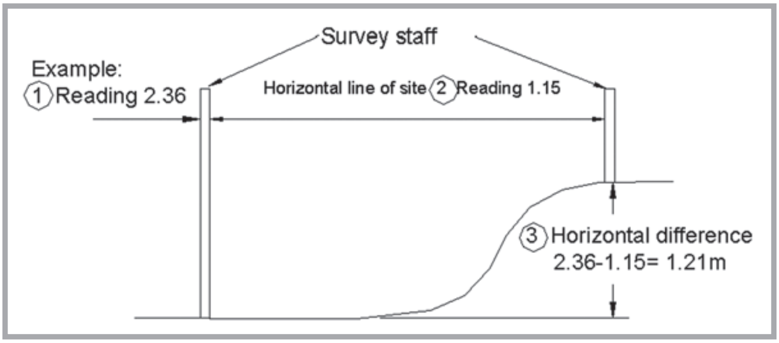


Figure A 2.2: A horizontal line of sight intersecting two staff positions to measure height difference

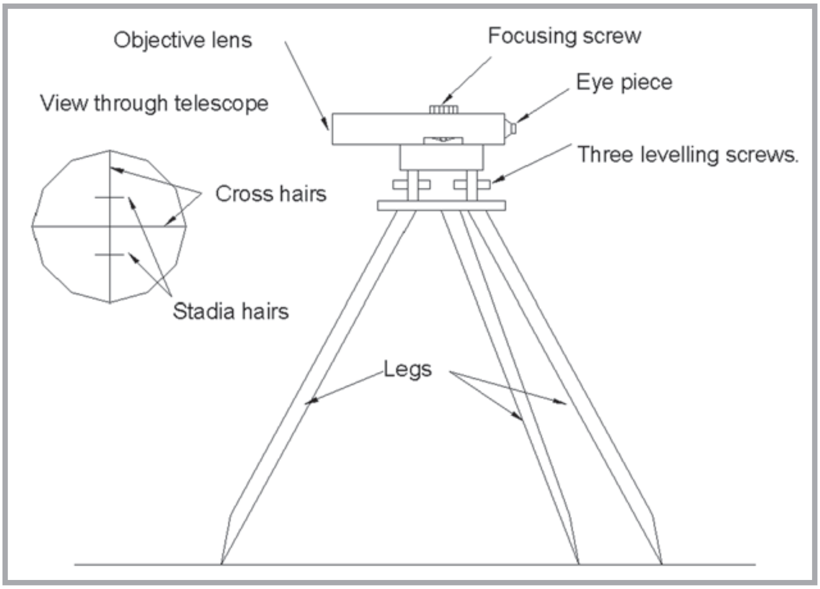


Figure A 2.3: The Dumpy Level

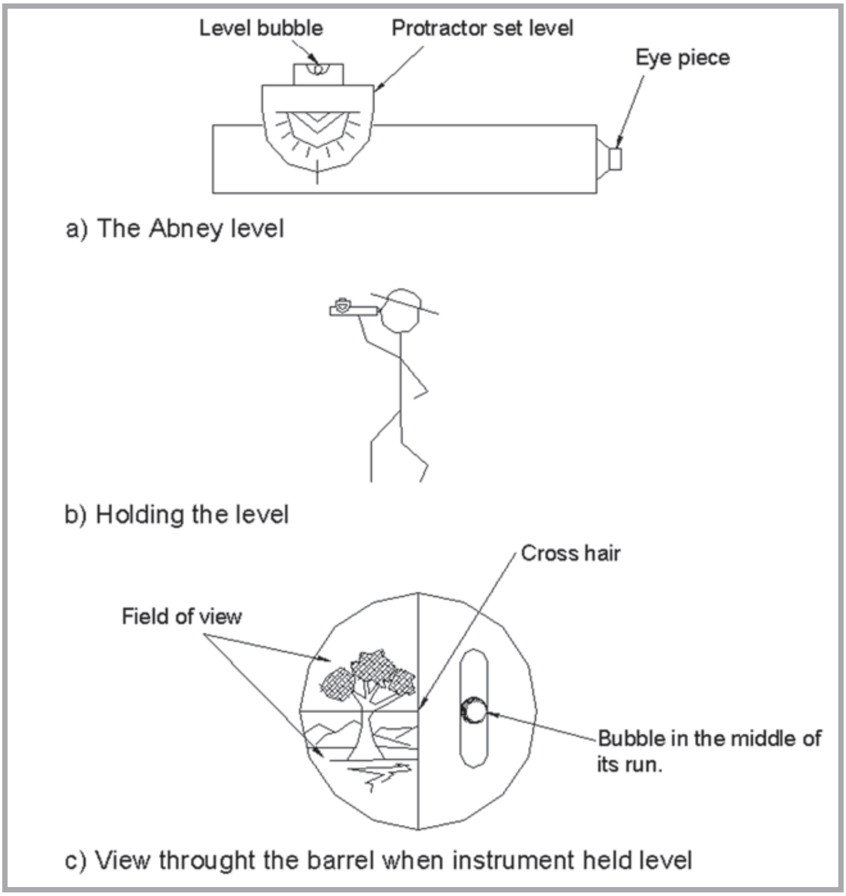


Figure A 2.4: The Abney Hand Level

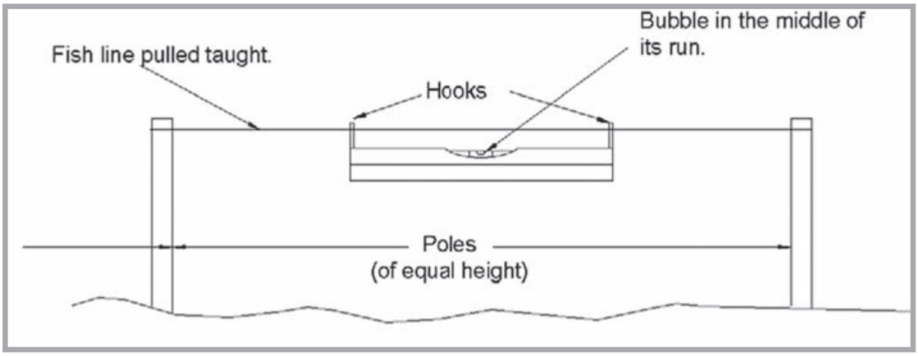


Figure A 2.5: Line Level

2.2 Surveying a gradient

It is sometimes necessary to survey a line with a given gradient; for example when wanting to excavate a drain carrying water to bypass the construction site. Another example is when pegging out a spreader canal, or a storm water drain. In the latter instance one needs to place pegs at intervals so that the channel is level for most of its length, while in the former the channel bed must drop away at the required slope. This means that in the case of a survey with the gradient falling in the direction of survey, the length between the crosshair on the staff and the bottom of the staff resting on the ground must increase.

A typical gradient would be 1 : 100, or 1 m fall over 100 m. Quite obviously it would not be suitable, from a construction point of view, to put a peg in only every 100 m, and a distance of 25 m would be more suitable. The question arises as to how to determine what the height difference between pegs should be for the chosen gradient when the pegs are not put in at the given horizontal interval. All one does is to remember that the gradient can be expressed as a fraction. Thus:

Given gradient is 1 : 100, or 1/100, and height difference between pegs = 1 m if the pegs are put in at 100 m intervals. If the distance between pegs is to be 25 m, then the height difference between pegs must be:

1/100 x 25 = 0.25 m for the same gradient.

The same procedure applies to any other gradient and any other chosen distance between pegs: the required gradient in the form of a fraction, multiplied by the distance apart that the pegs are to be put in, will give the difference in height between any two adjacent pegs. If, in the above example it was decided to place the pegs every 10 m, then the height difference between adjacent pegs would be

1/100 x 10 = 0.1 m

Commencing the survey, the start of the gradient line is chosen, a peg put in at that point, and the survey staff is held there:

- Using a dumpy level, a reading is taken on the staff, the staff is moved the requisite 25 m, and the staff placed at that point. The surveyor now adds 0.25 m to the previous reading and moves the staff bearer up or down slope until the new calculated reading on the staff is at the crosshair. Knock in peg no. 2. The procedure is replicated as many times as is necessary to achieve the length of channel required, each 25 m interval moving the staff so that an extra 0.25 m higher on the staff is recorded at the cross-hair. See Figure A 2.6(a) for an example.
- Using a hand level, stand upright at the first peg and measure the height of the instrument while holding it at eye level. Move the staff 25 m away along the expected line and aim at it with the instrument. Move the staff up or down the slope until a reading of the original height plus 0.25 m is on the crosshair. Fix this point (no. 2) with a peg. Repeat the procedure, the surveyor always moving to the last peg inserted, and reading to the next point, with an extra 0.25 m added on to the previous reading. See Figure A 2.6(b) for an example.
- Using a line level, take two poles, the one 0.25 m longer than the other, and have the shorter one held by a helper at the start of the survey line. Tie a piece of fish line to the top end of both poles and position the line level at the middle of the line. It must hang freely. A second helper moves the longer pole to a point the requisite 25 m away on the approximate contour, and pulls the line tight. The surveyor stands at

the midpoint of the line (where the line level is hanging) and directs the second helper up or down slope until the bubble of the line level is in the middle of its run. A peg (no. 2) is fixed in place and the three persons move in unison along the apparent contour line until the shorter pole is held at peg no. 2. The procedure is repeated until the required length of surveyed line is reached. Note that if the day is at all windy the bubble may sway too much. It is then advisable to shorten the fish line to 10 m and make the longer pole 1/100 x 10 = 0.1 m longer than the other. See Figure A 2.6(c) for an example.

Naturally, where a level line is required (e.g. for a spreader canal) the procedure is the same, except that there is no height difference from one peg to another.

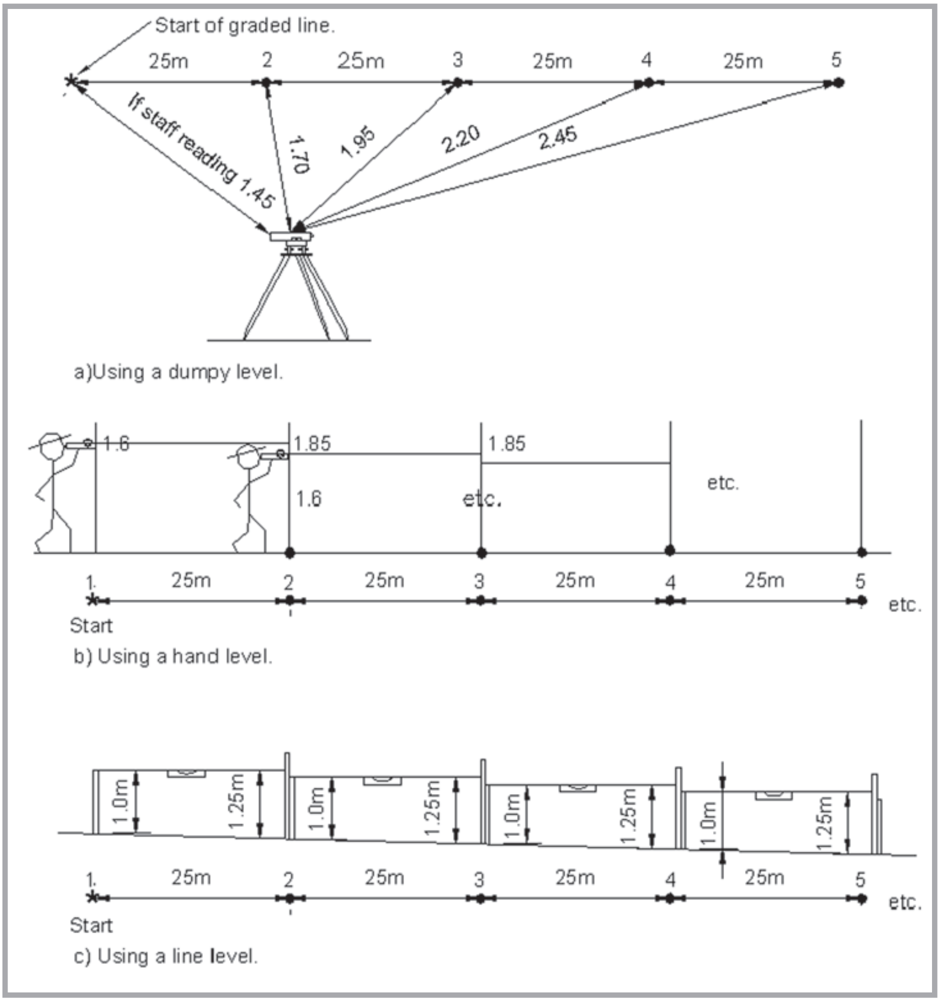


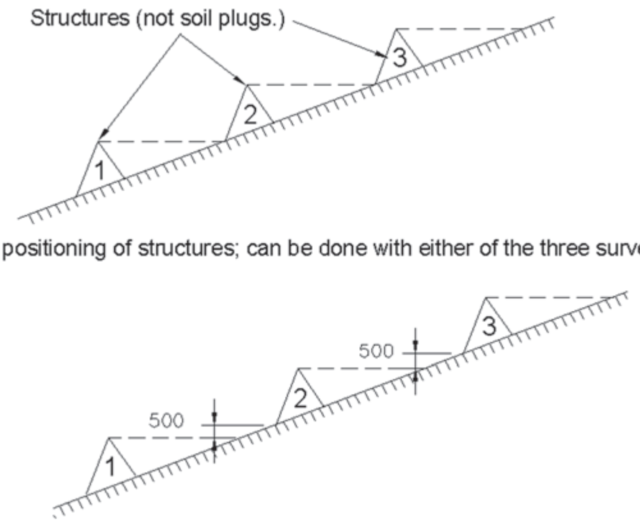
Figure A 2.6: Pegging a gradient of 1:100, using three different survey instruments, with pegs placed every 25 m (i.e. 0.25 m fall over 25 m)

2.3 Positioning successive structures along a gully

It will be remembered from various chapters in the body of the manual that when a series of structures are to be constructed along a gully or drain, there should be a best and most effective position for each one. For example, where water only is to be stored in order to raise the water table, they may be spaced top-to-toe, as long as the structures are not made of soil. It is bad practice to have water resting against both sides of an earthen embankment. Saturation of the soil in the plug will result in collapse of the structure. Where sediment is to be trapped in order to raise the bed of the gully, the structures should be spaced so that the sediment stored behind one structure will not interfere with the adjacent structure upstream.

One therefore needs to be able to ensure that the positioning of these structures is correct in the vertical sense, i.e. they are separated from each other the correct vertical interval apart. Top- to -toe spacing means that they should be separated their individual height apart. Soil plugs should be no closer than approximately structure height plus 500 mm apart, and where a sediment buildup is to be planned for, a small mathematical exercise will be required which is more easily explained using the geometry route. See Figure A2.7 for the solution to the problem.

Once again, the three survey instruments discussed above may be used for small structures.



(a) Top-to-toe positioning of structures; can be done with either of the three survey instruments.

(b) Siting soil plugs with at least 500mm vertical spacing above waterline of lower structure. Can be done with either of the three survey instruments.

* For major structures the gully bad gradient is surveyed with a proper survey instrument, plotted on paper, and their positions determined more precisely.

Figure A 2.7: Setting out a series of structures in a gully bed

2.4 Marking out the structures

In order to be able to mark out structures one must be able to read the proposed specifications for the structures. Marking out entails the transfer of the proposed dimensions on to the ground in a manner that will enable the builder to commence work. This is not too difficult as long as one goes methodically through the diagrams and reads off the dimensions required. Details on reading plans are given in Appendix 3.

Pegs, either wooden or round bar and preferably flagged, should be used to mark out all the ends and corners of the required work, as well as the extent of any excavations required. In doing so, it will regularly be necessary to hammer in pegs that show lines at right angles to each other. A right angle may be laid out with a dumpy level, but it is easier to do so with a simple tape measure or length of twine.

A triangle with sides in the ratio of 3:4:5 will automatically result in a right angled triangle. This ratio is often used, after setting out a base line, to erect a right angle on it as the means of squaring off the other side of the structure (Figure A 2.8).

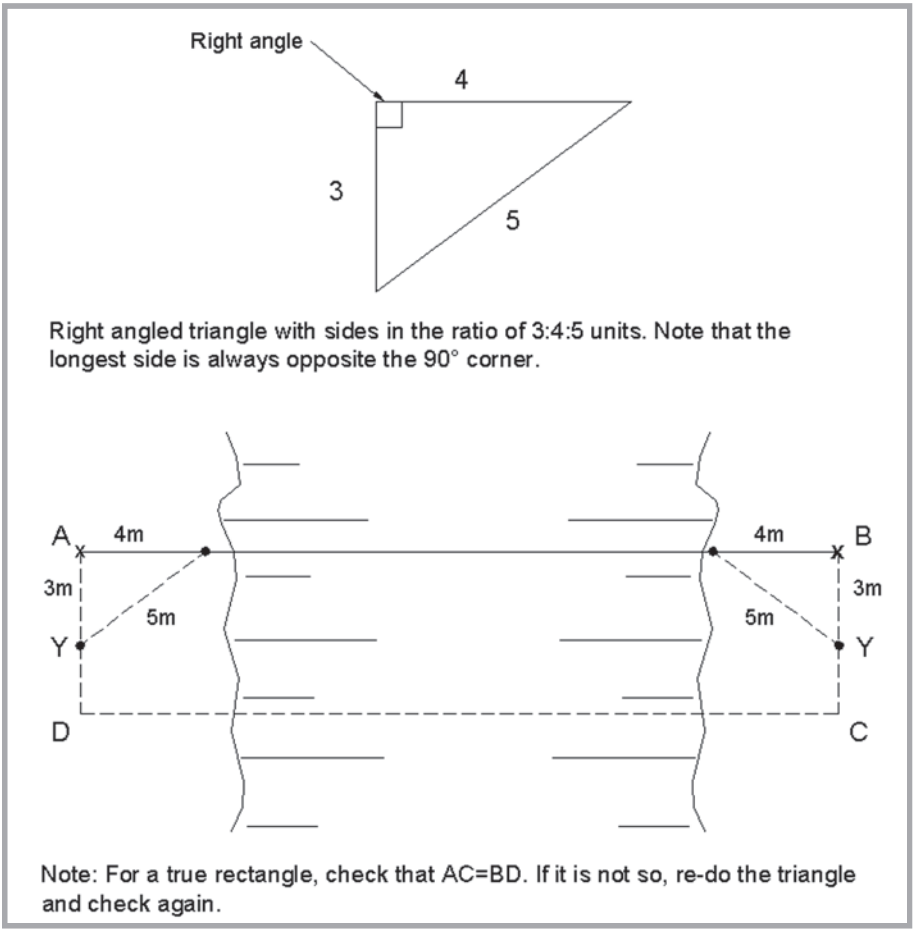


Figure A 2.8: Marking off the rectangle that circumscribes the structure

With a structure that is to be erected across a gully, the base line would be the chosen position across it and either the waterside edge in the case of a weir, or the centreline in the case of an earthen embankment, or a chute. Both ends of the structure are marked with suitable pegs A and B (see Figure A 2.8) ensuring that this baseline is truly at right angles to the gully (weir or diversion) or to the contour line in the case of a chute. A piece of twine is strung tightly between them. From peg A a length of 4 metres is marked off along the baseline towards peg B – call this new position X. The zero position of the tape is now held at the end peg (A) and held by a second person at point X, 8m (i.e. 3 m + 5 m) along the tape. A third person holds the tape at mark 3 m on the tape and pulls it tight, taking up a position at point Y. This automatically forms a triangle with sides of lengths 3 m (AY), 4 m (AX), and 5 m (XY). This third person is then standing at right angles to the baseline. The line AY is then extended or shortened to complete the second side of the rectangle around the structure. The same procedure is carried out at point B, and the rectangle completed. Because errors are always possible it is necessary to check the correctness of the rectangle. This is accomplished by measuring both diagonals of the rectangle so formed. They must have the same lengths, otherwise it is not a true rectangle, and the process must be repeated.

With a rectangle describing the extent of the structure, further relevant dimensions can then be marked off, as the plan requires.

APPENDIX 3:

EXAMPLES OF DRAWINGS

This Appendix consists mainly of construction drawings. However, the first figures (Figures A 3.1-3.4) are photographs of some of the structures that can be depicted in construction plan drawings.

Specifications for simple rehabilitation structures generally comprise a PLAN VIEW, a LONG SECTION, and one or more CROSS SECTIONS. The designer may even, with the more sophisticated structures, include a sub-aerial three dimensional view of the entire structure, to give the builder an idea of what the final structure should look like. The diagrams will have been drawn to scale, although this is not entirely necessary with the simpler structures, as long as they are more or less to the required shape and proportion, and the dimensions are clearly given. One of the problems of draughting structures that are short in height but long in length is to choose a scale that will show all the relevant construction detail. Alternatively, one may exaggerate the vertical scale to make the detail more visible to the reader. It is often practice to standardize the units of all the measurements and to give them either together with the individual diagrams, or once off in the title block of the specification sheet.

Anyone preparing drawings for construction must ask themselves a simple question: Can the structure depicted be built correctly and in the right place using only the information shown in the drawing? If there is any possibility of a negative answer to this question then the drawing is inadequate and more detail must be added.

- The first diagram is usually the *plan view*. It is an image of what the completed structure should look like when viewed from above. Not only should it show the dimensions and angles of the outside border of the structure, but it is also the diagram used to indicate from where the various sections are viewed. It should show exactly where the structure is to be built and how it should line up with other features (see Figures. A 3.5 (a) and A 3.6 (a)).
- The *long section* is the diagram that indicates the variation in height of the structure (if there are to be any) across the width of the gully. In this instance the view will generally be from a downstream position looking upstream at the structure. It could also be used to show the variation in dimensions along the length of a structure such as a chute. It may even be used to show information along a gully, for instance when there is a need to position a number of structures along it in relation to its gradient and the original ground level. Pertinent dimensions will be given along its length (see Figures A 3.5 (b) and A 3.6(b)).
- The *cross section* is a view(s) always at right angles to the long section. Especially with wetland rehabilitation structures, there could be a number of different cross sections that show the builder where changes must occur from one point to another (see Figures. A 3.5(c) and A 3.6(c)).
- Construction notes should always be provided as an addendum to the specifications. These deal with the detail of the construction process, such as the binding of gabion baskets, size of stone, concrete mix(es), method of soil compaction, etc.
- Drawings must always contain a little block with the following information:
  - The name and contact information

of the drafts person who should be available to answer queries.

- The name and contact information of the designer for the same reason.
- The scales used unless they are indicated adjacent to the different parts of the drawing.
- A drawing number and revision number.
- The date the drawing was first prepared and the dates of all revisions.
- Brief descriptions of all revisions.
- The signature of the person responsible for the design indicating that they are happy that the drawing accurately depicts the design intention.
- A list of other drawings that may be referenced.

- A Bill of Quantities (BoQ) should be a further addendum to the specifications. This is a list of all the building material that will be required, as well as the ancillary hardware such as shuttering, binding wire, pliers, saws, spades, picks, shovels, wheel barrows, etc. that will be needed in order to carry out the construction. It should include also an estimate of the time taken (in terms of man days) to complete the structure.

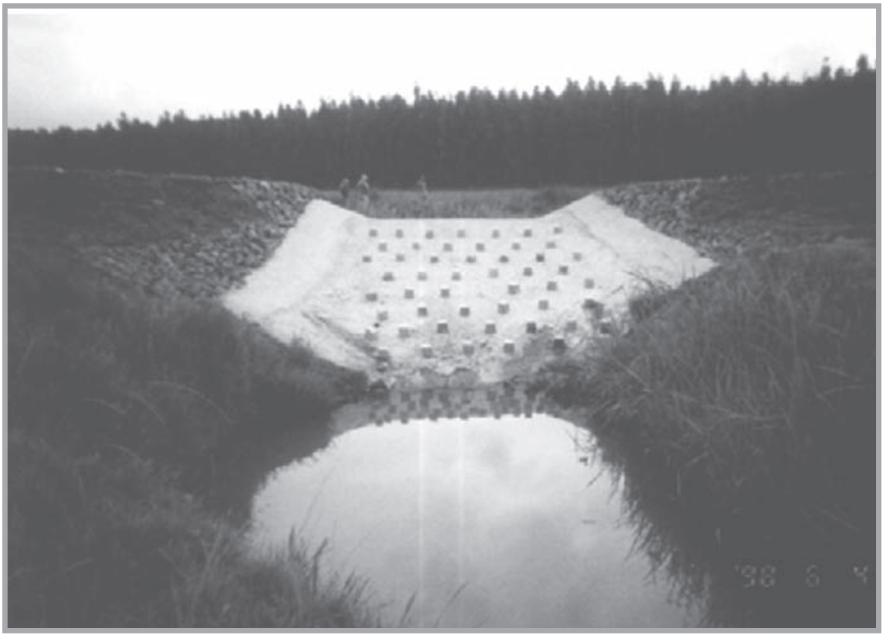


Figure A 3.1: A large earthen plug with central spillway protected with concrete in geo-cells **and provided with baffles**

Figure A 3.2: Building an arch weir. Double walls of concrete bricks with concrete fill in-between. Planned for raising once the sediment has reached the spillway level

Figure A 3.3(a): A 10 year old gabion box weir gone wrong. The wire is rusting and the rocks are falling out of the baskets. The team is enclosing the structure in concrete

Figure A 3.3(b): The job completed. Note that the U-shape of the structure is to provide for a longer length of spillway than could be provided for straight across the gully

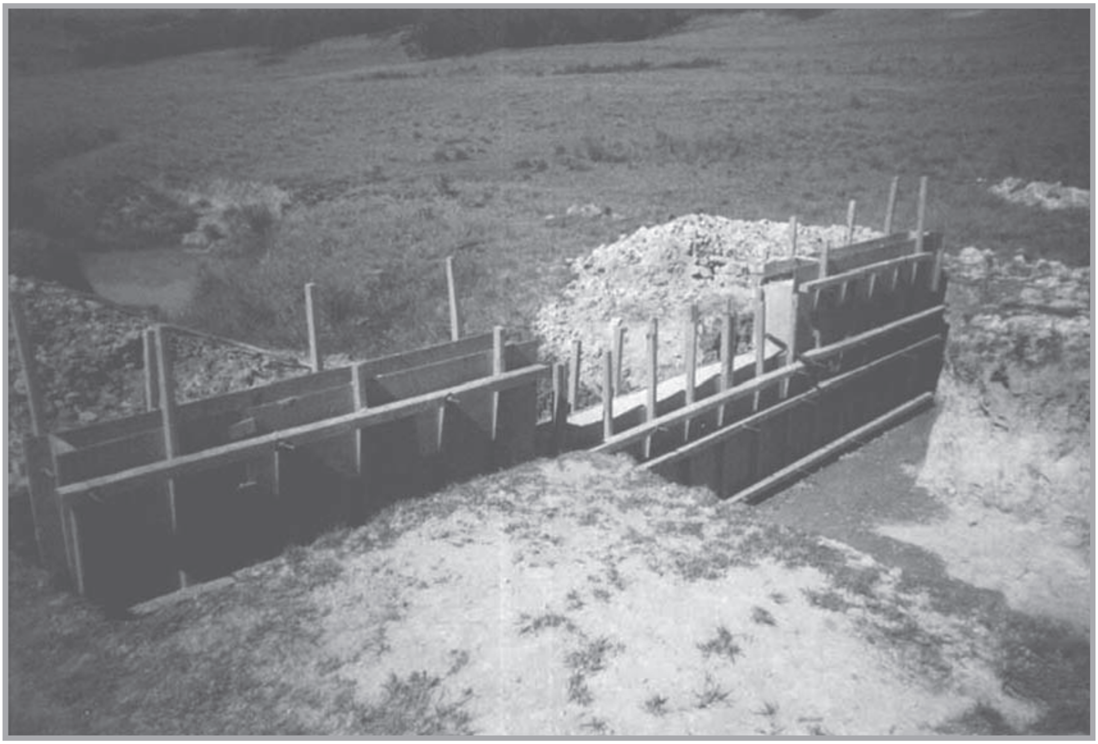


Figure A 3.4(a): A buttress weir under construction. The key and the overflow sections have been cast. Next step is to remove the shuttering

Figure A 3.4(b): The wall and buttress complete, the shoulder walls are now being built, as indicated by the position of the shuttering

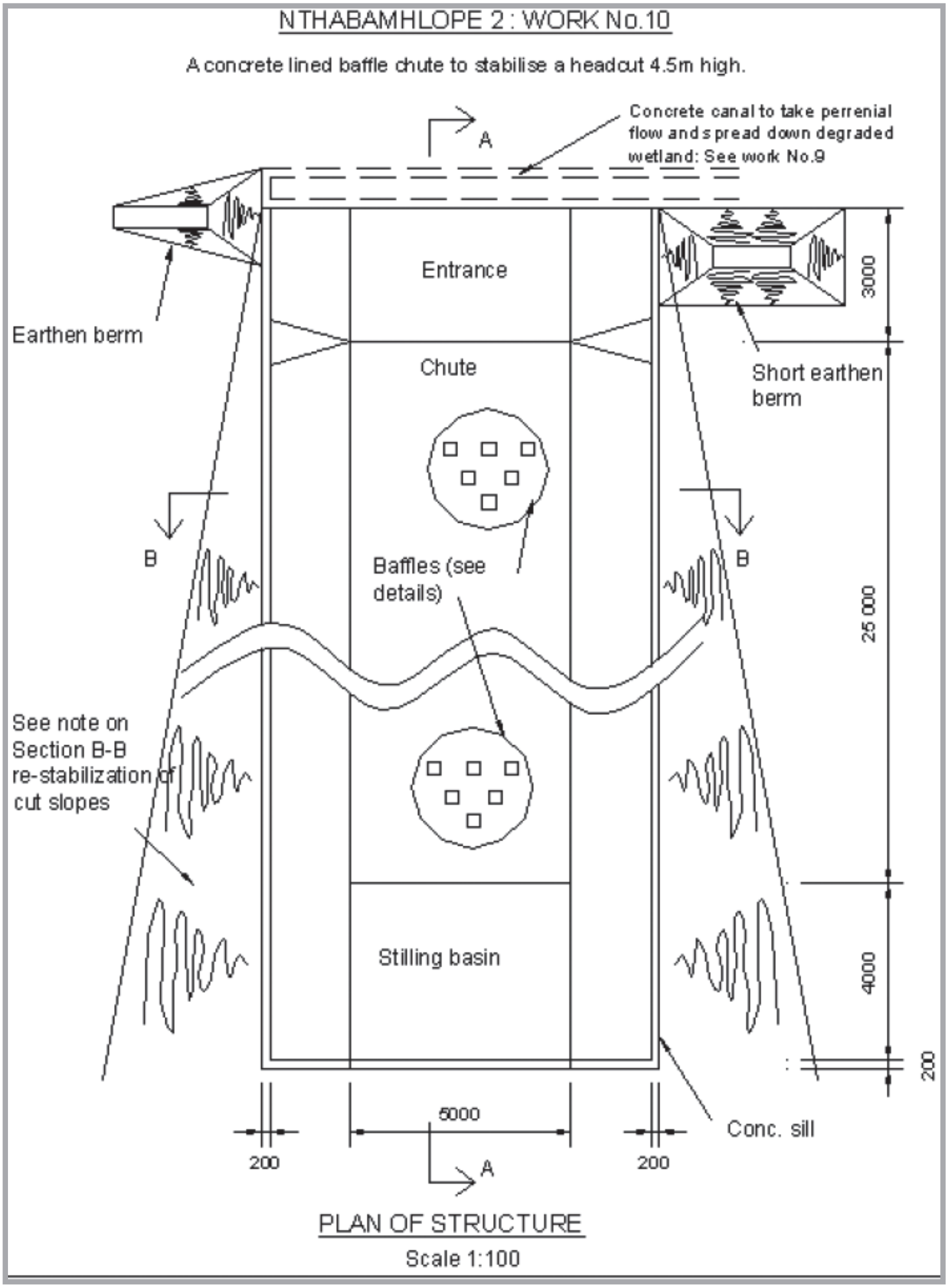


Figure A 3.5(a): Plan view of a concrete lined baffle chute, used to stabilize a headcut

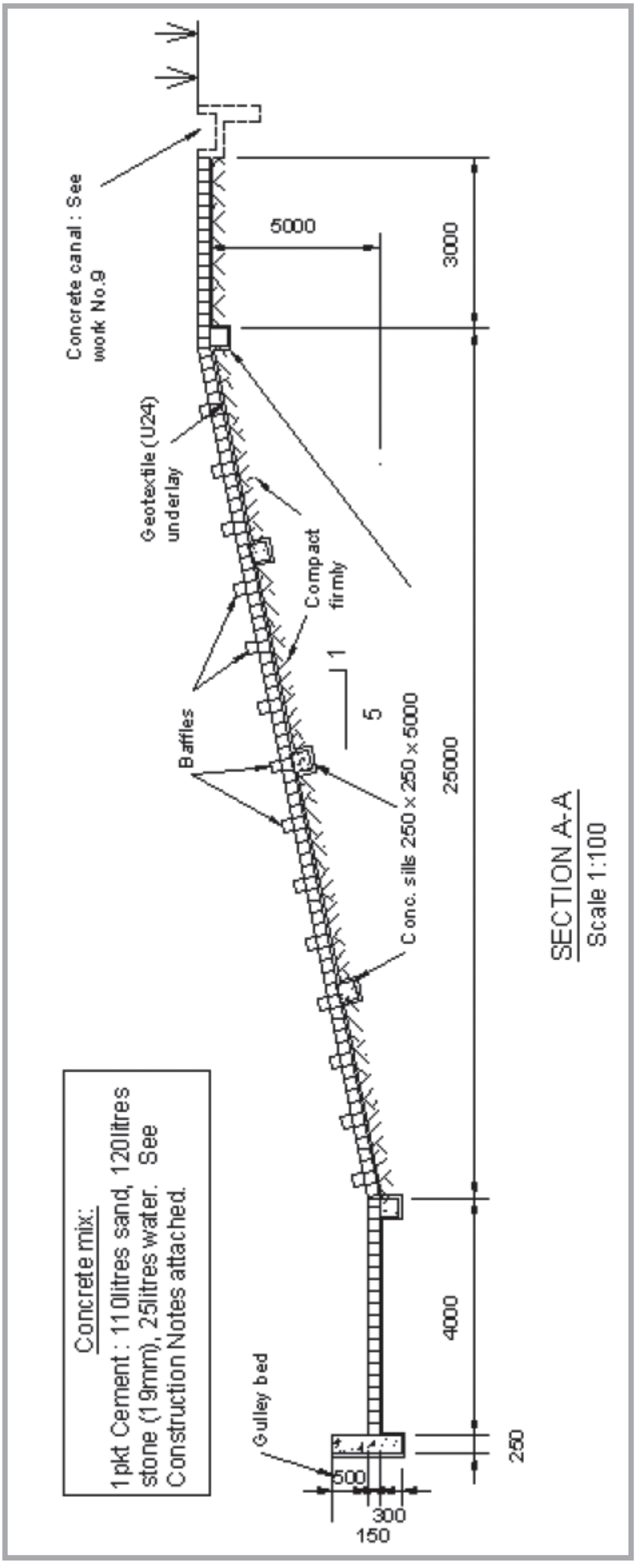


Figure A 3.5(b): Long section of the concrete lined baffle chute

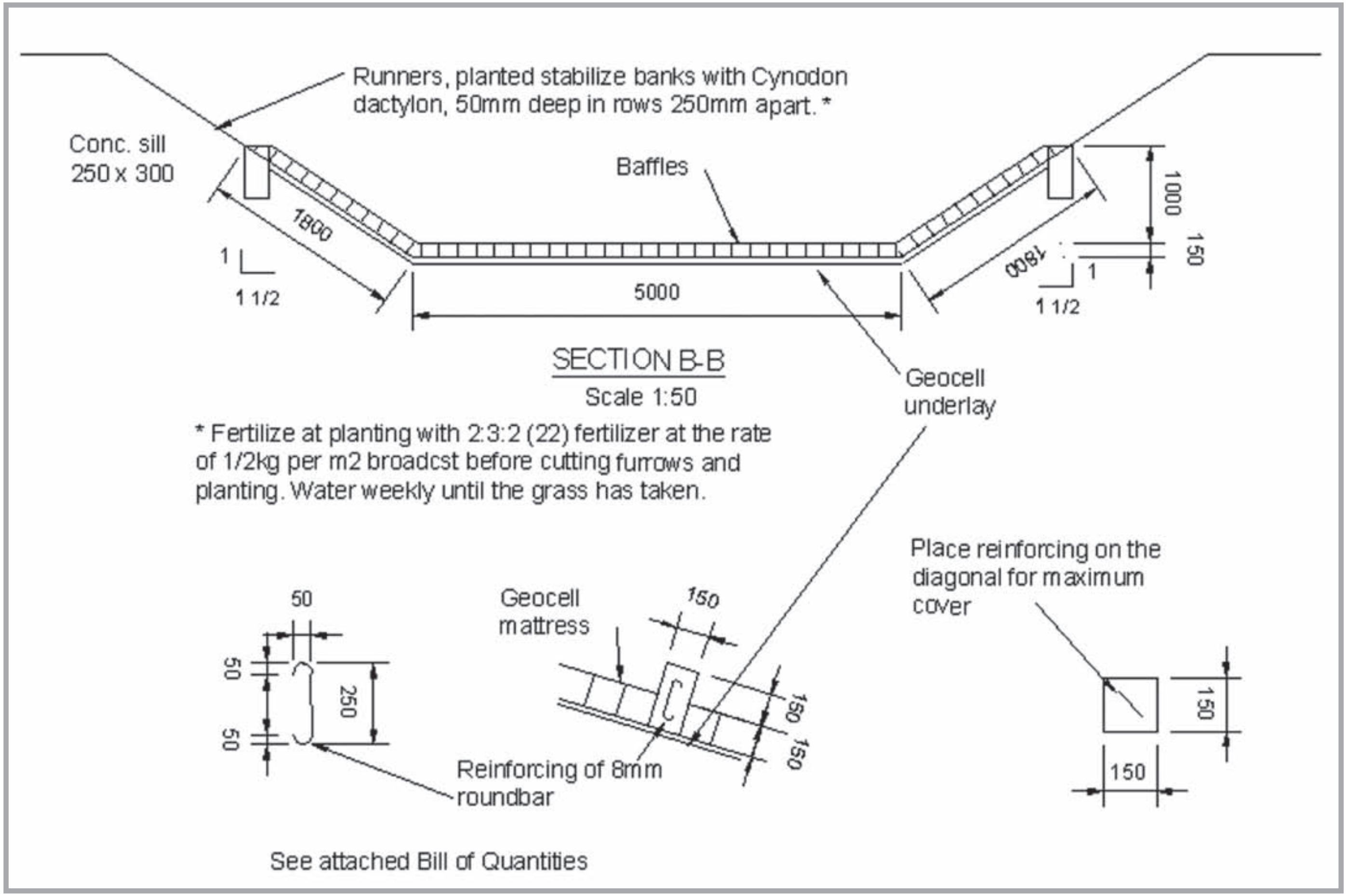


Figure A 3.5(c): Cross-section of a concrete lined baffle chute

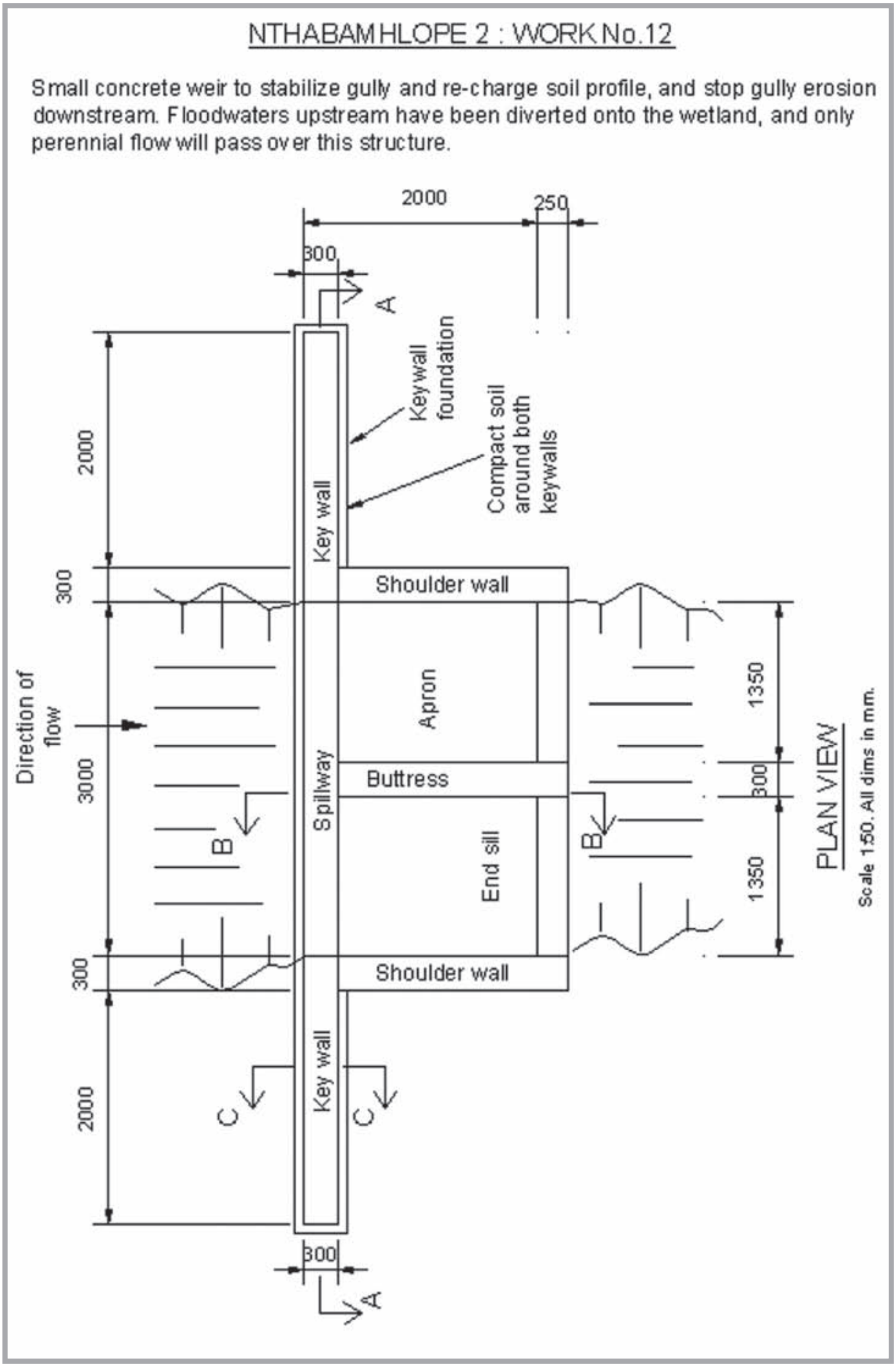


Figure A 3.6(a): Plan view of a small concrete weir to stabilize a gully, recharge the soil profile, and stop gully erosion downstream

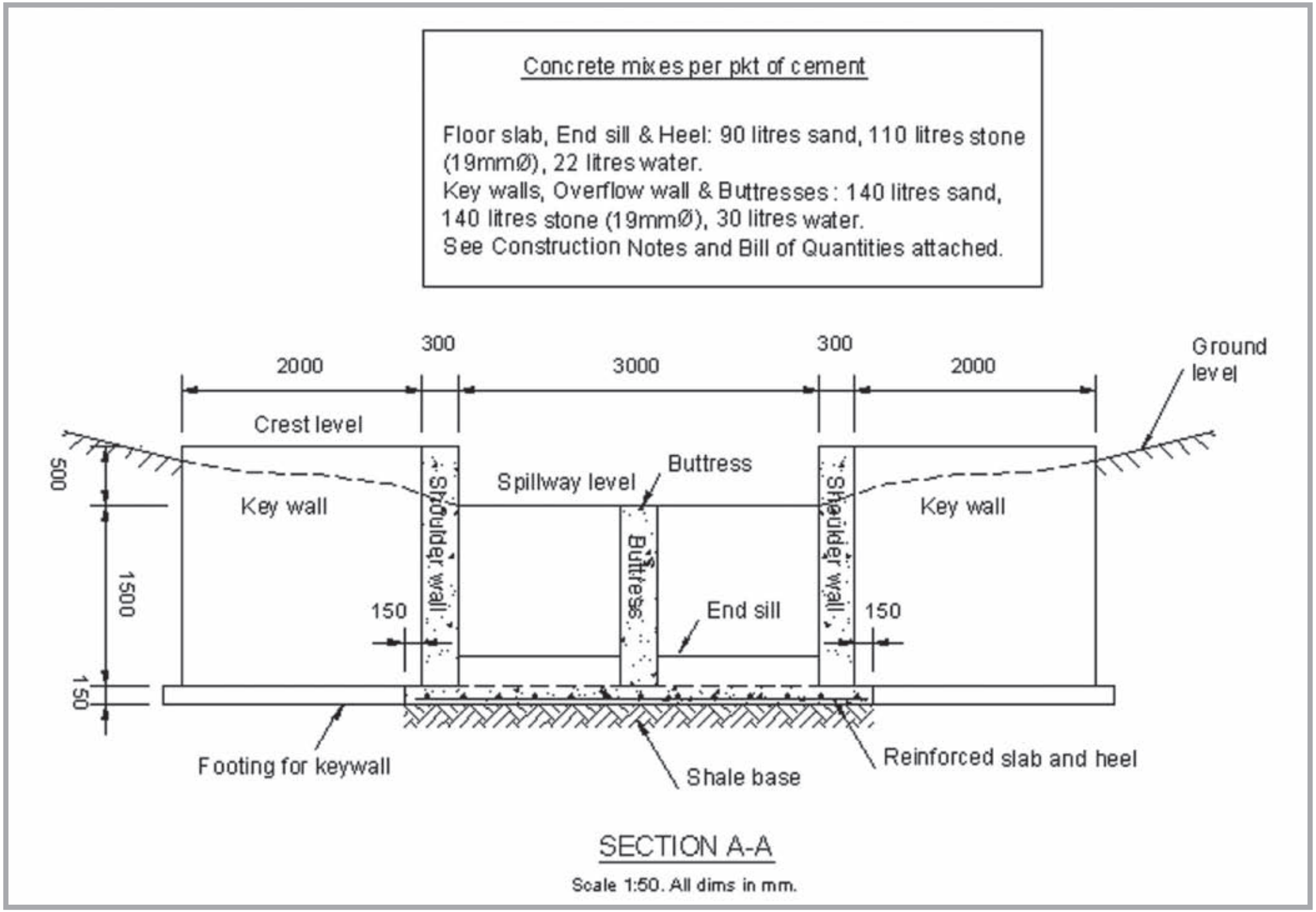
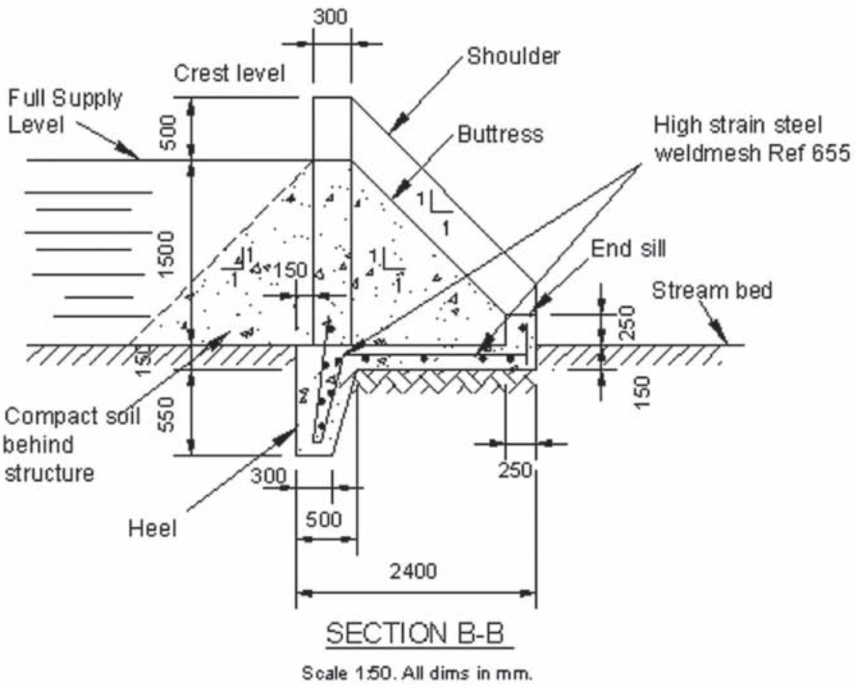


Figure A 3.6(b): Long section of a small concrete weir



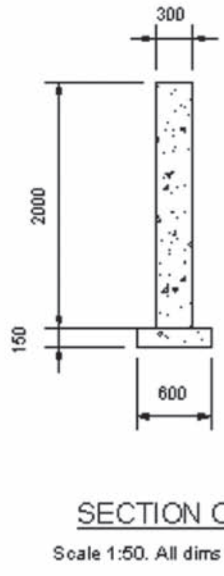


Figure A 3.6(c): Cross section of a small concrete weir

APPENDIX 4:

BEST MANAGEMENT PRACTICES

INTRODUCTION

The purpose of this best management practice document is to ensure that all projects implemented under the Working for Wetlands programme adopt an effective and appropriate approach to wetland rehabilitation and that all activities are compliant with relevant legislation. This includes, as top priority, ensuring that the safety of people involved in the projects is not compromised at any time, that rehabilitation interventions are sustainable and that the objectives of the Expanded Public Works Programme (EPWP) and Working for Wetlands are maximised through the projects.

This document forms part of the agreement between the National Botanical Institute and each project implementer. It consists of two main sections. The first outlines areas in which compliance is required and serves as a reference against which practices can be audited. The second section lists guidelines on best management practices that will be made available to implementers. The use of these guidelines, which have been extensively tested and refined in related programmes, is strongly recommended in order to optimise performance. Given that each project operates under specific conditions, innovation by the implementers, and modification and use of the guidelines where appropriate is encouraged, within the framework of the prescripts in section one.

A full version of the best management practices document, which includes all appendices and the full set of guidelines, will be provided to implementers on CD.

PRESCRIPTS

1. EXPANDED PUBLIC WORKS PROGRAMME

1.1 Compliance with the requirements of the Expanded Public Works Programme

All projects will comply with:

- The Ministerial Determination on Special Public Works Programmes (Government Notice No. R 63, 25 January 2002)
- The Code of Good Practice for Employment and Conditions of Work for Special Public Works Programmes (Government Notice No. R64, 25 January 2002)

1.2 Employment

1.2.1 The implementer will not employ any contractor or staff member who has been dismissed from any other project or expanded public works programme.

1.2.2 The implementer will ensure representivity with respect to race and gender in the selection of staff

1.3 Target groups

1.3.1 Projects will work towards the following targets in all occupational categories, with respect to employment:

- 60% women
- 20% youth (18 to 25 years)
- 2% disabled

1.3.2 Where these targets are not immediately realised, a transformation plan will be put in place to achieve them. The plan will include targets and reasonable timeframes. Progress will be evaluated annually.

1.4 Remuneration

1.4.1 Wherever possible, work is to be task-based. Written approval from the Regional Coordinator is required when this is not possible. Workers are to be paid on the basis of the number of tasks completed.

1.4.2 Employers will pay workers the following rate of pay set for the EPWP:

- Contractor R150 a day or R120 per day if there is a supervisor
- Supervisor – R65 per day
- Driver – R60 per day
- Worker – R39 per day

1.4.3 Contractors will pay the workers the wage agreed for the task.

1.5 Employment contract

1.5.1 Contractors will have an employment contract with each of their workers.

1.5.2 Workers will have the contents of the contract explained to them, and will indicate that they understand its contents

1.5.3 The grievance procedure and disciplinary code will be available and understood by the workers.

1.6 Management structure

1.6.1 The implementer's organogram is to be made available to Working for Wetlands on request

1.6.2 Project management capacity will be adequate to deal with the size of project.

1.6.3 Each contractor may only have one team.

1.6.4 The implementer and its staff may not have any financial involvement with contractors outside of the formal tender agreements.

2. HEALTH AND SAFETY

2.1 Medical examinations

2.1.1 Prior to employment, all employees must undergo a medical examination performed by a registered occupational health practitioner.

2.1.2 Specific job classes will have annual medical examinations or other tests as specified in the Occupational Health and Safety (OHS) Act.

2.1.3 Records of all medical examinations are to be kept by the implementer.

2.2 First aid kit

2.2.1 An adequately equipped first aid kit will be easily accessible at all work sites.

2.2.2 The first aid kit will be kept fully stocked according to the stock list.

2.2.3 All first aid treatment and usage of stock will be recorded in the dressing book kept on site.

2.2.4 The first aid kit will be under control of a trained and competent first aid officer with a current certificate.

2.2.5 Each team will have at least one trained first aid officer and one alternate

2.3 Personal protective equipment and clothing (PPE)

2.3.1 The PPE prescribed in the agreement between the implementer and contractor will be worn at all times during work.

2.3.2 PPE will meet the minimum prescribed standards of quality (SABS approved).

2.3.3 PPE will be replaced when it becomes ineffective through wear and tear.

2.3.4 In order to maintain consistency within the programme, Working for Wetlands will provide designs to be used on the t-shirts worn by the workers

2.4 Occupational health and safety

2.4.1 All relevant OHS standards will be fully implemented.

2.4.2 Each project manager and contractor will have a copy of the OHS Act.

2.4.3 In terms of the OHS Act, the provincial director will be notified of planned construction work.

2.4.4 The designated health and safety officer will also be appointed as the construction safety officer. The appointment letter will be available on site.

2.4.5 Incident reports will be up to date and available. All incidents will be reported within 24 hours to the Regional Coordinator.

2.4.6 All incidents will be investigated by a trained incident investigator within 7 days of the incident.

2.4.7 All near misses will be reported to the Regional Coordinator on a quarterly basis.

2.5 Water Quality

2.5.1 In wetlands with a high risk of pollution, such as those in urban areas, the project manager will take steps to ensure that he/she is aware of changes in water quality. If water quality is found to be so poor that it is a threat to health, the following steps are to be taken:

Workers will be made aware of it immediately.

If unable to supply appropriate PPE, work will stop.

As a general rule, workers will be encouraged not to drink water directly from the wetland.

- Technical Advisors will be informed of poor water quality.

2.6 Substance Abuse

2.6.1 The use of any narcotic substances is not allowed on sites.

2.6.2 The implementer and contractors will ensure that workers do not perform their duties under the influence of any narcotic substances.

2.6.3 Workers who are under the influence during work hours will be dealt with in terms of the appropriate disciplinary procedures

2.6.4 Awareness of the potential dangers of drug use will be created.

3. TRANSPORT

3.1 Compliance of vehicles

3.1.1 All vehicles used by projects will comply with all legal requirements in terms of roadworthiness and licencing

3.1.2 All vehicles will display a valid license at all times.

3.1.3 The following vehicles will display a valid Certificate of Fitness:

- Any truck, bus or minibus where the gross vehicle mass exceeds 3500 kg.
- Any vehicle designed or adapted to convey 12 persons or more, including the driver.
- Vehicles used in transporting persons for reward.

3.1.4 Vehicle size will be suitable for the number of passengers to be transported. For bakkies, the minimum space required per person translates to the following capacity, including driver and passengers in the front and back:

- Short wheelbase bakkie
  - 0,25 m² per person standing = 15 persons
  - 0,35 m² per person seated = 11 persons

- Long wheelbase bakkie
  - 0,25 m² per person standing = 17 persons
  - 0,35 m² per person seated = 13 persons.

3.1.5 Minibus taxis may not carry more than the number of people for which they are certified.

3.2 Daily vehicle checklist

3.2.1 A daily pre-trip vehicle check will be done and recorded by the driver on a suitable checklist. Faults will be recorded. The checklist will be up to date and kept in the vehicle.

3.2.2 The project manager will verify and sign the checklists weekly.

3.2.3 Faults affecting the roadworthiness of the vehicle will be repaired immediately or alternative transport used.

3.3 Driver's licenses and permits

3.3.1 All drivers will have a valid driver's license for the vehicle category used. The competence of all drivers will be verified by the implementer.

3.3.2 All contractor drivers will be in possession of a valid appropriate Professional Driving Permit (PDP) for the category of vehicle.

3.3.3 Drivers will undergo an annual medical check and the results will be filed with the project manager.

3.3.4 Drivers licenses will be verified annually by the local traffic authority or by telephoning 012 303 2718.

3.4 Passenger safety

3.4.1 Vehicles used for transporting workers will have suitable passenger facilities, including as a minimum:

- Sufficiently strong railings to a height of 350 mm above seat surface or 1000 mm above standing surface.
- If installed, benches will be properly secured.
- If installed, canopies or tarpaulins will be properly secured and ventilated.
- Tools, equipment and containers will be suitably secured and isolated from passengers.
- Workers and materials, such as rock, cement etc. may not be transported in the same vehicle at the same time.

3.4.2 Workers using project vehicles will comply with vehicle and passenger safety regulations.

4. ENVIRONMENTAL MANAGEMENT

4.1 Legal requirements

4.1.1 Implementers will comply with legal requirements for authorisation of activities in terms of relevant legislation. Assistance in this regard will be provided by Working for Wetlands technical advisors and regional coordinators.

4.1.2 Environmental impacts from rehabilitation work will be identified, minimised and mitigated.

4.2 Environmental management plan

4.2.1 Each site will have an environmental management plan that identifies potential impacts arising from project activities and the measures that will be put in place to avoid or mitigate these impacts. A correctly and comprehensively completed rehabilitation plan can serve as an environmental management plan.

4.2.2 The project manager will design a site plan for each site that identifies suitable locations for all work, storage, parking, toilet and other areas.

4.2.3 In projects where rocks are to be collected from the surrounding environment, prior approval of the technical advisor will be obtained, with respect to suitable rock types, suitable areas for collection and appropriate collection methods. Rock collection from the natural environment will be included in the environmental management plan.

4.2.4 All litter will be removed and disposed of in an acceptable manner at an appropriate site. Recycling should be encouraged.

4.3 Sanitation

4.3.1 When toilets are not available, a spade and toilet paper will be easily accessible on every site.

4.3.2 Human waste and used toilet paper will be buried at least 20 m from any watercourses or wetlands.

4.3.3 In sensitive areas a portable toilet will be provided on site and the waste removed and disposed of in an acceptable manner.

4.3.4 Clean water and soap will be provided for hand washing.

4.4 Biodiversity

4.4.1 Disturbance of indigenous plants and animals is to be minimised.

4.4.2 Collection of indigenous plants, parts of plants or animals may only take place with the appropriate permits.

4.4.3 Level 2 and 3 structures will take into consideration the migration of fish species.

4.4.4 Bio-engineering methods that involve re-vegetation will, as far as possible, use individuals of local species taken from surrounding areas, in order to avoid or reduce genetic pollution. Collection will not lead to habitat destruction.

4.4.5 Alien species may not be used for re-vegetation unless approved by the technical advisor.

4.5 Work site rehabilitation

4.5.1 All working areas will be rehabilitated once work has been completed and before the team leaves the site. This includes closure and rehabilitation of temporary access routes, removal of foreign material and re-vegetation where necessary.

4.5.2 Any potential erosion risks will be addressed before the team leaves the site.

5. RISK MANAGEMENT

5.1 Hazard Identification and Risk Assessments (HIRA)

5.1.1 In terms of the OHS Act, the HIRA document will be available on site and be understood by every manager and contractor.

5.1.2 An emergency evacuation plan will be available for each work site.

5.2 Fire Precautions

5.2.1 As a rule fires should not be allowed on work sites. When exceptions are made the following precautions will be applied:

- Smoking and fires only allowed in safe demarcated areas designated by the project manager.
- The contractor is responsible for ensuring that the fires are completely extinguished after use.
- Fires are strictly forbidden in fire prohibition areas and in weather conditions that could easily result in the uncontrolled spread of fire.
- Site specific reaction and evacuation rules will be applied in the case of wild fires.
- Basic functional fire fighting equipment will be available at each work site (1 back pack and at least 5 beaters).

- Where fuels and machines are used on site, the prescribed fire extinguishers in working condition will be available.

5.3 Water and flooding

5.3.1 Teams working near open water will have a life jacket on site.

5.3.2 Consideration will be given to the safety of team members working near water who are unable to swim

5.3.3 Given the nature of the work, project managers and contractors will be sensitive to the potential dangers of floods. A highly risk averse approach is to be followed whenever dealing with an actual or potential flood event.

5.3.4 Rainfall in the catchment above the wetland, and flow within the wetland will continually be visually monitored by project managers and contractors. In high rainfall events where there is an increased risk of sudden floods, workers will be withdrawn from the site.

5.4 Wildlife

5.4.1 Where work takes place in areas containing dangerous game, especially nature reserves and national parks, workers will receive training in basic animal behaviour.

5.4.2 In these areas, before work commences each day, the site will be checked for dangerous animals.

5.4.3 A person trained in dangerous animal behaviour will be present and suitably equipped to deal with such threats at all times.

5.4.4 Wherever possible, first aid training should include treatment of snakebite.

6. STORES AND WORKSHOPS

6.1 Stores and workshops

6.1.1 Stores buildings and containers will be secure and provide safe storage space where equipment and materials will not deteriorate.

6.1.2 All stores and workshops will comply with the OHS Act and should show a high standard of housekeeping.

6.2 Fuel and flammable liquids stores

6.2.1 Buildings and containers used for storage of fuel and other flammable liquids will meet the standards laid out in the OHS Act:

- Where proper storage facilities are not available, quantities stored will be limited to the permitted maximum per class:
  - Class I: 45 litres (petrol, thinners)
  - Class II: 270 litres (diesel, lube oils)
- Suitable, safe location of store.
- Suitable construction for safe and secure storage.
- Safe lighting, wiring, earthing and ventilation.
- Proper housekeeping and handling procedures.
- Correct signs and fire-fighting equipment.

6.3 Stock control

6.3.1 The receipt and issue of all equipment and supplies will be adequately controlled.

6.3.2 All issues and receipts will be recorded.

6.3.3 The balance of stock recorded will correspond at all times with stock in the stores.

6.3.4 Designated managers will verify stock periodically and an annual stocktaking will be done.

6.3.5 The proper procedures will be followed in disposing of unserviceable or surplus items.

6.4 Storage at contractor's facilities or houses

6.4.1 Where contractors cannot make use of proper dedicated stores, all equipment and supplies will be safely and securely stored with controlled access.

7. METHOD OF WORK

7.1 Implementation

7.1.1 All work will be based on an approved rehabilitation plan

7.1.2 Interventions will be carried out according to the contract documentation and design specifications.

7.1.3 All teams will work on task based contracts

7.1.4 Daily tasks will be set and actual production will be measured and recorded.

7.1.5 A construction supervisor will be appointed. The appointment letter will be available on site.

7.1.6 All persons on site, including visitors, will comply with the OHS Act and wear the required PPE.

7.1.7 Work sites will be properly planned and marked out, preferably in collaboration with the contractors. Areas will be demarcated for vehicle access and parking, off-loading, mixing etc.

7.1.8 Unloading of construction material will be done on a flat area. The unloading area will be marked with barrier tape.

7.1.9 No unauthorized person may enter the work site.

7.1.10 The location and position of all rehabilitation interventions will be precisely demarcated by the project manager, according to the rehabilitation plan.

7.1.11 Dimensions of rehabilitation interventions will also be marked out where appropriate (e.g. depth of an excavation).

7.1.12 Any excavation deeper than 1.8m will comply with the relevant sections of the OHS Act.

7.1.13 Implementation of all interventions will be done with a focus on cost-effectiveness and efficiency, while maintaining quality and appropriateness

7.2 Verification of work

7.2.1 Actual work done (volumes and areas) will be verified and recorded. The implementer is responsible for ensuring that contractors' invoices correspond to actual production.

7.2.2 The head of the implementer will verify a minimum of 5% of the work done monthly and record these checks.

7.2.3 On completion of an intervention, a certificate of completion will be submitted to the regional coordinator by the implementer.

7.3 Corrective action for sub-standard work

7.3.1 Payment will not be made for work that does not comply with contract specifications.

7.3.2 A record will be kept of non-compliance to standards and poor performance.

7.3.3 Copies of instructions issued to contractors to correct deficiencies will be kept.

7.4 Maintenance

7.4.1 Maintenance of structures will be planned and budgeted for.

7.5 Efficient team operation

7.5.1 Operational planning for each site will be evident. Different tasks will be co-ordinated in an efficient manner for optimum productivity.

7.5.2 Tool use and tasks will be adapted to site-specific requirements.

8. MINIMUM STANDARDS FOR CONSTRUCTION

8.1 Gabions

8.1.1 Gabion work will be done according to design specifications.

8.1.2 Minimum 2.2 mm double galvanised wire will be used, with a mesh size that is appropriate to the size of the rock being used.

8.1.3 Support and binding wire will be of the same specification as the gabion baskets.

8.1.4 Lacing will be done according to specification.

8.1.5 Support wires will be in place (bracing).

8.1.6 All adjoining baskets will be laced together.

8.1.7 Geotextile will line all faces of the gabion baskets that are exposed to earth and certain water exposed sides.

8.1.8 Water corrosivity will be determined at each site. If necessary, PVC coated gabions will be used.

8.1.9 Soil dispersivity will be determined at each site. If dispersive soils are detected, the technical advisor will be contacted.

8.1.10 Density of fill material will satisfy the gabion design. Clay bricks, weathered rock and sandstone and shale may not be used as fill material. Any unconventional fill material will be approved by the technical advisor.

8.1.11 Fill material will not be smaller than mesh size.

8.1.12 Workers will be trained in gabion construction by an accredited organisation.

8.2 Concrete work

8.2.1 Concrete mix will be according to specifications and correct MPA concrete will be used. Manufacturer's directions for mixing, consistency and treatment after pouring will be complied with.

8.2.2 Cement will be stored in dry conditions for no longer than six weeks after delivery.

8.2.3 When cement is stored temporarily infield it will be kept on a dry waterproof base with a waterproof cover.

8.2.4 A demarcated site at least 20 m away from water/wetland edge will be used for cement mixing. Water runoff will be contained and leaching to ground water prevented. Mixing will be done in such a way as to limit damage to surrounding vegetation.

8.2.5 Water used for mixing purposes will be of suitable quality.

8.2.6 Construction using shuttering will not take place at more than 1 m height increments.

8.2.7 Reinforcing will be used according to specification.

8.2.8 Concrete will be mixed and used on the same day.

8.3 Geo cells

8.3.1 Geo cells will not be used in conditions that exceed their design specifications.

8.3.2 Geo cell material will be UV resistant.

8.3.3 Geo cells will be anchored in by the 'trench' method and in such a way that prevents undermining of the cells.

8.3.4 Fill material will conform to the design specifications. The following general rules will be applied:

- If soil is used to fill the cells, it will be re-vegetated immediately,
- If concrete is used to fill the cells, some degree of permeability of the structure will be permitted. If concrete is used as fill, concrete baffles will be inserted. Rock is not suitable for this purpose.

8.4 Earth Works

8.4.1 Excavations may not exceed 1.8 m depth without shoring and reinforcement.

8.4.2 Excavation and compaction will comply with design specifications

8.4.3 The technical advisor will be consulted for work undertaken in dispersive, unstable and organic soils.

9. TOOLS AND EQUIPMENT

9.1 Hand tools

9.1.1 Hand tools will be suited to the nature of the work.

9.1.2 Tools will have correct, properly secured handles and will be in safe working order.

9.1.3 Tools will be properly maintained and sharpened regularly.

9.1.4 Tools will be used in the correct and safe manner.

9.2 Concrete mixers, compactors and other machinery

9.2.1 All machinery will have the required machine guards.

9.2.2 All nip points, pulleys, fan belts and revolving parts will be suitably enclosed.

9.2.3 Power take offs will be provided with suitable covers in good condition. Covers will be chained to non-revolving machinery.

9.2.4 Only trained operators may operate machinery, and will wear the required PPE.

9.2.5 Workers, other than machine operators, will not be within two spade lengths of operating machinery

9.2.6 Concrete mixers may only operate on a stable, level site.

9.2.7 Correct re-fuelling procedures are to be followed and proper containers used for fuel.

9.2.8 Machinery will be in good working order. If owned by the implementer or contractor there will be a maintenance schedule and record for the machinery.

9.2.9 Machinery will be used safely and efficiently at all times.

9.3 In-field fuel site

9.3.1 A demarcated cleared area will be used to store fuel. At least one fire extinguisher will be in this area.

9.3.2 The site will be at least 6 m from rest areas. Refuelling spills will be cleaned up immediately and reported to the manager. Waste from the spill will be appropriately disposed of.

9.3.3 Fire-fighting equipment will be at least 3 m from the fuel site.

9.3.4 Mixing of lubricants will be on a non-pervious layer in a demarcated area at least 20 m from the wetland edge.

10. ADMINISTRATION

10.1 Contractors documents

10.1.1 The contract between the implementer and the contractor will be readily accessible to project managers and contractors. Both parties will understand it.

10.1.2 Each contract will be allocated a unique identity number.

10.1.3 The following will form part of the contract between the implementer and contractors:

- Rehabilitation specifications
- Technical drawings of the structures, including a list of the material required.
- Environmental management plan
- Site plans

10.2 Records, data and quality control

10.2.1 Each contractor will maintain an up to date timesheet of daily worker attendance. Details of new appointments will be submitted to the implementer. Timesheets will be available for inspection by any Working for Wetlands staff member.

10.2.2 A record will be kept of equipment and consumables issued against the contract document.

10.2.3 A quality control sheet completed by the implementer will record ongoing quality checks and the final check before payment. This will certify that work done complies with contract specifications.

10.3 Payments

10.3.1 The implementer will ensure that the contractors' workers have been paid on time and in the amount to which they are entitled. Proof of such payment, signed by all team members, will be submitted to Working for Wetlands on request.

10.3.2 Disabled team members will be paid the same amount for the days worked as other workers, and the contractor will claim the half disabled wage back from the implementer.

10.3.3 In situations where tasks are completed before the expected time period, workers will still be paid for the original number of days quoted. For example, if a team planned to take 15 days to complete a task that is subsequently accomplished in 10 days, the contractor will still pay the workers for the full 15 days.

10.3.4 Each worker will receive a payment advice that complies with the requirements of the EPWP documents listed in section 1. A copy of all contracts and documentation relating to payments to workers will be retained by the contractor and implementer. This documentation will provide proof of receipt of payment by workers, and will be made available to Working for Wetlands on request.

11. REHABILITATION PLAN

11.1 Purpose of rehabilitation plan

11.1.1 The purpose of the rehabilitation plan is to provide a robust and legal basis from which to implement rehabilitation interventions. An approved rehabilitation plan demonstrates that the correct information has been gathered in assessing the causes and effects of degradation and that rehabilitation interventions have been developed appropriately. The plan can also double as an environmental management plan and as a source document for various authorizations that may be required.

11.1.2 Implementation of rehabilitation interventions may not begin until the rehabilitation plan has been approved by the technical advisor.

11.1.3 Any amendments to rehabilitation plans during the course of the project must be approved by the technical advisor prior to their implementation and appended to the original document. New or modified rehabilitation interventions that have not been approved by the technical advisor will be considered unauthorised expenditure, and payment for this work may be withheld by NBI

11.1.4 At the end of each year the rehabilitation plan must be updated with the following information and submitted to the technical advisor:

- All modifications to the rehabilitation plan during the year
- Completion certificates for all structures completed.
- Photographs of the completed work.
- Actual cost for each structure, including person day breakdown.
- Monitoring sheets and photographs.
- Details of any maintenance work completed.
- Actual cost, including person day breakdown, of maintenance work.
- Any other relevant information

11.2 Monitoring against the rehabilitation plan

11.2.1 The following minimum monitoring will be completed by the implementer:

- Photograph of each problem before work starts.
- Fixed point photograph at completion of the work.
- Fixed point photography on a monthly basis for the first 3 months after the structure has been completed.
- Fixed point photography every 3 months for the remainder of the year.
- Fixed point photography on a yearly basis for the remainder of the contract
- During each of the visits a monitoring sheet will be filled in.

12. COMMUNICATION

12.1 Implementers' forum

12.1.1 A representative from each implementer is required to attend quarterly meetings of the implementers' forum. The purpose of these meetings is to share information, develop links between projects and enhance communication between Working for Wetlands and its implementers. Venues for these meetings will rotate between projects. A national health and safety meeting will form part of this forum.

12.2 Working for Wetlands logo

12.2.1 Working for Wetlands encourages its implementers to use the programme's logo in promoting the programme and wetland conservation and sustainable use in general. However, written permission should be obtained from the programme manager before the logo is used on anything other than the prescribed signage or workers' t-shirts.

12.3 Signage

12.3.1 Each project will erect at least one gate board per property on which work is done and one billboard in a prominent position. The basic designs for this signage will be those prescribed by Working for Wetlands, with provision for the addition of project-specific information.

13. TRAINING

13.1 Training entitlement

13.1.1 In compliance with EPWP requirements, each worker will be entitled to a minimum of two days training for every 22 days worked.

13.1.2 All training funded through the Department of Labour will be planned in conjunction with the department's provincial representatives. A minimum of 50% of all training must be accredited, and all first aid and health and safety training must be accredited.

13.2 Induction

13.2.1 All employees will be inducted within 3 months of starting on the project.

13.3 Wetland Awareness

13.3.1 All project personnel will be trained in basic wetland awareness, including a basic understanding of the components of wetlands, how wetlands function, the benefits they provide, why they need to be conserved and used sustainably, and the importance of rehabilitation in contributing to wetland conservation and sustainable use

13.4 Health and Safety training

13.4.1 The following minimum levels of training are required with respect to health and safety:

- All workers and contractors must successfully complete phase 1 health and safety training.
- All project managers must successfully complete phase 2 health and safety training.

13.5 First aid training

13.5.1 Two first aid officers will be trained per team.

13.6 Training Records

13.6.1 Training attendance records will be kept by the implementer. The implementer will be responsible for obtaining all contractor and worker training information.

13.7 Deviations from business plan

13.7.1 Any training not listed in the business plan must be approved by the regional coordinator or social development and training coordinator.

14. SOCIAL DEVELOPMENT

14.1 Primary health

14.1.1 An HIV/Aids information session will be held with each team in conjunction with an approved institution at least once every six months.

14.1.2 There will be a minimum of one HIV/Aids peer educator per team.

14.1.3 Measures aimed at reducing the spread of HIV/Aids, including condoms, literature and posters, should be available to all workers.

14.1.4 Access of workers to local clinics should be facilitated wherever possible.

14.1.5 Training will, where possible, include other aspects of primary health, including nutrition, reproductive health and hygiene

14.2 World Wetlands Day

14.2.1 World Wetlands Day should be celebrated in an appropriate way by each implementer and include all project personnel

14.2.2 Each project will hold at least one open day per year, targeting surrounding communities, stakeholders and project partners

15. ADVISORY COMMITEES AND WORKER PARTICIPATION

15.1 Active employee and contractor participation in project management

15.1.1 Workers will have a formalised forum through which they can make inputs into the overall management of the project (e.g. a workplace committee).

15.2 Active forums for public participation in projects (Advisory Committees)

15.2.1 Each project will have a functional advisory committee, based on the guidelines provided by Working for Wetlands.

15.2.2 Advisory committees will represent all communities from which workers are drawn and in which work is being done.

15.2.3 Meetings will be run according to the Working for Wetlands guidelines for advisory committees

15.2.4 Minutes of advisory committee meetings will be made available to Working for Wetlands on request

15.2.5 Advisory committees will assist in the identification of potential contractors and target groups for employment.

15.2.6 Community-based forums should participate in advisory committees in order to contribute to the prioritisation and implementation of social development activities

16. ERADICATION OF INVASIVE ALIEN PLANTS

16.1 Compliance with Working for Water norms

16.1.1 Where project activities include the eradication of invasive alien plants, Working for Water guidelines and policies will be adhered to.

16.1.2 Any invasive alien plant clearing undertaken through Working for Wetlands projects will be registered on the Working for Water Information Management System.

GUIDELINES

The following guidelines and recommended templates will be made available to all implementers:

1. Guidelines for completing Working for Wetlands business plans and project implementation plans

2. Working for Wetlands risk assessment framework

3. Project management tools:

- Daily attendance register
- Vehicle check sheet
- Production sheet
- Project manager's inspection sheet
- Implementer's inspection sheet
- Incident report for near misses
- Format for toolbox talk minutes
- Receipt of goods
- Consumables used sheet
- Pay sheet
- Personnel update sheet
- Contractor's invoice
- Filing of information
- Safety plan and emergency numbers
- Tender document
- Contractor safety policy
- Risk assessment
- Registration form for Compensation for Occupational Injuries and Diseases Act
- OHS Act notification of construction work
- Construction supervisor appointment letter
- Health and safety construction representative appointment letter
- First aid officer appointment letter
- First aid kit contents
- Training matrix
- Record of completed training
- Grievance procedure and grievance form
- PPE matrix
- Record of PPE issued
- Disciplinary procedure
- Contractor and worker contracts

Working for Wetlands

Working for Wetlands (WfWetlands) uses wetland rehabilitation as a vehicle for both poverty alleviation and the wise use of wetlands, following an approach that centres on cooperative governance and partnerships. The Programme is managed by the South African National Biodiversity Institute (SANBI) on behalf of the departments of Environmental Affairs and Tourism (DEAT), Agriculture (DoA), and Water Affairs and Forestry (DWAF). With funding provided by DEAT and DWAF, WfWetlands forms part of the Expanded Public Works Programme (EPWP), which seeks to draw unemployed people into the productive sector of South Africa's economy, gaining skills while they work and increase their capacity to earn income. Rehabilitation projects maximise employment creation, create and support small businesses, and transfer relevant and marketable skills to workers.

Working for Wetlands
South African National Biodiversity Institute
Private Bag X101
Pretoria, 0001
Tel: 012 843 5191
Fax: 012 843 5250
wetlands@sanbi.org
http://wetlands.sanbi.org

The Water Research Commission

The Water Research Commission (WRC) aims to develop and support a representative and sustainable water-related knowledge base in South Africa, with the necessary competencies and capacity vested in the corps of experts and practitioners within academia, science councils, other research organisations and government organisations (central, provincial and local) that serve the water sector. The WRC provides applied knowledge and water-related innovations by translating needs into research ideas and, in turn, transferring research results and disseminating knowledge and new technology-based products and processes to end-users. By supporting water-related innovation and its commercialisation where applicable, the WRC seeks to provide further benefit for the country.

Water Research Commission
Private Bag X03
Gezina, 0031
Tel: 012 330 0340
Fax: 012 331 2565
info@wrc.org.za
www.wrc.org.za

University of KwaZulu-Natal

William (Fred) Ellery and Donovan Kotze of the University of KwaZulu-Natal (UKZN) managed the programme that supports the production of this component of the *WET-Management* Series. They can be contacted at:
f.ellery@ru.ac.za
kotzed@ukzn.ac.za

School of Environmental Sciences
University of KwaZulu-Natal
Durban, 4041
Tel: 031 260 1278
Fax: 031 260 1391
www.ukzn.ac.za

The institutions whose logos appear on this page have made a substantial contribution to the production of this document.

Titles in the Wetland Management Series

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