Sustainable river stabilization using groynes in the Western Cape

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Abstract:

In many parts of the Western Cape rivers are seen as being out of control. During the annual floods, farmers lose expensive infrastructure and developed land when riverbanks erode, bridge approaches are damaged and communities are cut off from the outside world. It is becoming ever clearer to those working frequently with these rivers that the greatest threat posed by the soil loss at individual sites, is not so much the loss at the site but rather the effect of the abnormal sediment pulse as a result of the erosion on the behaviour of the river as a whole. With the spectre of global warming looming, it seems that these problems will only get worse.

Various types of erosion control methods have been employed in the Western Cape to curb the erosion of riverbanks. Of these, in some situations, the use of groynes has been found to be most suitable. Unfortunately, although a lot of research has been published describing the flow of water between groynes, great reliance has been placed on model studies for the planning of groynes and a comprehensive design procedure is not available. This was initially a major impediment to the use of groynes in the Western Cape but experience gained has enabled the use of groynes to become common.

Since the year 2000, groynes have been constructed in the Western Cape as part of emergency flood relief river bank erosion control projects, as well as poverty alleviation projects. Effectively these have been full scale model tests. Based on this work the author has compiled a design procedure for planning the layout and structure of groynes. As part of an effort to better understand the functioning and application of groynes, the author has recently visited the planners of groyne projects in Europe and South America.

This presentation starts by looking at the need for river bank erosion control in the Western Cape, general river rehabilitation objectives, and an overview of many types of bank erosion control methods that could possibly be used, before focusing on the use of groynes. The main

purpose of this presentation is to illustrate the use of groynes as a sustainable and environmentally appropriate option for river bank erosion control.

Acknowledgements:

I would like to thank the following for their contributions to this work:-

1) The Western Cape Department of Agriculture for allocating resources to assist farming communities, by making rivers and riparian areas more resilient to flood disasters.
2) The National Department of Agriculture for funding disaster relief work in the Western Cape
3) The Western Cape Department of Agriculture LandCare section for their support with fieldwork and the supervision of construction
4) Dr Liz Day of Freshwater Consulting Group has over the years assisted me with getting to know wetland vegetation and the value it offers to river stabilization projects.

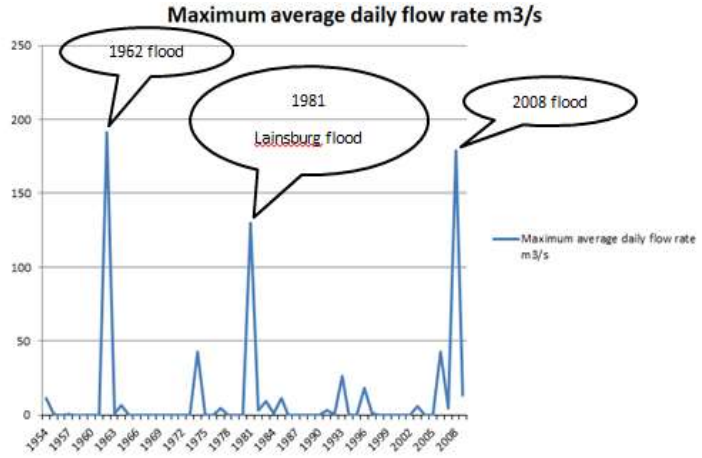
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1 Background – why is river stabilization needed?

The stability of river channels in the agricultural areas of the foothills of mountains in the Western Cape is rapidly becoming a big problem. High value orchards, farm and public infrastructure such as roads, bridges and water reticulation systems are being regularly damaged. Floods of the same magnitude seem to have greater impact now than previously, for instance, the Nuy River flood of 2008 near Worcester (see Figure 1). The concerning issue is that these floods are by no means extreme, such as in the case of the Nuy River having occurred at least three times in the last sixty years, and one can only wonder what will the impact of extreme floods be? It is also apparent that as ecological resilience decreases (ie the channel form narrows and deepens, and the stabilizing effect of indigenous vegetation diminishes), the impact of disturbance events are more damaging and recovery before the next event is less likely.

There is an array of factors that drive river instability that have been identified. These include the flourishing of invasive alien vegetation in the rivers, the random bulldozing of rivers and the alteration of flow regimes by water impoundments, abstractions and irrigation releases. All of these factors have only come into being within the last 50 years and can be verified by the inspection of aerial photography dating back as far as 1938. All of the factors in one way or another increase the flow velocity in river channels and decrease the capacity of natural vegetation to bind the river sediment.

- The woody alien vegetation (most notably wattle *(Acacia mearansii, Acacia longifolia)*, Port Jackson willow *(Acacia saligna)*, various gum trees, and more recently beefwood *(Casuarina cunninghamiana)*) block river channels, invade floodplain and valley bottom wetlands and cause erosion of river banks and river beds. When washed out during floods large masses of this vegetation pack against bridge piers and any other obstruction in a river magnifying the impact of the obstruction. Alien vegetation which is fast and tall growing, outcompetes and displaces flexible, deep rooted



Flood peak flow rates past Keerom Dam on the Nuy River since construction



Flood damage along Nuy River 2008

Figure 1: The Nuy River below the Keerom dam

indigenous vegetation, and makes a river more susceptible to erosion damage, in part by blocking floodplains and locally increasing flow velocities forcing channel incision.

- Bulldozers have only been available to farmers and municipalities post the Second World War. Bulldozers have been used to clear obstructions and straighten rivers with a view to increasing the discharge capacity of the river and reduce the vulnerability of the river environment to flood damage. The bulldozing has removed indigenous vegetation, loosened sediment and deepened and narrowed river channels creating higher flow conditions during floods and creating a self-perpetuating cycle of channel incision, as larger and larger flood volumes are accommodated in a deepening channel. In effect, the bulldozing has increased the erosion potential at the site where it has been done, as well as initiated abnormal sediment flow downstream, increasing further the potential for river instability there. In addition, the deepening channels can drain surrounding wetlands, making them less resilient and more vulnerable to erosion (e.g. Langtou, Duiwenhoks).

- The construction of in-stream water storage dams reduce the amount of small floods in rivers which aid in removing you alien vegetation while it is young. Should alien vegetation survive long enough, it does not wash out as easily and subsequent larger floods passing the dam have to pass through a river channel that has become blocked and the erosion of the upper reaches of river banks results.

- Summer irrigation releases into naturally seasonal rivers allow invasive (alien and indigenous) species to thrive along the river channel, in habitats from which they would normally be excluded by summer drought, thus contributing to floodplain

constriction (e.g. indigenous willows along the Breede) and higher flow velocities during floods.



Figure 2: The recent flourishing of alien trees in the river to the right have deflected the flow of the river to the river bank on the left, causing it to erode (the flow direction of the river is towards the viewer).

While it is normal and acceptable that all rivers have a measure of sediment movement especially during large flow events, experience has shown that when sediment movement takes place after the artificial disturbance of a river, this extra load of sediment creates obstructions in the river channel that deflect the flow of water into the banks, causing more erosion and sediment movement (for example the large scale erosion in the upper Duiwenhoks River near Heidelberg between 1975 and 2006 which released some 250 000 m^3 of soil into the river over three major runoff events and contributed significantly to the destabilization of the river for at least 20 km downstream). This un-natural movement of sediment constitutes a chain reaction which does not die out until the slope of the river is flat enough or the river is wide enough to accommodate the extra sediment. For this reason it is viewed as pointless to address localised river bank erosion without addressing the source of un-natural sediment movement.

The Conservation of Agricultural Resources Act (CARA: Act 43 of 1983) mandates the Western Cape Department of Agriculture to protect the production potential of agricultural soil in the Province. To this end the Department has been attempting to assist farming communities from the ravages of river bank erosion, as it impacts on the deepest and generally the best agricultural soil in the Western Cape. To achieve this, the author has been involved with the planning river stabilization projects for the last 30 years, first on a very small experimental scale and later, based on observations of the performance of previous interventions, progressively larger scale projects. In the last 10 years the author has undertaken several projects where stretches of river several kilometres in length have been successfully stabilized. This work would not have been possible without the support of the National Department of Agriculture disaster management funding. Invaluable assistance and insights regarding the potential for reducing the number and size of structural interventions by incorporating indigenous wetland vegetation into projects have obtained from many in the

local wetland research and management community, but in particular Dr Liz Day of Freshwater Consulting.



A gulley resulting from poor agricultural in a wetland. The gulley formed in 3 major runoff events (1975-2006) - about 250 000 m^3 soil washed downstream



Typical massive blocks of peat washed out of the gulley (in image to the left) deposited downstream impacting on the river's flow direction, and causing in turn more erosion

Figure 3: The downstream impact of erosion in a peat wetland (Duiwenhoks River 2008)

Please note that the "stabilization of rivers" referred to in this document, refers only to rivers that have been shown to have been degraded and disturbed by in-appropriate human interventions. It is not intended for the management of pristine rivers.

2 Design philosophies

The source of most of the instability problems in the Western Cape rivers can in one way or another be ascribed to the artificial increase in flow velocity in the river channel. Whether it is due to land users deepening and narrowing an existing river channel to create more space for agricultural production, or urban development on the river bank, invasive (alien or indigenous) vegetation blocking the channel and forcing the water to flow through a singular high velocity channel, or the removal of indigenous vegetation which traditionally gave roughness to the channel and reduced flow velocities, the nett effect is that flow velocities in rivers have been increased and similarly the erosive power and sediment carrying capacity of the water as well. The increase in river flow velocity, coupled with the loosening of the river bed soil by bulldozing, the stripping of vegetation which traditionally bound the soil, and the injudicious random realignment of rivers by land users to suit their developments, has resulted in the abnormally high levels of river instability we see today, which indicate that the magnitude of disturbance is beyond the .capacity of the river to recover between events.

From the point of view of the Department of Agriculture, the objective of the intervention to stabilize rivers is not for environmental biodiversity objectives, but solely to protect and preserve the production potential of the agricultural soil adjacent to rivers. As a result, the objective is not to restore rivers to their pristine state, but rather to prevent a river from meandering unnaturally due to an abnormal sediment load. That is, to focus on rehabilitating river and wetland ecosystem services rather than patterns. The application of these measures is however to severely degraded rivers, the restoration of which to natural conditions would in any case not be feasible.

Significant features of the desired solution would therefore include, the alteration of the river cross section to allow slower and more acceptable flow velocities, the improvement of river alignment to streamline the flow of water and reduce the chance of the flow being directed into a river bank where it could cause erosion, and the restoration of indigenous wetland vegetation to assist stabilizing the soil of the river bed and river bank.

The intended outcomes of the river stabilization process would usually be:

- The river channel is large enough to carry reasonably expected floods (say a 1:10 or 1:20 year flood) at low enough flow velocities, so that damage to the surrounding agricultural or urban areas is eliminated.
- It should not be necessary except in exceptional circumstances to manage sediment in the river with earthmoving equipment – this is because such disturbance makes the bed unstable and prevents natural stabilisation with vegetation over time between floods.
- Appropriate wetland vegetation should be employed to assist with the stabilization process and reduce the need for engineered structures (the bio-diversity benefits are seen as a bonus value to the process).

- The river training structures constructed, should to a large extent be able to disappear under the re-established indigenous vegetation over time as sediment gets trapped between the structures and the vegetation grows higher.

One important consideration when doing this work is that for all practical purposes, the river channel may not be relocated to somewhere where it has not been recently. The location of river channel can with reasonable certainty be digitized off historical aerial photography. The intention is not to artificially straighten a channel, or abandon higher level secondary channels.

Another important consideration is that there is no intention to train rivers from top to bottom between sets of groynes, only to judiciously employ groynes where the landscaping and revegetation of riverbanks has little prospect of success should there not be structures reducing the flow velocity of water along the banks.

3 Planning the river horizontal alignment of the rehabilitated river channel

Before thought can be given to structures and landscaping that will help stabilize a river, consideration must first be given to the minimum width and horizontal alignment of a river channel.
A minimum channel width must be determined, so that when applied it will ensure a basic discharge capacity in the channel. The minimum channel width is usually determined by the greater of, a channel width near to the site in the same river which was stable during the flooding which caused the damage, and the channel width needed to accommodate the 10 year return period flood with a non-eroding flow velocity.

Very often during a flood in a disturbed river, sediment deposits deflect the flow of water and create scour holes in river banks. Should the river bank be stabilized on the eroded alignment (ie simply hardened by adding a rip-rap layer to it), the alignment of the bank will be such that it is likely to permanently direct the flow of water into the opposite bank, causing erosion there.

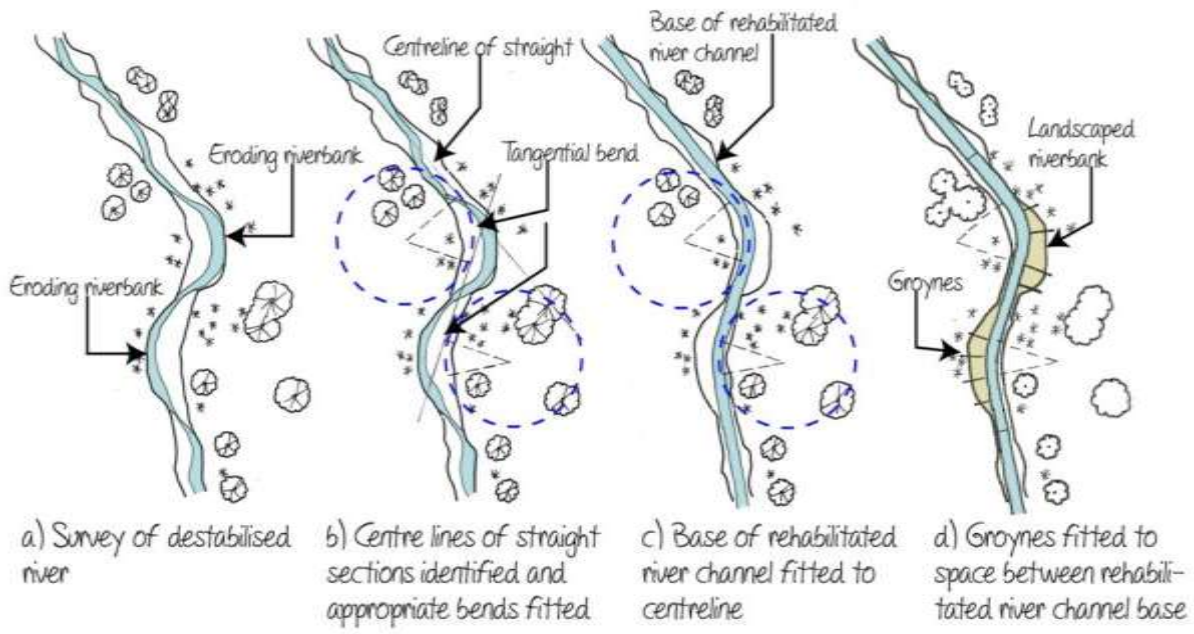


Figure 4: Images showing the steps in the production of a horizontal alignment from a survey/aerial photography

The proposed horizontal alignment of a river is based on a collection of straight sections and tangential bends fitted to the surveyed river channel, and possibly the historical river channel location as digitized off recent aerial photography. This requires a trial and error process which results in a balancing of a host of factors. These factors include the fitting of the rehabilitated river channel base to what was known as the position of the river, keeping the number of bends and bend radii to realistic values, the minimising the construction cost, and

should groynes be used for stabilizing the river, adequate projection length of the groyne from the eroded area towards the river channel so that the groyne can have an impact on the flow of the river.

The series of aerial images below shows a site in the Hex River close to de Doorns. The first image show the original channel before the 2008 flood, the second shows the channel after the 2008 flood, and the third shows the planned horizontal alignment of the river plus groyne structures. Note that the planned river channel is about twice the width of the pre 2008 channel to reduce flow velocities and to increase the discharge capacity, and that the groynes are all planned within what was formerly the river bank (so that it cannot be argued that the groynes are blocking the channel and lifting floods unnaturally out of the channel). A sustainable solution for this problem would not have been possible had the horizontal layout of the river channel not been planned first. Had the watercourse been stabilized in front of the sewage pond settling ponds in its 2008 eroded location, the return flow would have continued to erode the vineyards on the opposite bank downstream.



Watercourse prior to 2008 (2006)



Eroded watercourse 2008 – the watercourse moved right up to the toe of the sewage farm settling pond fill



Rehabilitated watercourse – showing layout of minimum channel width and groyne structures in footprint of eroded river bank

Figure 5: A practical example of river allignment planning – Hex River 2006

As mentioned the selection of appropriate bend radii is important to the success of a project. Sources in the literature (Przedwojdski et al) generally refer to minimum bend radii as not less than twice the river channel width. This must be used with caution as it is the result of research for northern hemisphere rivers which have different characteristics to those of the Western Cape, where the flow very often becomes supercritical during floods and larger minimum bend radii are more appropriate. The author's experience with the design of river

stabilization with groynes, has shown that quite often the selection the largest possible bend radius enables the use of long groynes which are fewer and hence more cost effective (as the construction of the underground groyne tips is relatively much more expensive than the rest of the groyne and reducing the number is beneficial).

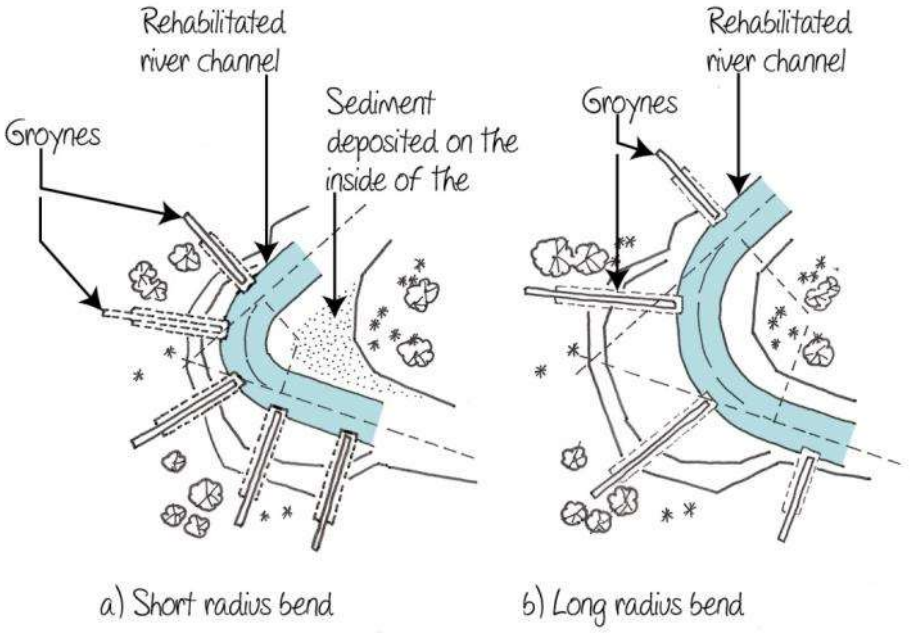


Figure 6: The use of longer radius river channel bands enables more cost effective bank protection by employing fewer groyne structures

The planning of a re-alignment for a river (much as the alignment of a road) is an understandably artificial construct. Although the planned alignment has the very beneficial objective of making sure that a river will have sufficient space and reasonable alignment to function without abnormal sediment movement (ie in a sustainable manner), it also has the negative impact of, to a large extent, preventing a river from meandering naturally. This trade-off between designing a non-eroding space for a river, and at the same time constraining its alignment so that agricultural and urban development can take place close to the river without undue risk of the river changing its alignment in response to unnatural sediment movement, should only be used in seriously degraded rivers (such as those in the Western Cape agricultural and urban areas).

4 Situations where using groynes for river bank stabilization is appropriate

There are many types of engineered structures that may be used to stabilize river banks, and many materials to construct them with. The structures include longitudinal structures such as retaining walls and the armoured landscaping of the bank, and transverse structures known as groynes.

Generally longitudinal structures are employed in urban areas where river flood plains have become severely constricted and there is no other option but to manage a river in a narrow and deep artificially constructed channel designed to increase conveyance capacity. These structures are also used in areas of limited application such as around bridges and culverts where roads cross rivers.



Figure 7 An example of an incising river where groynes would not be appropriate to address bank erosion (rather a series of weirs could be employed to flatten the river slope and facilitate a lower flow velocity)

Especially in the Western Cape where river environments have been altered and degraded by the spreading of invasive alien vegetation, the bulldozing of rivers to straighten and remove vegetation from them, and the confinement of rivers between artificial terraces which increase the riparian agricultural production area, groyne structures have become a popular choice for river training. The main reason for this is that groynes assist in achieving the objective of facilitating wider and slower flowing rivers with less unnatural sediment movement. To achieve this long, low groyne structures promote a far more ecologically acceptable river cross section than concrete retaining walls or riprap protected landscaping. In

addition to promoting wider and slower flowing channels, the use of groynes creates zones in the river where indigenous wetland vegetation may be established and this helps stabilize the river further and reduce the number and size of structures required. The indigenous wetland vegetation has the added benefit of enhancing bio-diversity in the environment.



Brandwacht 2015 before rehabilitation – the river is being pushed by alien vegetation deeper into the road fill



Brandwacht 2017 – after alien vegetation removed, groynes constructed and river back on original flow path

Figure 8 – Before and after photos at the Brandwacht project showing an appropriate use for groyne structures for river stabilization



Figure 9 – looking downstream over the two groynes above the bridge in Figure 8

5 The use of groynes for river stabilization

5.1 What are groynes?

Groynes are finger-like structures, projecting from a river bank into a river. Groynes are employed sometimes for erosion control on the river bank (as is used in the Western Cape), and sometimes for managing the location of the deep channel in a river for navigation purposes (such as in the Rhine River). These structures can be planned to different standards using a variety of materials, but they all have the objective of either deflecting the flow of a river away from the river bank, or at least the slowing down of the flow velocity adjacent to the river bank.



Figure 10 Groynes on the Buffeljags River near Swellendam



Figure 11 Groynes on the Waal River at Zaltbommel (Netherlands)

There are a variety of plan view layouts for groynes and a lot of debate as to what should be used. The groyne orientation can be from slightly upstream all the way to slightly downstream. There are a variety of plan view shapes such as straight groynes, Tee-headed groynes and cranked groynes. Different orientations and plan shapes have different impacts on the flow of water and the formation of scour holes at the tip of the structure. Although there is a lot of comment in the literature regarding the pros and cons of different concepts, the Department has found that straight groynes perpendicular to the flow direction are most practical and economical.

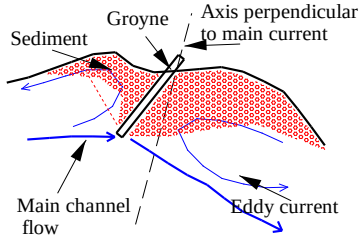
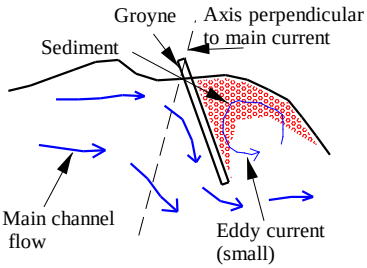
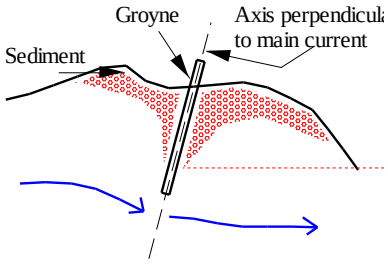
	Sketch	Comments
Groyne pointing upstream		• Attracts silt upstream and downstream of structure • Pushes main current away from bank • Has great potential for scour hole at head.
Groyne pointing down-stream		• Attracts only silt downstream of structure. • Does not form much eddy current and pulls main current to bank • Has relatively low potential for scour at head • Definitely not recommended for concave bend
Groyne perpendicular to the flow direction		• Groyne attracts moderate amount of sediment upstream and downstream • Keeps current more or less parallel to bank • Has medium potential for scour at head

Figure 12 The impact of groyne orientation with respect to stream flow direction

5.2 How groynes function

Groynes oriented at right angles to the flow direction (or oriented upstream), when in a field of appropriately spaced groynes, function by trapping a pool of relatively stationary water along the bank and this pool deflects the main current of the river past the tip of the groyne. In the Western Cape it has been common during floods to see a half meter difference in water level above and below groynes which are not submerged.

When groynes are not submerged, the interaction of the main current of the river and the pool causes an eddy current in the pool where water flows upstream along the bank (see the sketch below).

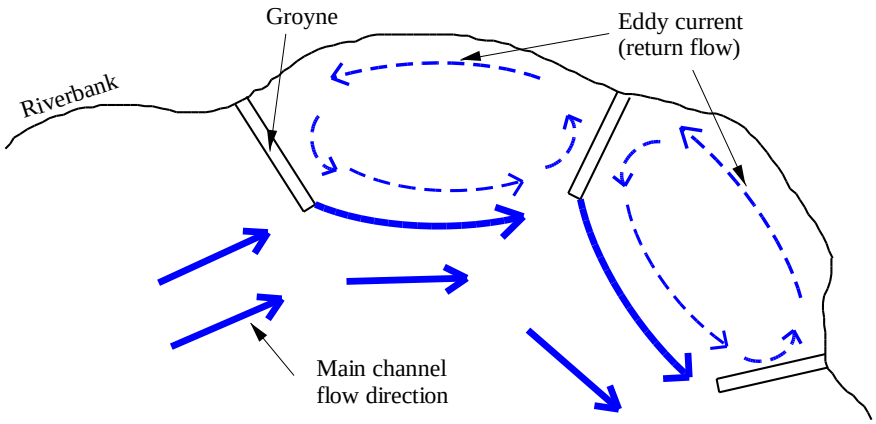


Figure 14 Simplified flow pattern between non-submerged groynes

Once groynes become overtopped, the flow between the groynes becomes more 3-dimensional as the water flowing over the groyne mixes with water circulating behind it. The main discharge channel (with the high flow velocity zone) of the river remains still in the deeper water just beyond the tip of the groynes. Part of the cost management strategy with the design of groynes in the Western Cape is to use indigenous wetland vegetation to bind the soil between the groyne structures, so that groynes can be designed to a lower level and allow them to be overtopped at a greater frequency, and still keep the river bank safe from erosion.

5.3 What is the expected outcome of the structures?

Rivers are very dynamic systems and one cannot expect the same impact from a structure under all conditions. Varying levels of response from the structures can be expected as flood levels, flow velocities and levels of turbulence change. The type and density of vegetation between the structures has a significant impact on the functioning of the structures and the system as a whole. The designer of groyne structures must then be aware that there are decisions regarding design parameters to be made where the economy, level of assurance that the banks will not erode, and environmental suitability of the solution, are all balanced against each other. It is thus very important at the outset to clarify what is required of the design.

In rural agricultural settings, the most pragmatic approach is felt to be use long low groynes, widely spaced with colonies of robust vegetation (such as palmiet *prionium serratum*) established between the structures effectively forming additional groynes. The bulk of the groyne structures should be just high enough to locate the fast flowing main current of the river away from the bank and to provide enough shelter for the establishment of vegetation between the structures. It is then intended that the structures are eventually covered over by the established vegetation.

6 How are groyne projects planned?

There is no international standard for the design of groyne structures for river training purposes. In Europe this is traditionally done by means of laboratory model testing. In the Western Cape a design process has developed based on the experience gained from planning and observing the behaviour of very small structures at first, and then progressively larger. In a sense these were full scale model tests.
In the time when these trial structures were being monitored, observations were also made about the dynamic of un-natural pulses of sediment in the river (arising from erosion as a result of un-natural river disturbance) and the knock-on effect of erosion and sediment transport was identified. This supported the strategy to resolve river instability problems starting at the top of a catchment and working downstream.
Also during the monitoring of these trials the beneficial impact of indigenous wetland vegetation on river instability was observed. It was observed that once established, appropriate vegetation can bind river sediment as well as reduce stream flow velocities during floods by providing hydraulic roughness.

6.1 Summary

The planning of river stabilization projects with groynes is arranged around the need to reduce abnormally high channel flow velocities in transformed and degraded rivers, to something which could have been expected to have existed prior to the human disturbance of the river system, and thereby reduce the potential for erosion and sediment transport in the river.

In the Western Cape the following process is followed:-

- Confirm that the river is already highly disturbed / has been permanently transformed from its natural flow regime and thus that the changes wrought by groynes will not result in significant biodiversity impacts (changes in natural patterns and processes)
- To determine the nature and extent of protection works, flood heights and flow velocities during a range of floods must be determined. This necessitates:-
    - a detailed topographical survey of the site plus usually a half kilometre up- and downstream.
    - a hydrological study of the catchment is needed, and it should yield a regularly expected flood (say a 1:10 year flood) and a more extreme flood (say a 1:100 year flood)
    - the topographical and hydrological data are combined with surface roughness data in a flood modelling package (HECRAS is used in the Western Cape) which gives an indication of flow paths, flood levels and average flow velocities
- A horizontal alignment for the rehabilitated river is planned (see section 3). The provision of a streamlined rehabilitated channel of slope and base-width suitable for an appropriately low flow velocity during expected floods is essential. Remember that

once groyne structures are being planned, it will probably be necessary to revise the horizontal alignment once or twice to achieve a balanced design (ie when groynes are too short, their spacing shortens and it is likely that too many resources will be required constructing groyne tips).

- A long section down the existing river channel is studied to determine a stable foundation level. To do this a line joining the underside of pools in the river is drawn and a second line a meter below that is used as a foundation level. Note that this is an appropriate measure in the Cape gravel-bed rivers – elsewhere other measures such as estimates of maximum scour depths may be more appropriate.
- On bends where erosion and or meandering of the river is expected, groynes can be fitted into the space between the base of the rehabilitated river alignment and the river bank. If there is not enough space for this, then the river alignment must be reconsidered. Note that as a general rule (to prevent the creation of flood levels higher than what were traditionally experienced), groynes are only placed in the footprint of where the bank can be shown to have washed away recently.

The image below gives a graphical representation of the design process.

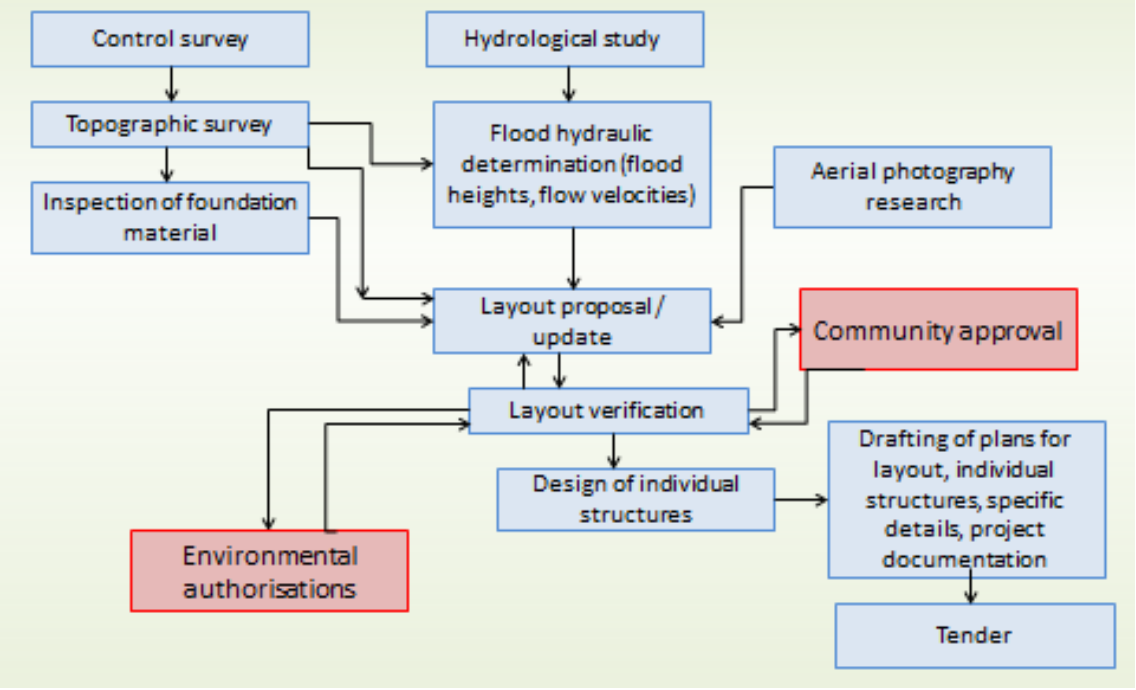


Figure 15 Flow chart showing the engineering aspects of a groyne project design

6.2 Preliminary studies

6.2.1 Topographic survey, hydrological study, flood height analysis and bed material.

A topographic survey is carried out so that it is extensive and detailed enough to:-

- Extract cross sections through the watercourse to compute flood heights with HEC-RAS or similar software. The survey must extend far enough downstream so that the flood routing calculation can begin at a suitable control point in the river (usually 300-500 m from the site). During the survey, the hydraulic roughness of various parts of the river and floodplain must be assessed for flood routing calculations.
- Extract long sections along a river to determine the required foundation depth of the groynes.
- Determine the position of the eroded bank, the rehabilitated bank and the projection length of the proposed groynes at any possible position, so that the required groyne spacing may be designed.
- Extract detailed sections along the centerlines of proposed groyne positions for the design of the individual groynes.
- Determine earthworks volumes.

6.2.2 Hydrological study

A hydrological study is performed to determine the peak flood discharges for the 1:10, 1:20, 1:50 and 1:100 year return period floods. The hydrological study as far as possible takes into account changes to rainfall patterns brought about by global warming (or at least considers the consequences of changing weather patterns). In the Western Cape a form of the Rational method (Taylor-Schwartz) is used for this purpose, with a lot of information (catchment area, slopes, flow path length, mean annual rainfall) being prepared using ArcGIS. In the Overberg and Eden areas the rainfall intensity determination has been modified to take into account the nature of storms experienced since the mid 1990's– the storm runoff here was previously determined assuming frontal rain (i.e. coastal) but the severe flooding experienced is usually associated with thunderstorms, so the "inland" dataset is used.

6.2.3 Flood height analysis

Flood levels and average flow velocities for the peak flood discharges are determined. Ideally this should be done for three cases, the situation prior to erosion, the situation existing at the design stage, and the post construction situation. In practice only the second case gets computed, unless the size of the groynes is large relative to the size of the river channel, then the third case is computed as well. In the Western Cape the HecRas software is used to determine flood heights (although this is a crude tool for computing the third case because it cannot simulate 3-dimensional flow effects).

6.2.4 River bed material

The d50 of the riverbed material should be determined or estimated for scour depth predictions. This is in practice difficult because of the variability of sediment nature with

location (for example fine sediments dominate on the inside of bends while coarser material is on the outside). In the Western Cape when groynes are planned in boulder-bed rivers, the d50 is not determined, but to reduce scour the tips of groynes are sloped and the foundation is set to one meter below the normal pool depth (see later in text).
The position and extent of rock outcrops must be clearly indicated on the topographical survey. The presence of rock outcrops in the river is significant because they may influence the flow direction of the river, they will influence the ability of the river to incise once the flow width is constricted, and they may provide a strategic location to construct groynes with less expensive scour protection.

6.2.5 Vertical alignment

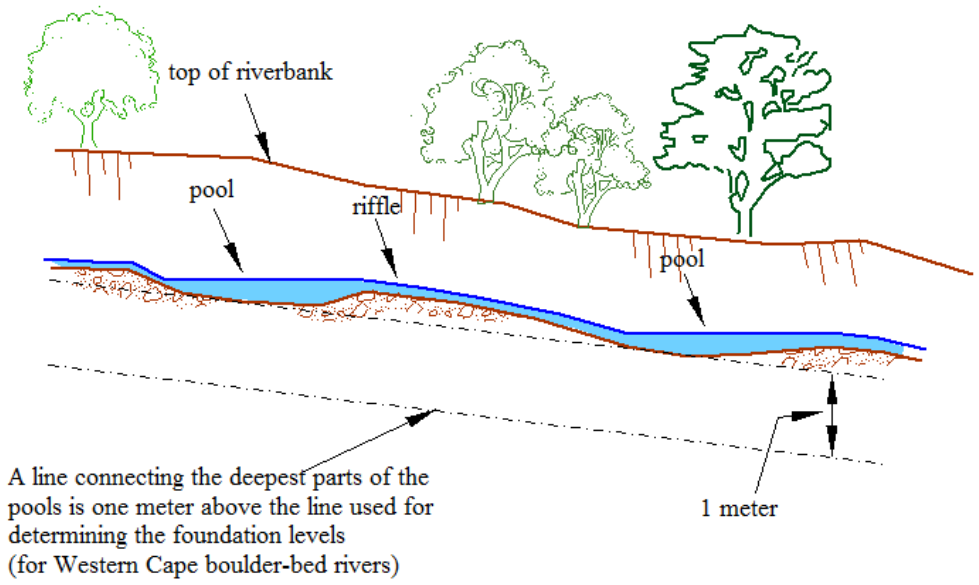


Figure 16 The determination of the groyne foundation level

The vertical alignment of the rehabilitated river channel (which is used for planning the foundation level of the groynes) must be determined from the long section of the existing river. Providing that the riverbed is stable, a line connecting all the lowest points of pools on the surveyed long section in the river indicates the potential bed-level of the un-rehabilitated river (as observed between floods – during floods depending on circumstances, the river bed will be mobile to a deeper depth). The foundations of the groynes must not be higher than this level.

Remember that during floods the river bed gets mobilized, the level where the sediment is not moving may be even deeper than the potential bed-level identified above, and if possible the groynes should be founded at a deeper level than that given by the line. In the Western Cape, the foundation of the tip of the groynes is set to one meter below this line. In rivers where the riverbed is unstable (i.e. the riverbed is dropping due to erosion) it is advisable to address the instability of the riverbed with the introduction of a weir first before trying to stabilize the banks.

1.3 Planning a field of groynes

1.3.1 The refinement of the location of the rehabilitated river channel when planning a field of groynes

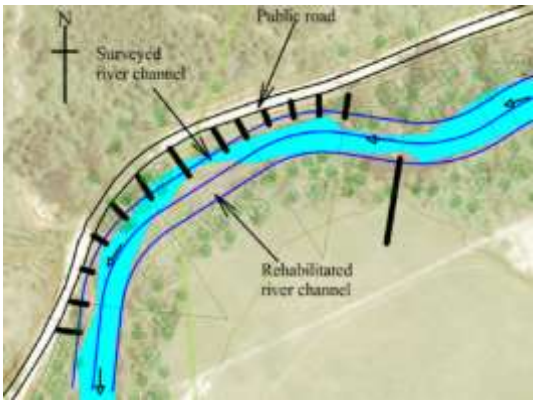
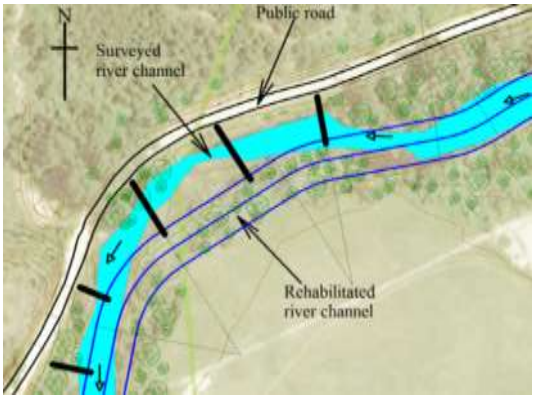
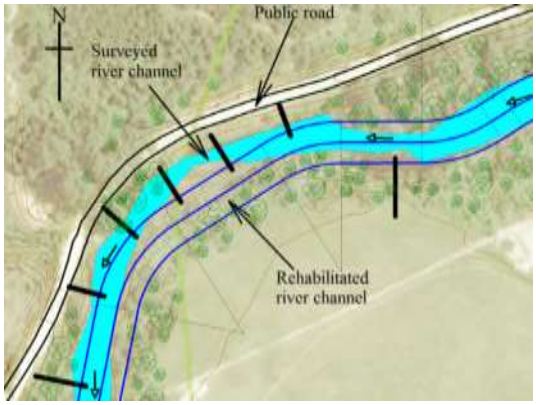
TRIAL LAYOUT 1 : KEEP TO EXISTING CHANNEL AS MUCH AS POSSIBLE 	• This option involves the least disturbance to the south bank • The proposed groynes are short, their projection into the flow little, and so the spacing between the groynes is short • It is not a desirable option because of the number of groyne tips that get dug deep into the river for scour protection.
TRIAL LAYOUT 2 : STRAIGHTEN RIVER AS MUCH AS POSSIBLE 	• This option involves a maximum disturbance to the south bank. Almost the entire river channel has to be dug 4 m deep into virgin soil. • The proposed groynes are long, their projection into the rehabilitated river is significant, and so the spacing between the groynes is large. • The option is attractive because apart from the cost of excavating the south bank, the groynes are long and shallow, and the deep tips are few. The option also provides a large area for wetland rehabilitation and biodiversity enhancement. • The option is undesirable because of the extreme disturbance of the south bank, and the legal implications of relocating the river to a position where it has not been for a long time.
FINAL LAYOUT 	• This option involves a limited disturbance of the south bank. • Most of the groynes are of a length that they can adequately influence the flow direction of the river. The spacing of the groynes is acceptable. • The option is attractive because the amount of groyne tips are not excessive, and the disturbance of the south bank can be shown to be only in an area where the river bed was positioned in the last 10 or so years (from historical aerial photography).

Figure 17 Example determination of layout of channel and groynes (Bottelierskop project 2014: Project objective to protect road from frequent wash-aways)

The layout of a field of groynes is planned to support the flow of water along the rehabilitated river channel as described in section 3 above. With particular reference to planning the river channel for protection with groynes,
7 illustrates the iterative process needed to refine the rehabilitated channel position.

1.3.2 The positioning of structures within a field of groynes

Start and end position of a field of groynes

Generally a field of groynes begins at the beginning of a curve of the rehabilitated river channel, continues to the end of the curve, and then an additional groyne is placed beyond the end of the curve to align the water with the straight section that follows (see Figure).

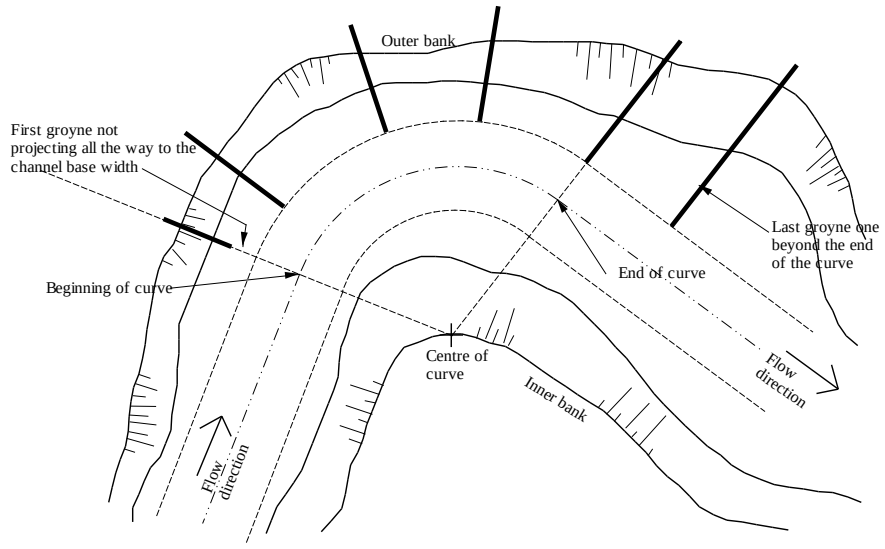


Figure 18 The positioning of groynes relative to the start and end of a bend in the rehabilitated channel

It can be prudent sometimes to not position a groyne on the actual beginning of the curve, maybe just before or just after depending on conditions, and the same for the end of the curve. Observe that the sharper the bend and the greater the angle of deflection of the bend, the more groynes will be needed to achieve the desired result.

Groyne spacing

The generally accepted rule for groyne spacing is three times the groyne 'projection length' on bends, and six times the 'projection length' on straight sections of river. A good discussion of different researcher's recommendations is presented by Przedwojski et al (Przedwojski B, Blazejewski R, Pilarczyk KW, 1995). It is of interest to note that these recommendations have been made largely by researchers of Northern Hemisphere rivers, which do not necessarily behave like Western Cape rivers. These recommendations have also probably been influenced by the Northern Hemisphere need to use groynes to provide permanently navigable channels in rivers, and not for river bank rehabilitation so it is possible that a different standard will be developed for the Western Cape with time. There is definitely room to improve the recommendations – for instance defining when a bend radius

is large enough to treat the river as straight. The author is looking into the use of greater groyne spacing as a norm.
The groyne spacing is related to the groyne 'projection length'. The 'projection length' is a measure of how far the groyne protrudes into the river to influence the flow. This is not bound by hard rules and experience with the use of the structures and knowledge of local river behavior as influenced by these structures helps very much when choosing this value. For instance where rivers are wide enough, the author prefers long low groynes with the main objective of holding the fast flowing channel away from the river bank, but allowing the groynes to be submerged at an early stage so that the full valley bottom gets used for flow capacity. In the case of the Frankenhof 2 project (see Figure 10) , the top of the shank of the groyne has been designed at just below the 10 year flood level, these groynes have been significantly submerged several times and there has been no sign of erosion of the river bank.

1.3.3 The level to which groynes are constructed

The foundation level of groynes has a significant impact on the stability and durability of the structures and must be chosen with care. Choosing a foundation level below the water line can necessitate an expensive construction technique. Choosing a foundation level too high will make the structure susceptible to failure by undermining even if scour protection is provided. The foundation level must be determined by considering the natural depth to which the river is inclined to make pools, as well as making provision for additional depth to account for bed mobility during floods and scour around the tip of the structure.

In the Western Cape the foundation of the tip of the groyne gets placed 1 meter below the line connecting the underside of the pools in the pool and riffle sequence (see Section 6.2.5) – this is appropriate for the boulder-bed rivers. The "anchor" (gabion) below the upstream edge of the scour protection mattress is below this level.

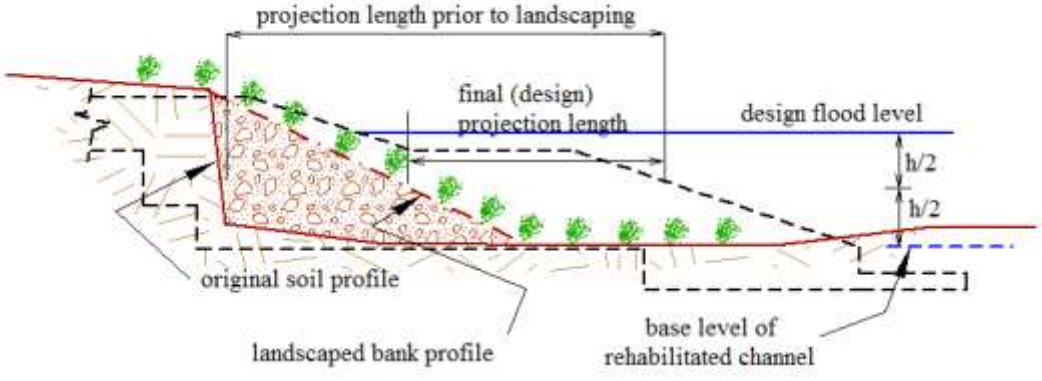


Figure 19 A long section of an idealized groyne showing the projection length

The crest level of the groynes has a significant impact on the functioning of the groyne field. Uijttewaal reports that significant changes to the flow pattern of water between groynes occur after the flood water rises and the groynes become submerged (Uijttewaal, 2005). When not submerged, a 2-dimensional eddy forms between groynes with the most serious turbulence only at the groyne tip. When submerged (depending on the degree of submergence), an unstable 3-dimensional state of flow develops with serious turbulence at places other than the

tip. For this reason the main body of the groyne must be constructed to at least the level of the 1:10 year flood (or higher unless the space between the groynes has been well covered with indigenous riverine vegetation).

The crest of the shank is designed to be at roughly the 10 year flood level (in other words the groyne shank is only submerged when floods are greater than the 10 year flood). As mentioned earlier in this section, there can be value in keeping this level even lower should the groynes be very long, and the objective of the groynes is to only locate the fast flowing portion of the stream away from the bank.
The crest of the root of the groyne is planned to be at the 100 year flood level, or the top of the bank, whichever is reached first.



Figure 20 Side view of a groyne showing design level of different components (flood return periods)

6.3.4 Length of groynes

The horizontal alignment of the rehabilitated channel determines the groyne projection length, as the groyne tip is placed at the edge of the rehabilitated channel. If the river width is not much wider than the rehabilitated channel width, and difficulty is being experienced obtaining sufficient projection length and groyne spacing, the tip of the groyne plus that portion of the groyne which is planned to be below the rehabilitated river bed level, may intrude into the rehabilitated channel space (as it in theory does not influence the flow in the channel). To this the root length of the groyne must be added to get the total length.

1.3.4 The embedment of groynes into the river bank (groyne root)

Early groynes in the Buffeljags River were only embedded 2 to 4 meters into the bank to save costs. When high level flooding was experienced and water flowed behind the weirs, soil behind the weirs was washed away, outflanking the groynes. In the Western Cape, depending on conditions, the top layer of a groyne is embedded 8 to 20 meters into the lands behind the groyne. Sometimes the top of the root is kept 500 m below the soil surface so that the land may be cultivated.

6.3.6 Orientation of the groynes relative to the flow direction

The orientation of groynes is discussed in Section **Error! Reference source not found.**. In the Western Cape it has been found most practical to orient groynes at right angles to the flow direction of the river. This not only provides a shorter and more cost effective groyne,

but because the Western Cape groynes are kept low and submerge relatively often, the orientation of the groyne maintains the flow in the direction of the river.

6.3.7 Scour protection

The most serious scour takes place at the tip of the groyne – the flow of water in the channel shears past the relatively stationary water pooled between the groynes. If this shear plane is vertical, it initiates the formation of vortices (see Figure 1). The turbulence of these vortices can cause serious localized erosion of the river bed and result in scour holes that threaten the stability of the tip of the groyne. The depth of the scour-hole increases until a state of equilibrium is found between the amount of material being removed from the hole and that being deposited in the hole.

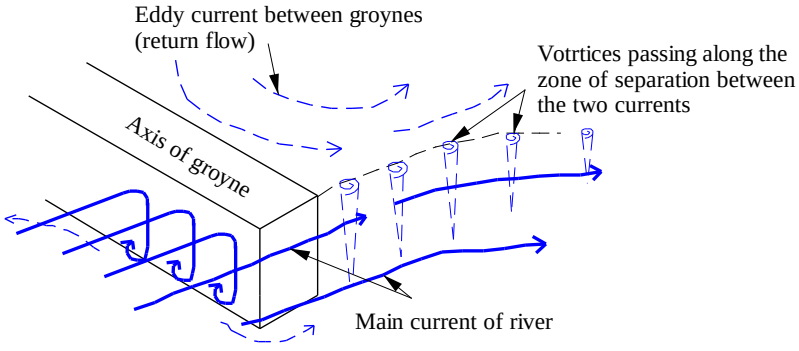


Figure 21 Illustration of the formation of vortices at the tip of a groyne with vertical edges



Figure 22 Early Western Cape groyne with vertical edges at the tip that promoted the formation of deep scour holes



Figure 23 A more recent Western Cape groyne showing the sloped tip which greatly reduces scour.

Although the formation of the scour hole can be controlled with gabion mattresses or riprap, it is best to limit the formation of the vortices in the first place. This can be done very effectively by sloping the top surface of the tip of the groyne, first proposed by Maza Alvarez (Alvarez, 1989), where the flatter the slope the more the shear forces are distributed over a wider contact area and the weaker are the vortices. Maza Alvarez recommends a slope of between 1:4 and 1:10, Uijttewaal recommends 1:6 (Uijttewaal, 2005). In the Western Cape a slope of 1:4 is usually used (King, 2011), except if a river channel has limited width and then this may be reduced to 1:3. Figure 2 and Figure 3 show early and more recent groyne tip layouts, the difference was motivated by the need to reduce the scour at groyne tips.

The normal practice when providing gabion mattresses for scour protection is to provide a width of mattress equal to 1,5 times the estimated scour depth. The available relationships for computing scour depth are discussed by Przedwojski et al (Przedwojski B, Blazejewski R, Pilarczyk KW, 1995), and are mainly applicable to structures with vertical faces, not the sloping tips used by the Western Cape, so the scour depth determination has been abandoned in the Western Cape and a standard four meter wide gabion mattress is provided around the tip of the groyne (in addition to the sloping of the tip) to ensure that the tip does not get undermined by scour. On the underside of the upstream edge of the mattress, a gabion basket "anchor" gets fastened to prevent to upstream edge of the mattress getting lifted during floods.

6.3.8 Structural stability of groynes

When groynes are submerged, it is commonly found in the Western Cape that the water level difference from the upstream side to the downstream side of the groyne is in the order of 500 mm. This in itself does not represent a large force in relation to the self-weight of the structure, especially when the groyne section is wider than it is high. More serious considerations for the design of the thickness of the groyne section are damage that occurs as a result of floating trees during floods, and instability as a result of the undermining of the foundation (upstream or downstream). Floating tree stumps can be up to 20 tonnes and move



Figure 24 Preparing envelope for cellular construction - note the mesh below the geotextile envelope (the space between the gabion walls is now 1,8 m)



Figure 25 Compacting the granular fill in the envelope before closing and sealing

To address these needs of stability, in the Western Cape, unless groynes are less than 2m high, they are usually constructed with a four meter thick base. The four meter thick section is convenient because it provides for 'cellular construction', in other words two parallel skins of rock filled gabions joined top and bottom by a roll of two meter wide gabion mesh, and the

void is filled with geotextile wrapped, compacted granular fill (Figure 4 and Figure 5). Care must be taken during construction that the geotextile wrap, firstly cannot leak (joints must be securely stitched together), and secondly that the geotextile is not exposed to sunlight which will cause it to degrade (for this reason the cellular fill is now made 1,8m and the total section is only 3,8m wide). This section has been found to be very robust and cost effective. The tip of the cellular section groynes is constructed with solid gabions.

6.3.9 Protection of gabion baskets from abrasion

The abrasion of the wires of the gabion baskets and mattresses by rolling rocks and floating trees during floods has been a problem, especially around the tip of the groynes. For this reason the horizontal and sloping surfaces of the tips of groyne structures are now covered with a matrix of concrete pads 500mm x 500mm x 100 mm thick (40 mm below gabions wire), with 50 mm gaps between the pads. The use of pads in place of a continuous concrete skin has been chosen so as to maintain some of the flexibility of the gabion structure, especially the mattresses.



Figure 26 The provision of concrete abrasion pads to gabion matresses around tip of groyne

7 Vegetation for the stabilization of rivers

Why include vegetation in rehabilitation projects?

River rehabilitation as described in this document is intended for the stabilizing of transformed and degraded river systems where human interference with rivers has caused them to lose their natural stability during floods, and this leads to induced damage of farm and urban infrastructure.

The option of creating stable rivers by encasing them concrete channels is un-affordable, un-sustainable and environmentally un-acceptable. In the search for more pragmatic techniques to protect the production potential of agricultural land adjacent to rivers from flood damage, the author has developed the use of groynes to facilitate the provision of wider spaces where rivers can flow slower and transport less sediment. A further development of this concept is to strategically use appropriate indigenous vegetation to bind the soil of river beds and banks, and to provide hydraulic roughness that assists slow the flow velocity of rivers and reduce the amount and size of groyne structures needed.

The use of indigenous vegetation can have the added value of contributing to the partial restoration of biodiversity in the environment.

What sort of vegetation is required?

Vegetation for river stabilization should display the following characteristics:-

- Locally indigenous (don't make the mistake of assuming that a species that occurs in the Highveld of South Africa is "indigenous" to the fynbos biome of South Africa!)
- Deep rooted , so that it can bind soil and prevent bank slumping
- Is appropriately flood-adapted (e.g. lies flat during floods or has sacrificial branches / fronds that are easily stripped in floods but that can re-sprout from the established, deep-rooted main stem after flooding, while the roots retain soils)
- Note that naturally occurring species that quickly dominate a transformed landscape (such as Bullrush *Typha capensis* and Fluitjiesriet *Phragmites australis* are not recommended in situations where maintenance of high levels of plant diversity is a priority. In situations where the functional attributes of plant species are required, these species, and *Phragmites australis* in particular, may be useful cost effective ways of achieving high levels of plant cover in a short space of time
- As a general guide, plants used where soil stabilisation rather than biodiversity is the priority should be sourced from seed stock from the same catchment (ideally sub-catchment) hardy, readily available from local nurseries and/or easily propagated

Not only do we need to consider that there is a natural variation in vegetation species between different ecoregions, but also that there is vertical zonation from the river bed up the river bank at any given site (ie different plants thrive in the permanently wet zone to those that are

in the less frequently inundated zone). It is thus not helpful to prescribe a mix of plant species that fits all rivers and all situations in a river. For site specific information it is best to obtain the advice of a wetland ecologist or botanist, but it is essential to keep the abovementioned characteristics in mind to ensure that species with the right functional traits are selected. Generally tall trees have the dis-advantage of outcompeting lower growing species for sunlight, planting too many of them too close to a river can result in patches of riverbank not covered by vegetation that could have protected it from erosion – although this said, deep-rooting tree species can also provide valuable habitat and prevent bank slump. References for wetland vegetation include the Water Research Commission report TT 479/10 "Wetland plants" (Ginkel, et al., 2011) and the SANBI publication "The vegetation of South Africa, Lesotho and Swaziland" (Mucina, et al., 2006).

In the Western Cape coastal belt projects (Eden, Overberg and Winelands) the plants in Figure 27 are used where appropriate. The list is not exhaustive but indicates the type of species that one could use. Some of these tend to be present also in the East Cape and KZN.

SPECIES	IMAGE	COMMENTS
Palmiet *Prionium serratum*		Has deep roots and lays flat during floods, and is highly recommended in rivers where it occurs. Suitable for planting from in the wet zone of the river to the top of the bank providing that there is enough moisture for the plant to get established.
Cyperus *Cyperus textilis* ***Note not Nile papyrus from the Okavango which is alien***		Has strong root mat and lays flat during floods, highly recommended in rivers where it occurs although like typha it has a tendency to dominate the landscape. Suitable for planting from in the wet zone to the top of the bank

Besembos *Elegia capensis* and other		Has deep roots and lays flat during floods. Highly recommended in rivers where it occurs. Suitable from close to the waters edge to the top of the bank providing enough moisture is available.
Cliffortia *Cliffortia strubilifera*		Stabilizes soil during floods because vegetation lies flat on soil (or gets stripped and re-sprouts quickly). Suitable from close to the water's edge to the top of the bank (providing enough moisture available).
Vleibiesie *Carpha glomerata*		This is not a particularly remarkable erosion resisting plant but is commonly found in wetlands with other species that are suitable from close to the waters edge to the top of the bank providing adequate soil moisture is available.
Thatching reed *Elegia tectorum*		A useful plant for the edge of wetlands Very similar to *Thamnochortus insignis* and others. Suitable from close to the waters edge to the top of the bank. Not resistant to high velocity flows but provides soil cover and habitat

Wachendorfia *Wachendorfia thrysiflora*		A common West Cape wetland plant. Propagation by the division of rhyzomes.The roots are not exceptionally deep but the vegetation lies flat during floods and assists limiting soil erosion. Suitable from close to the waters edge to top of bank providing that there is adequate moisture.
Dune slack *Juncus kraussii*		This reed is useful in slightly saline environments for erosion control purposes. It is suitable from close to the water's edge to the top of the bank, except when flow velocities are high.
Soft rush *Juncus effuses*		Tends to appear naturally. Not a particularly erosion resistant plant but is very useful in a mix of plants along a river. Suitable in wet margin of river.

Figure 27 Examples of plants used in the Western Cape stabilization projects

Where vegetation should be planted?

Although the concept of using vegetation to aid the stabilization of rivers is still in a development phase, it has been agreed that opposed to spreading all plant species equally over the river margin and bank could result in poor survival rates if the plants are too far apart, and especially with plants such as palmiet it could be better to group them in strategic colonies where they could support one another during floods. Developing this idea it was believed that planting colonies of palmiet reed like groyne structures could lead to a reduced need for the structures. This is possible because Palmiet can be used across a wide zonation

of the river. For this reason a standard detail such as that in Figure 28 was developed. The Palmiet would be planted such that it forms a 3m wide strip from in the water to as high up the bank where it can still survive.

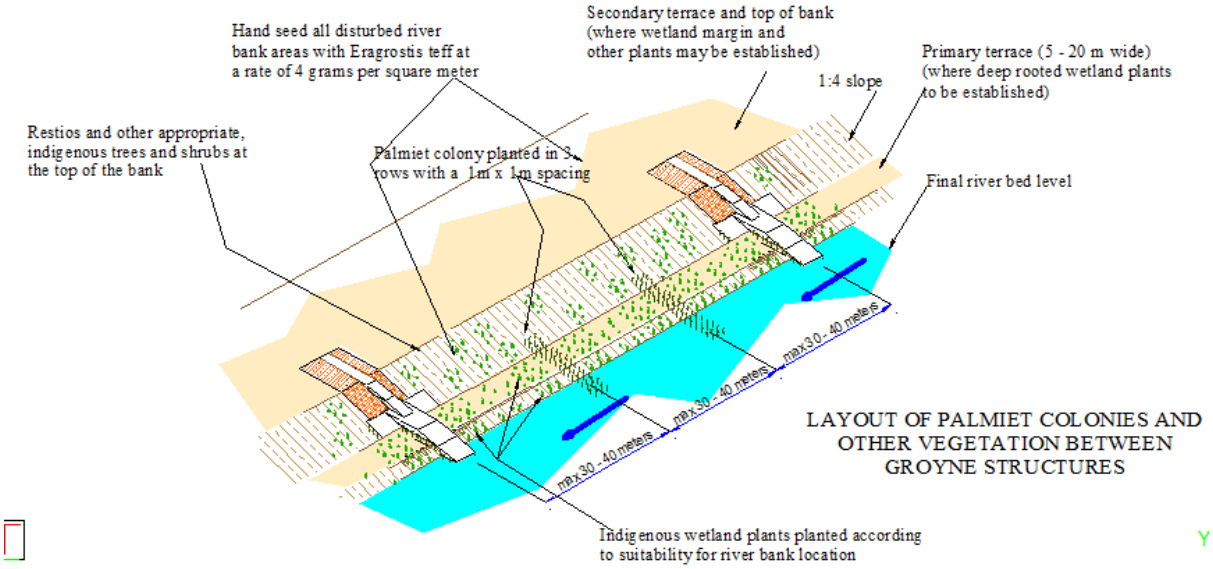


Figure 28 Plan detail showing the trial planting of palmiet in colonies to form "groynes"

Plants other than Palmiet should be spread over the whole bank, and where the water depth allows, into the river. Still there is value in making small clumps of the same species (3-5 plants).

How much vegetation should be planted?

On most projects so far experienced in the Western Cape, after the removal of dense stands of alien vegetation the sites have been largely bare of vegetation. The number of plants required depends on the site. On some sites suitable indigenous plants have appeared naturally, but this is not common.

Depending on the design objectives and budget, it is better to propagate and establish suitable indigenous species, at least to kick-start the re-vegetation process, and to place plant species strategically (such as the bands of Palmiet). Bear in mind that the cost of propagating and establishing plants is usually a small fraction of that of the civil works (2-4%), and if a good planting program can reduce the civil works by only 10% it makes good sense. Although controversial, the planting of Teff (an alien grass which does not re-seed) has been helpful in quickly covering bare soil and reducing the potential for erosion, until such time that the indigenous vegetation can get established.

What conditions need to be created to facilitate the survival of the plants?

Especially you plants are sensitive to the soil drying out and will struggle. Either irrigation must be provided for the first season or two to enable the plants to get established and get

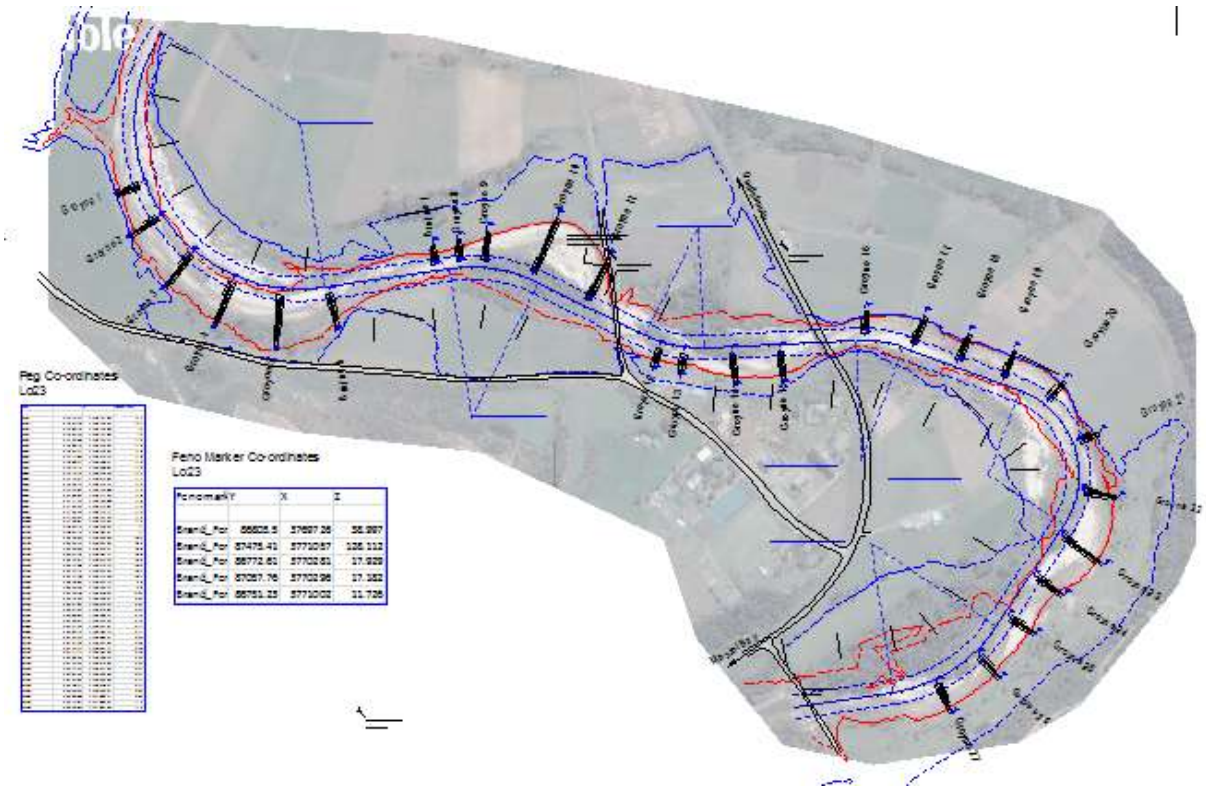
roots to a level where they can find water, or low planting terraces must be created between the groynes where the roots of the plants are at or very close to the water table. To do this the standard practise is to construct a planting terrace around 500 mm higher than the river bed, between the groynes. This creates an opportunity to establish plants without irrigation.
Thought should be given to the fencing off of the river bed and bank if there are grazing animals in the area. This can be relaxed after three years once the plants have got properly established, but then the river bed and bank should be grazed intensively for short periods with long periods of rest to recover.

8 Case studies

Brandwacht 2017

DATE: 2017
FUNDING: Western Cape: Department of Agriculture
COMMENTS:

- Over the last few years various sites along this 3 km stretch of river displayed high levels of instability. Alien vegetation was growing vigorously on the inside of bends causing the river to wash away the opposite banks. In addition to this the two public roads crossing the river were threatened as the river was eroding the bridge approach fill.
- With the combined objectives of protecting the public road and reducing the amount of sediment moving unnaturally down the Hartenbos River, the Western Cape Department of Agriculture planned the project and sourced funding to execute it.
- This project is characterised by long low groyne structures with indigenous wetland vegetation established between the groynes.
- Construction was completed in 2017.



The layout of the project showing the rehabilitated channel and groyne structures

See Figure 8 on page 12 for before and after views from the upstream bridge.



March 2017 View downstream from upper bridge



July 2018 View downstream from upper bridge



July 2018 View upstream over groyne 5

Duiwenhoks River: Project Klipdrift

DATE: 2015
FUNDING: Western Cape: Department of Agriculture
COMMENTS:

- Over the last few years the riverbank at this site has moved towards the public road perched on a slope some 10 meters above the river. During the 2012 flood the road finally collapsed into the river.
- With the combined objectives of protecting the public road and reducing the amount of sediment moving unnaturally down the Duiwenhoks River, the Western Cape Department of Agriculture planned the project and sourced funding to execute it.
- Bergstan South Africa were already working with the road upgrades in the area post the flood, and agreed to manage the project.
- With the first of two river bends in this project, very long and low groynes were used to locate the high velocity flow channel away from the river bank.
- Construction was completed in 2015. The revegetation of the site is in progress.

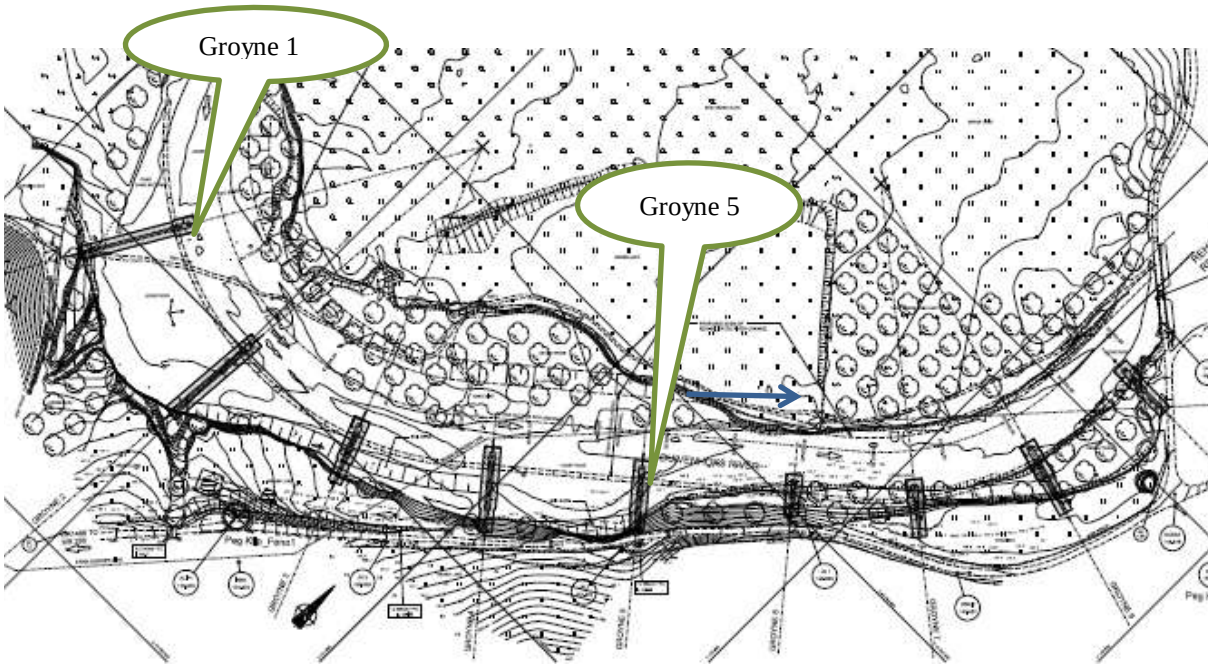


Figure 1 Portion of layout plan Klipdrift project (Bergstan South Africa; Department of Agriculture)



The road wash-away 2014



Groyne 5 2015



View of most upstream groyne (groyne 1) showing its length relative to its height – its function is mainly to locate the fast flowing channel away from the river bank

Moordkuil River : Project Bottelierskop 2014

DATE: 2014
FUNDING: Western Cape: Department of Transport
COMMENTS:

- The riverbank at this site had a history of instability and flooding caused frequent damage to the adjacent public road. During the 2012 floods a large quantity of flood debris was deposited next to the road with a lot of ensuing damage.
- On the instruction of the Department of Transport, Kantey and Templer planned the upgrade of the road and managed the construction phase, the Department of Agriculture planned the river stabilization works.
- Construction was completed in 2014.

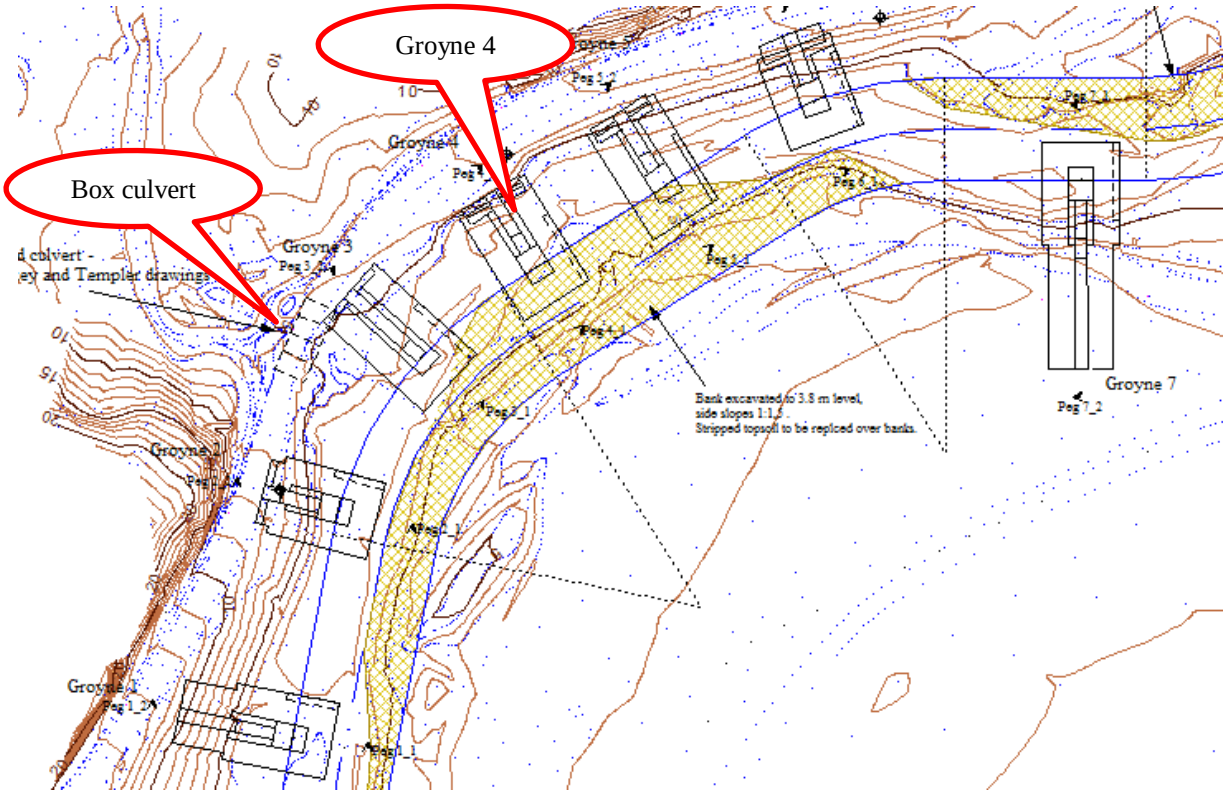


Figure 2 A portion of the layout of the Bottelierskop project (Kantey and Templer, Department of Agriculture)



Bottelierskop site 2 : post flood - 2012

(photo R Tyndall, Kantey and Templer)



Bottelierskop site 2 : post construction - 2015

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