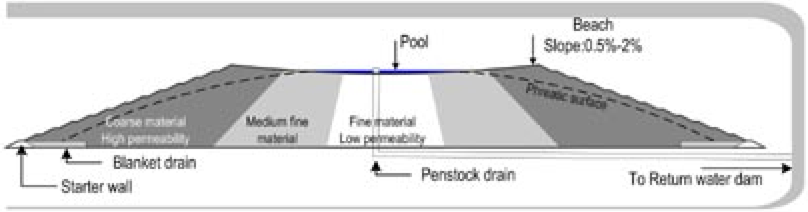
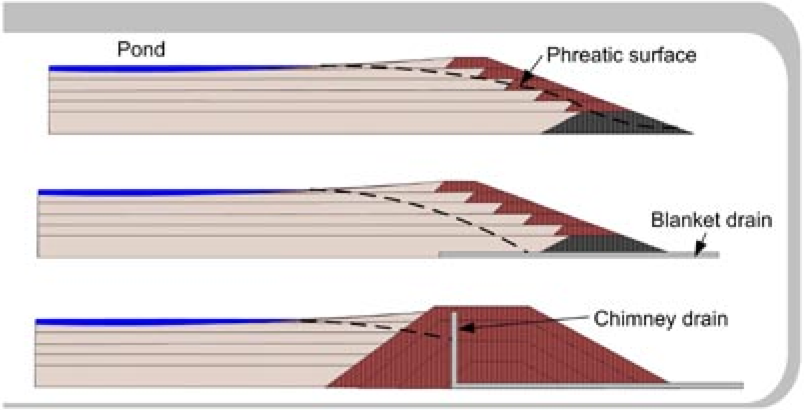
TECHNICAL

IMPOUNDMENT STABILITY
EROSION CONTROL PRACTICES
HYDROLOGICAL CYCLE
WATERCOURSE AND WETLAND DESIGN
LAND-USES ASSOCIATED WITH CERTAIN SLOPES

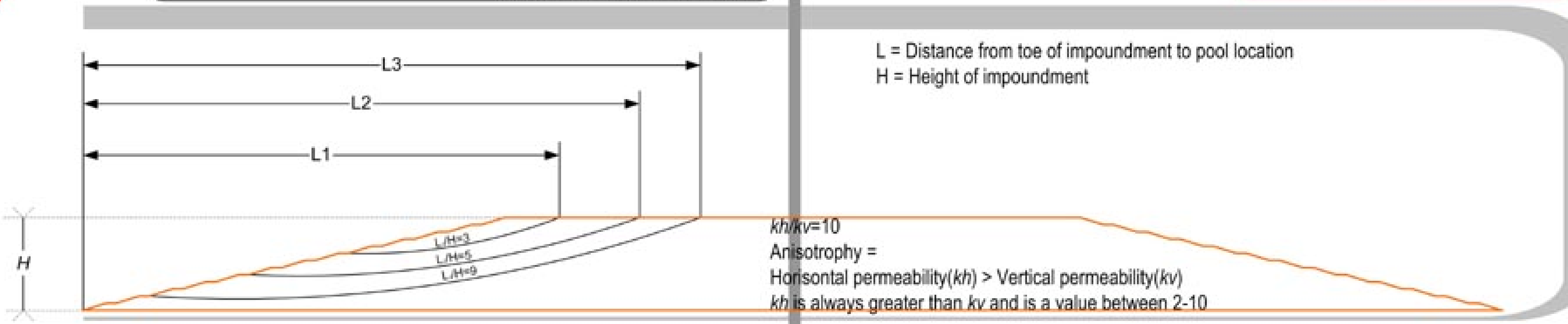
1 SECTION THROUGH A TDF ILLUSTRATING INTERNAL ELEMENTS



2 INTERNAL DRAINAGE SYSTEMS AND EFFECT ON PHREATIC SURFACE (FROM CHAMBER OF MINES OF SOUTH AFRICA 1996)



3 RELATIONSHIP BETWEEN POOL LOCATION AND PHREATIC SURFACE (FROM VICK 1983)



Introduction

The first goal of any impoundment design should be to accommodate the deposit within the parameters of safety and stability. The breaching of stability will have considerable environmental and economic impacts as well as potential loss of life.

Factors influencing stability

The most important factor influencing stability is the position of the phreatic surface (similar to a water table) in the impoundment (fig 4-1). The phreatic surface is determined by the position of the pool in the center of the impoundment. If the the pool is allowed too close to the outer edge, an increased phreatic surface could jeopardise the stability of the embankment. In order to control the phreatic surface, blanket drains and chimney drains are installed. The penstock is responsible for controlling the pool size (fig 4-2).

The determination of the phreatic surface location for an upstream impoundment (fig 4-4)is in many cases more complex than for other impoundments. Some important factors influencing the phreatic surface location is the following:

- Pond location
- Lateral and vertical permeability variations of the tailings
- Anisotropic permeability of tailings
- Boundary conditions (Vick 1983:177)

A common principle for determining the phreatic surface is illustrated in figure 4-3. A L/H value greater than 9 is desired. Values of 5 and smaller pose serious stability problems.

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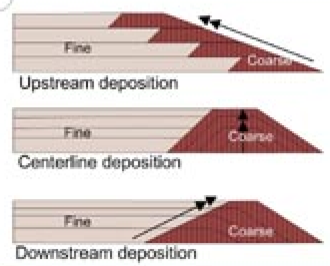


Artificial wind breaks

In order to reduce wind velocity and in effect reduce erosion, a number of artificial wind break options can be implemented.

- Reed fences
- Stone mulching

Ridge ploughing of the surface (Scorgie & Randell 2001) (fig 4-5)

Ridge ploughing is considered an effective short-term measure to control dust at the top of the impoundment. Particles lifted from the crest by a slight increase of wind velocity, is immediately deposited in the adjacent valley (*ibid*) (fig 4-7).

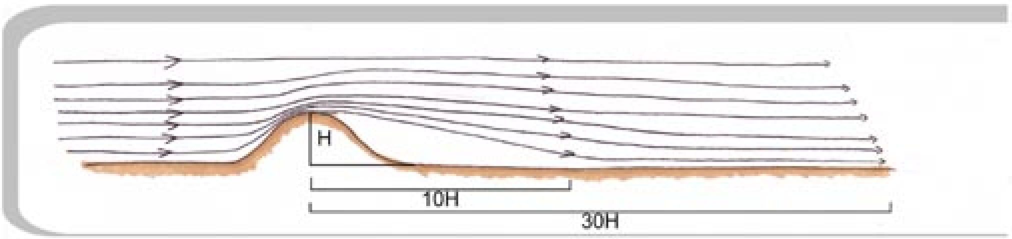
To be most effective, barriers should always be perpendicular to the angle of the predominant wind (*ibid*).

The presence of a barrier results in an increase in wind speed over the crest and a reduction in velocity on the leeward side of the barrier. Observations confirmed that the maximum reduction in wind velocity occurs within 10H of the downwind leeward side. The flow of air becomes fairly normal again at about 30H from the barrier (H being the height of the barrier) (*ibid*) (fig 4-6).

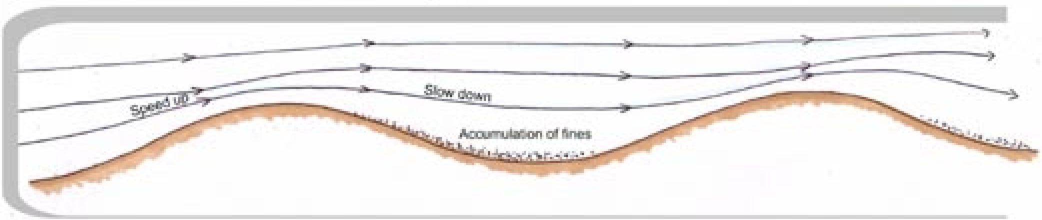
Vegetation as wind erosion control practise

A dense vegetation cover is the most sustainable and long-term solution. In order to establish an effective vegetation cover on a TDF, a suitable growth medium and adequate moisture is required. This criteria is often not met, thus implying a combination of wind erosion control practices.

4-6 THE EFFECT OF WIND BARRIERS ON WIND VELOCITY

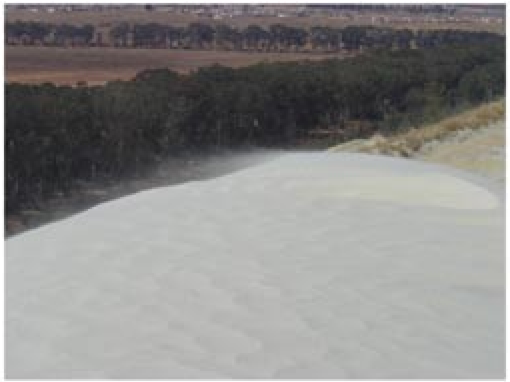


4-7 DEPOSITION OF FINES IN VALLEY



4-5 RIDGE PLOUGHING

4-8 WIND BLOWN PARTICLES



Rock cladding

Fine rock

The placement of rock on the surface of side slopes, have proven very successful in the reduction of wind and water erosion. Research indicates that the placement of a 300 mm layer of fine rock (< 150 mm diameter) onto the in-situ, unprepared side slopes, reduces water erosion by ±60%, when compared to erosion from an untreated slope. A significant improvement in performance occurs when the surface is appropriately leveled and compacted before application. A reduction of ±90% is possible if the surface is prepared (Smith 2004) (fig 4-10).

A 300 mm layer of rock virtually eliminates wind erosion from the side slopes (*ibid*). Protection from wind erosion arises by destroying the kinetic energy of the wind by forming vortices in the lee of each stone chip or pebble (Chamber of Mines of South Africa 1996).

Coarse rock

A coarse rock (average 150 mm diameter) layer of 300 mm resulted in reducing water erosion by 50%-60%. An increase to 90% is possible if the surface is prepared with the placement of a geofabric and the filling of voids between the coarse rock with smaller particles. The cost of surface preparation is significantly higher and could become an uneconomical practice (Smith 2004).

These tests were conducted on the status quo slope profile scenario of 33º. One can assume that the effectiveness of rock cladding will increase with the reduction in slope angle. The implication might be that a layer of less than 300 mm is needed to achieve the same results. This will have significant cost benefits if that is the case. For the purpose of this thesis, a minimum of 300 mm rock layer is proposed.

Planting in a rock layer

Smith (2004:13) proposes a 'vegetation pocket' (fig 4-9) to establish vegetation on a side slope capped with rock. The installation is relatively expensive, but is necessary to penetrate through the compacted surface.

Topsoil

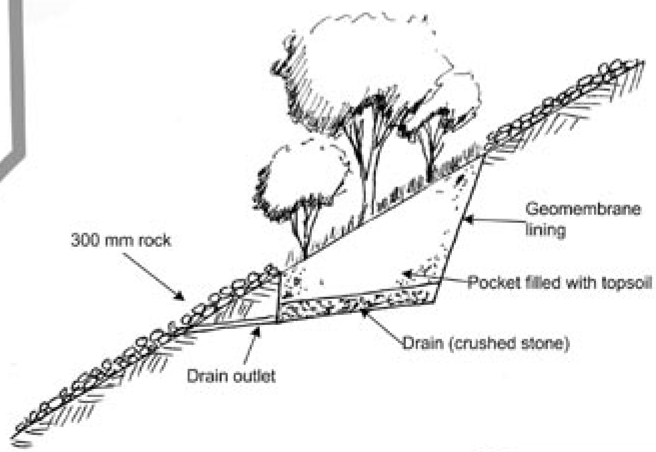
To overcome the installation of vegetation pockets, it is recommended to cap the side slope with a layer of topsoil. The topsoil should either be scarped off the construction surface before construction and stored as stockpiles, or it should be imported from elsewhere. Both options are relatively expensive and classified as energy intensive and unsustainable practices.

A mixture of topsoil and waste rock was applied on the Daggafontein Ergo TDF near Springs and proves reasonably effective in terms of erosion prevention. A layer of 500 mm is spread over the 18º inclined slope. Fertiliser and grass seeds are applied in situ. The layer aims at providing a suitable growth medium that will retain enough moisture to sustain a healthy and dense vegetation cover. Success is yet to be proven.

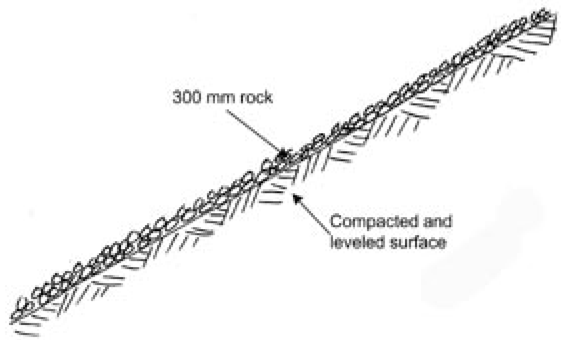
The required topsoil thickness according to proposed end-land use objectives are as following:

- Arable - 750 mm
- Grazing - 350 mm
- Wilderness - 250 mm (Chamber of Mines of South Africa 1996)

4-9 VEGETATION POCKET IN ROCK CLADDING (FROM SMITH 2004)



4-10 ROCK CLADDING



i1 IN SITU VEGETATION (KNOLL 2004)

i2 RIDGE PLOUGHING AND VEGETATION

i3 ARID CONDITIONS ON TDF

In situ planting of tailings

The re-vegetation of side slopes pursues a resolution for long-term instability and erosion issues.

Traditional practices involve the *in situ* propagation of indigenous grass species. Some specialists believe that grassing is an effective but short-term solution to dust control but will not contain seepage or achieve TDF closure (Knoll 2004) (fig 4-11).

Apparently only 50% cover remains three years after irrigation and fertilisation have ceased. It is difficult to obtain indigenous grass seeds to create the level of diversity needed to establish a preferable pasture grass. Large quantities of water and fertiliser are needed to establish pasture grass and irrigation promotes further leaching of pollutants (*ibid*).

Isabel Weiersbye of the School of Animal, Plant and Enviroscience at Wits states:"...the nutrient cycle necessary to get the whole ecosystem functioning and to ensure that cover is retained cannot be kick-started with grasses, as it can with woody species, because grasses produce less organic litter and this is low in nitrogen and phosphorus. In the event of fire further nutrient loss is experienced (*ibid* p25)." Weiersbye also states that the only way to maintain grassed slopes in peak condition is to make continual inputs of compost and fertilisers and to intersperse with a healthy population of legumes (*ibid*).

Weiersbye is the programme leader of an initiative to test the performance of woody, semi-woody and the containment of pollution from gold slimes dams, their effectiveness as windbreaks and in dust and hydrological control on TDFs.

This study will increase the success of rehabilitation on TDFs in South Africa and will probably reduce associated costs. This knowledge can also be applied to the rehabilitation of platinum overburden. Tailings of platinum mines are less toxic then gold mines residue due to the difference in processing techniques and the absence of cyanide in platinum tailings.

In situ planting requires little preparation in terms of soil amelioration and earthworks. Any supplementing amendments can improve success. One such practice is ridge ploughing (fig 4-12). Ridge ploughing breaks up the surface and improves water infiltration, so-called 'micro-catchments' occur between the ploughed ridges and wind erosion is reduced by a certain percentage.

Conclusion

A combination of the discussed surface coverings is recommended to achieve a diverse surface cover, capable of withstanding local erosion forces as well as establishing a regenerative, self-sustaining ecosystem. It is important to note that each cover is particularly effective in a specific scenario. The application should follow a strategically planned design that responds to the opportunities and constraints of the environment and associated elements in order to achieve the required end-land use.

HYDROLOGICAL CYCLE OF AN ARTIFICIAL SYSTEM

Supply

The supply of water from the plant is the greatest contribution to the system. Water is deposited, along with the tailings onto the TDF via cyclone or spigot deposition.

Precipitation also contributes water to the system. The system is designed to control excessive amounts of precipitation in order to contain contaminated water on the site for treatment in order to minimise pollution of natural water systems.

Convey

The conveyance of water in an artificial system, occurs in a number of ways. The greatest volume of water is displaced from the top surface to the return water dam via the penstock drain. Blanket drains drain the TDF internally, while surface run-off is conveyed with surface channels down the slopes. A solution trench is installed around the perimeter of the TDF. The internal drains and penstock drain connect to the solution trench and water is directed to the return water dam.

The approach is to dispose of water in and on the TDF as quick as possible without excessive erosion and infiltration in order to minimise pollution of surface and ground water.

Store

The TDF is capable of storing water on its top surface as well as retaining capillary water within the structure. Stability of the TDF is dependent on the quantity and movement of water in the structure, thus placing importance on the control and monitoring of water.

The return water dam's primary function is to retain contaminated water as well as controlling excessive runoff from the TDF. During the operational phase, water is returned to the plant to be used in the extraction process. Any water that is lost through the cycle have to be replaced. This is often an expensive exercise if water is bought from the local water supplier.

Treat

Contaminated water can be treated either with chemical or biological treatment.

Chemical treatment is often expensive and not an option except in extreme cases where quick results is necessary.

Biological treatment involves the implementation of wetlands and sediment basins or other biological treatment facilities. Systems such as this are very sensitive and depends on accurate control and monitoring of water quantities and quality.

Dispose

In a polluted system such as this, the disposal of water into an uncontaminated system must be strictly prevented. Water is lost through evaporation, evapo-transpiration and infiltration.

Even infiltration and seepage must be restricted either with the installation of a liner in order to reduce contamination of sub-surface waterbodies. Thus the safest and cleanest disposal methods is via evaporation and evapo-transpiration.

HYDROLOGICAL CYCLE OF A CLOSED ARTIFICIAL SYSTEM

SUPPLY

A natural system is dependent on precipitation and purged water tables for water supply. Subsequent to decommissioning, the whole system is dependent on precipitation only. As the system was designed to accumulate and dispose water as quick as possible, the rehabilitated system has difficulty to retain water in order to sustain vegetation growth. Thus the new system should be designed to make the most of the available water. The system should be altered from a concentrate-and-disposal-strategy to a retain-and-absorb-strategy. Evaporation and run-off should be reduced to a minimum and infiltration for plant-uptake encouraged to a maximum.

CONVEY

The systems that was used for artificial conveyance can be adopted as natural watercourses with minor alterations. Access routes and roads can also be used as watercourses, thus emphasising the importance of proper planning and locating of access routes prior to rehabilitation.

The construction of conveyance systems should encourage vegetation growth on its banks as well as being erosion resistant under the force of flowing water. Channel dimensions, lengths and gradients are factors that should be constructed appropriately to the system as a whole.

STORE

Water storage should occur in the root zone in order to present water for plant utilisation. To achieve containment of water in the top strata, it is necessary to apply suitable amelioration, enhancing absorption capacity to sustain plant growth.

If stability is ensured, water can be stored on top of the TDF. It is possible to establish a wetland system if sufficient water can be retained.

The return water dam can continue its function as an open water body presenting the opportunities for recreation and faunal habitat.

TREAT

The only treatment that exist in a natural system is biological treatment. Biological treatment occurs in systems that are rich in life. The aim of a treatment facility is to trap heavy metals and extract excessive nutrients in order to increase water quality. It should be a priority to aerate water before it enters the storage facility to satisfy the Biological Oxygen Demand (BOD). Fringe vegetation need to be harvested and discarded periodically in order to dispose of the heavy metals taken up by the vegetation.

DISPOSE

The disposal of water into the natural system should only be considered if water quality is similar to the quality of the adjacent, natural system. For this to happen the following parameters should be monitored:

- pH level
- Nutrient content
- Heavy metal concentration
- Oxygen concentration
- Organisms

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Introduction

Following the discussion on artificial water cycles and conversion to a natural, self-sustaining system, it necessary to set guidelines for the design of a pseudo-natural hydrological system.

Longitudinal profiles

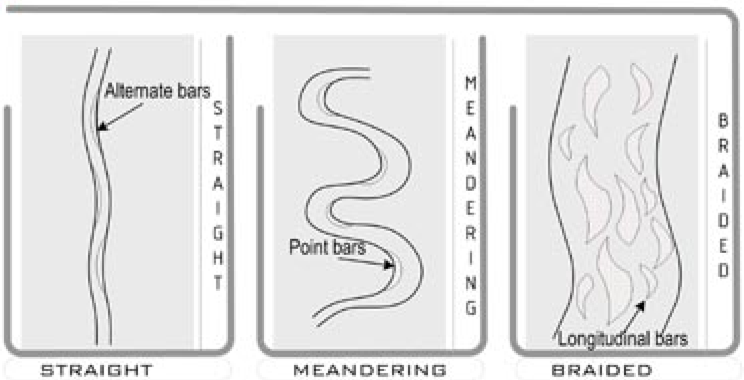
Longitudinal profiles represent the stream's gradient throughout its length. A simplistic portrayal indicates that channels adhere to a general concave profile with steep slopes in the headwaters and gentler slopes in lower regions with increasingly flat sections towards the mouth (fig 4-14). However, natural channels are seldom, if ever smooth and involves a degree of irregularity depending on certain influences.

Channel profiles

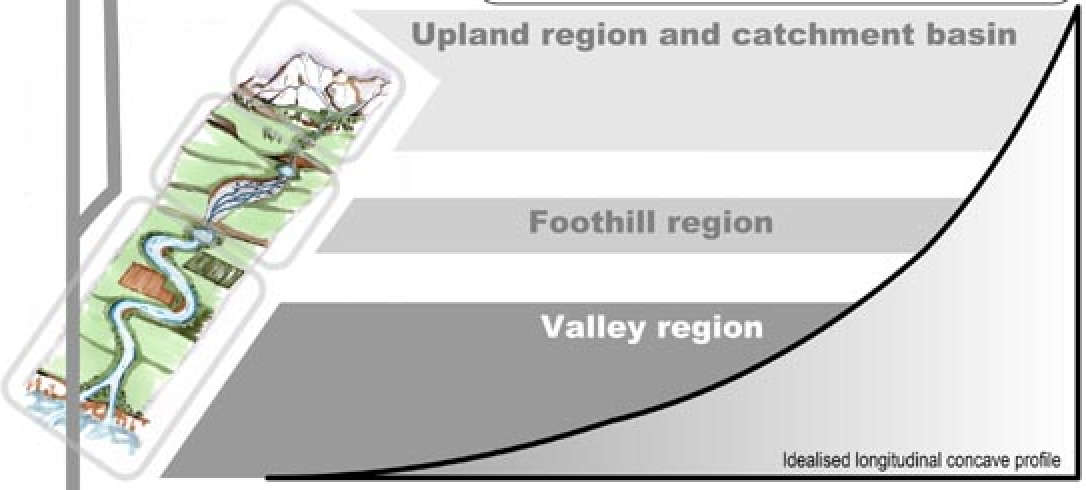
"As soon as water becomes confined in a channel it starts to modify the shape of that channel, both in cross-section and in gradient" (Selby 1985:260).

Cross-valley profiles are just as irregular and diverse as longitudinal profiles. Cross-valley profiles resemble longitudinal profiles in upland regions with similar steep, rock or talus slopes contributing coarse material to the channel bed. The foothill region transforms to a reduced slope scenario and subsequent deposition takes place. The valley opens in floodplains and widened channels.

15 GENERAL FORMS OF ALLUVIAL CHANNELS (FROM SELBY 1985)



14 SCHEMATIC ILLUSTRATION OF A TYPICAL RIVER SYSTEM (FROM SELBY 1985)



Natural water courses are unique in plan and cross-section. Their form are dictated by the following elements:

- Gradient
- Flow velocities
- Flow volumes
- Peak flood scenarios
- Riverbed material
- Terrain morphology
- Sedimentation
- Vegetation

Each portion of each water course consist of a diverse combination of these elements which gives rise to a morphologically varied system.

During the design or upgrade of a water course, one should consider the following design guidelines:

- Sinuosity
  Meandering, braided and straight segments, strategically placed (fig 4-15)
- Morphological diversity in plan and section
  Islands, variable bank profiles and river depths
- Biological diversity
  A variation in river depth and bank profile will create micro habitats for fauna and flora
- Presence of a flood plain
  Zones where flooding can occur is essential for runoff control in peak flood situations

Introduction

The design of a wetland in a waste management system is essential due to the large amounts of water present and the possible contamination that can occur. The primary objective is the treatment of water in order to improve water quality. Other objectives are secondary but just as important as it is synonym with wetlands. Wetland design guidelines is stipulated in Addendum 3.

Wetland objectives

1. **Water quality enhancement**

It aims at restoring the self-purification capacity and regenerative potential of the existing hydrological ecosystem. Treatment efficiency depends on:

- Water residence time
- Temperature
- Received concentration of pollutants
- Depth
- Vegetation distribution
- Hydraulic efficiency
- Light availability

2. **Water storage and flood control**

It aims at being a storage facility and act as an energy dissipater and detention structure in peak flood events. The hydrological engineering practices should be of the highest standard to act as a high flow buffer zone.

3. **Food web support**

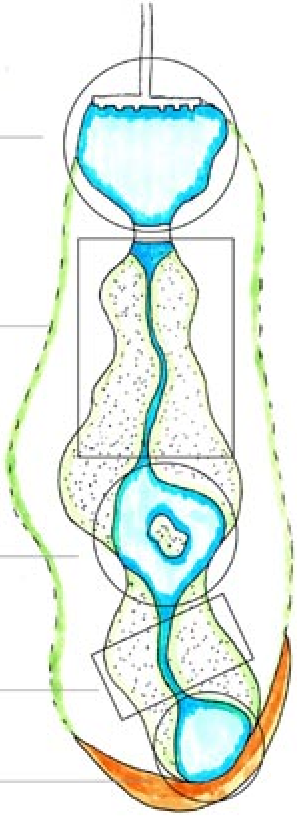
It aims at being a source of organic matter as the basis of a food web. The system design and operational control becomes critical when food production should correspond with the quantities needed to support current and future ecological systems. High net primary production correlates with:

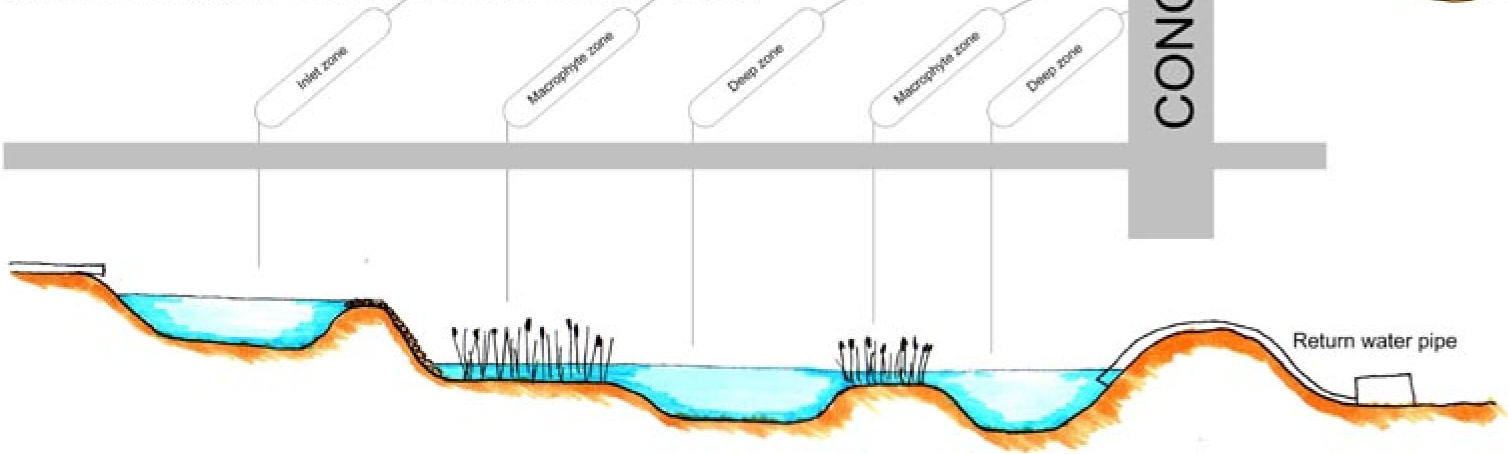
- Constant water availability combined with
- high sediment dissolved oxygen and
- light availability.

Fluctuating flood levels generally result in lower net primary production as the system is in stress during dry cycles.

4. **Energy exchange with adjacent ecosystems**

It aims to stabilise and function as a self-sustaining ecosystem supported and supporting adjacent ecosystems. As a potential food source, it is automatically linked with the adjacent ecosystems via faunal movement and migration routes. Wind blown or water transported seeds, carrying DNA information will be dispersed from and too this system.



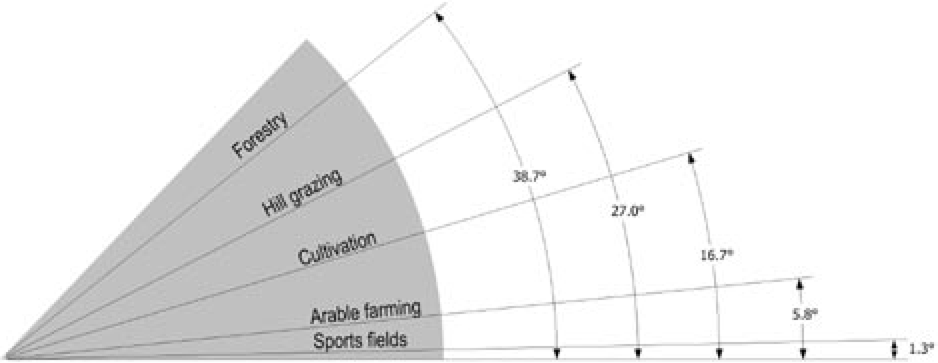


CONCEPTUAL DESIGN

4.16 APPROPRIATE LAND-USES ON DIFFERING SLOPES (FROM HANNAN 1984 & MARSH 1991)

Slope: Degrees	Slope: %	Slope: 1 in	Maximum slope for land-use
45	100	1	
42	90		
38.7	80		Forestry
35	70		
30.9	60		
27	50	2	Public stairs, Hill grazing
21.8	40		Some cultivatoin with specialised machinery
16.7	30		Pasture, cultivation with normal machinery, lawns
11.2	20	5	Exceptional buildings
8.5	15		Septic drains, secondary tar roads and dirt roads
5.8	10	10	Arable farming, Main tar roads, Sidewalks
2.8	5	20	Industrial development, residential development
1.3	2	50	Sport fields, Parking lots
0	0		

LAND USE OPTIONS



Introduction

Considering future use of a rehabilitated TDF, one need to understand the relationship between opportunities and constraints offered by the TDF and desired land-use options. It is in most cases impractical to assign a specific land-use option to a rehabilitated TDF if operation is active for a life time of 50 years or more. Projections this far into the future is likely to be inaccurate. The more suitable approach will be to design the TDF in order to accommodate a diversity of land-uses once it has reached safety and stability standards.

Land-uses on differing slopes

Figure 4-16 illustrates certain land-uses associated with gradients in the landscape. It is apparent that steeper gradients can only accommodate certain specialised land-uses. The lower the gradient, the more land-uses are expected to be facilitated on the TDF. This can be a useful guideline for development on a TDF.

There will always be a need for arable land as well as pasture. Slopes steeper then that can be set aside for wilderness areas.