SOUTH CREEK
BANK MANAGEMENT PLAN

Report Prepared for

Warringah Council

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GLOSSARY

Anastomosing Channel	A pattern of discrete channels which repeatedly separate and rejoin.
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	In 1971 the mean sea level for 1966-1968 was assigned the value of zero on the Australian Height Datum at thirty tide gauges around the coast of the Australian continent. The resulting datum surface, with minor modifications in two metropolitan areas, has been termed the Australian Height Datum (AHD) and was adopted by the National Mapping Council as the datum to which all vertical control for mapping is to be referred.
Average Thalweg Distance (ATD)	Average distance along the deepest point of the creek.
Average Recurrence Interval (ARI)	Refers to the long term average interval or average period between occurrences of a flood of a given size. The average recurrence interval does not imply that the flood of a given size will occur regularly.
Backwater	Morphologically detached side channel which is connected at the downstream end to the main channel.
Bedrock	An outcrop of material in the valley floor or sides which is significantly harder than the majority of river bed and bank material.
Bedrock Control	Description given to a river reach which is constrained vertically and/or laterally by bedrock outcrops.
Bedrock Pool	Area of deeper water formed behind a resistant strata lying across the channel.
Bench	Narrow erosion "terrace like" feature formed at edge of active channel and attached to the macro channel bank. Compare with a ledge.
Braid Bar	Multiple mid-channel bars forming a complex system of converging and diverging thalweg channels.
Bedrock Core Bar	Accumulation of finer sediment on top of bedrock.
Bedrock Pavement	Horizontal or near horizontal area of exposed bedrock.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.

Cataract	A succession of drops which become drowned out at bank full flows.
Channel Junction Bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a flatter gradient channel.
Design Flood (also Design Discharge or Design Flow)	A flood of known magnitude or average recurrence interval used for engineering design and planning purposes.
Drop	Abrupt continuity in channel slope which maybe less than the channel depth and which is drowned out at high flows. Compare with a waterfall.
Flood Chute (also Rip Channel)	High flow distributary channel on the inside of point bars or lateral bars, may form a backwater at low flows.
Floodways	Those areas where a significant volume of water flows during floods. They are often aligned with obvious naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, the areas of deeper flow or the areas where higher velocities occur.
Geomorphic Unit	Term given to a river feature associated with a distinct form process.
Hydraulics	The study of water flow; in particular the evaluation of flow parameters such as stage and velocity in a river or stream.
Hydrograph	A graph which shows how the discharge changes with time at any particular location.
Hydrology	The study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Islands	Mid channel bars which have become stabilized due to vegetation and which are submerged at high flows due to flooding.
Lateral Bar	Accumulation of sediment attached to the channel margins (banks). Bars may alternating from one bank to the other (alternating lateral bars) to form a sinuous thalweg (low flow) channel.
Landscape Unit	Term given to a distinct compartment of similar topography.
Ledge	Narrow depositional "terrace like" feature formed at edge of active channel and attached to the macro channel bank. Compare with a bench.
Lee Bar	A bar which forms immediately downstream of an obstruction to the flow, caused by the relatively lower velocity flow in the lee of the obstruction which allows increased deposition of sediment.
Lingoid Bars	A large mobile feature formed in sand bed streams which has a

(Also Sand Waves Or Transverse Bars)	steep front edge spanning the channel and which extends for some distance upstream. A surface composed of smaller mobile dunes.
Macro Channel	An erosion channel defined by the high river banks and usually containing a thalweg channel and 1 or more benches and/or ledges.
Mid-Channel Bar	Single bars formed within a stream and having primary flow channels on either side.
Morphological Unit	A single topographical feature.
Paleo Channel	An ancient ancestral river course now abandoned. May or may not be filled with alluvium.
Peak Discharge	The maximum discharge occurring during a flood event.
Plane Bed	Topographically uniform bed formed in (usually coarse) alluvium lacking well defined scour or depositional features.
Planform	The horizontal alignment and shape of a river.
Planform Control	Description given to a river reach which is unconstrained vertically and/or laterally by bedrock outcrops.
Plunge Pool	Erosional feature formed below a waterfall.
Point Bar	A bar formed on the inside of a meander in association with a pool on the opposite bank. Lateral growth of the point bar is associated with erosion of the outside bank and the migration of meander loops across the floodplain. A compound point bar features 2 or more distinct near horizontal surfaces.
Pool	Topographical low point in an alluvial channel caused by scour and characterised by relatively finer material.
Probable Maximum Flood (PMF)	The flood calculated to be the maximum which is likely to occur.
Probable Maximum Precipitation (PMP)	The precipitation calculated to be the maximum which is likely to occur (includes rain, hail and snow).
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller ex-explanation see annual exceedance probability.
Rapid	A steep transverse bar formed from boulders or bedrock or local steepening of the channel longitudinal profile. Local roughness elements are drowned out at intermediate to high flows.
Riffle	A transverse bar formed of gravel or cobbles and commonly separating upstream and downstream pools.
Runoff	The portion of rainfall which actually ends up as stream flow, also known as rainfall excess.

Stage	Equivalent to 'water level'. Both are measured with reference to a particular datum and location.
Stage Hydrograph	A graph which shows the variation in stage with respect to time. It must be referenced to a particular location and datum.
Step	Step like features formed by large clasts (cobble and boulder) organised into discrete channel spanning accumulations; steep gradient.
Terrace	The upper most surface immediately beyond the valley side.
Terrace Rise	The relatively steeper ground rising from the valley floor, bench or ledge to the terrace.
Thalweg	The longitudinal line traced by the lowest point in a valley / low flow channel.
Thalweg Channel	The lowest or primary channel in a river system.
Transverse Bar (also Diagonal Bar)	A bar which forms across the entire channel at an angle to the main flow direction. See also lingoid bar
Waterfall	Abrupt continuity in channel slope where the height of the fall is significantly greater than the depth of the channel and is never drowned out at high flows. Compare with a drop.

1. INTRODUCTION

This report has been prepared for Warringah Council to assist in the management of South Creek and to identify the type and scale of works that may be required to secure unstable sections of creek bank and to take these works into account in the hydraulic model representing possible future conditions.

1.1 Available Data

The data used for this report was primarily topographic mapping, cadastral mapping and estimated flood extents taken from existing reports.

The majority of the information used in preparing this report was recorded during site inspections in 2005. Detailed site inspections were undertaken along the entire length of South Creek from Narrabeen Lagoon to Spilstead Place approximately 250m upstream from the former Beacon Hill High School site, and along Wheeler Creek as far as the Willandra Bungalows (**Figure 1.1**).

Also utilised in this study was the *Warringah Council Creek Management Strategy* (MWH, 2004). This study details land use in the area and changes to the creeks. It details South Creek and Wheeler Creek water samples and lists outcomes for both of these creeks. It further details a management study and plan for South Creek. Specifically it notes that with regards to South Creek, increases in peak flows have widened and incised the creek in some areas, preventing bank stabilisation and revegetation.

Source: whereis.com.au (2007)

Figure 1.1 Locality Plan and Extent of Study

1.2 Hydrology

All creek flows referenced in this report are based on the estimated flow hydrographs reported in the South Creek Flood Study (WMA, 2006). Estimated flows with frequency intervals less than those reported have been calculated using the same hydrological model as adopted for the South Creek Flood Study (WMA, 2006).

2. CREEK MANAGEMENT ISSUES

The form of South Creek ranges from bedrock confined in the upper and middle reaches to a fully unconfined alluvial stream in the lower reaches. Many intermediate forms are present between these two extremes. Severe instability in creek planform and channel geometry is limited to a small number of discrete locations but several reaches are characterised by general degradation/retreat of the banks and accompanying siltation along downstream areas. Some of the bank instability noted is due to the sandy nature of the bank soils while in other areas banks had been stripped of most of the vegetation and not stabilised before replanting.

From a geomorphic perspective the key bank management issues are:

1. Areas of unstable bed and/or bank that is threatening drainage infrastructure.
   Upstream of the former Beacon Hill High School site a piped crossing has been undermined, several other locations show stormwater pipes which are being destabilised.

2. Areas of unstable bank that is threatening or resulting in the loss of private land.
   Eroding banks have destabilised a large tree at the confluence of South Creek and a local tributary draining from the Dorothy Reserve area.

3. Significant quantities of sediment deposited in the creek and/or being transported to Narrabeen Lagoon.
   Large sediment deposits are accumulating near Carcoola Road. Vegetation has become established on the deposits reducing the inlet flood capacity of the culverts as well as the conveyance capacity of the creek.

4. Presence of weed species within the riparian corridor.
   The effect of weed species is mixed. Some dense woody species such as Lantana can assist in stabilising an eroding bank, but may also trap sediments in unwanted locations that can then lead to further bank destabilisation. Overall it is preferable to establish less aggressive species that are native to the locality and will assist in stabilising the bank while maintaining floral diversity.

From a management perspective the flowing issues have been considered when developing the management strategies:

1. pipes and culvert crossing or adjacent to the creek;
2. land ownership;
3. land use influences;
4. sediment types and distribution; and
5. the sediment / flow balance.

The geomorphic assessment is provided in **Chapter 3**, field observations and remarks are presented on a reach by reach basis in **Attachment 1** and a collection of photographs taken during field investigations is provided in **Attachment 2**.

3. FLUVIAL GEOMORPHIC ASSESSMENT

3.1 Broad Characteristics of the Catchment

The South Creek catchment covers 7.3km^2 of the suburbs of Cromer, Beacon Hill, Narraweena, and Oxford Falls. The source of South Creek is at Red Hill at an elevation of approximately 150m AHD. Wheeler Creek rises at Cromer Heights at an elevation of approximately 110m AHD.

The terrain is characterised by a moderately sloping plateaux separated from the coastal plain by steep escarpments. The soils are characteristically derived from the sandstone bedrock of which there are significant outcroppings in the upper and middle reaches.

An estimated 59% of the catchment is developed for residential, commercial or light industrial purposes with the remainder comprising urban open space or bushland.

Vegetation includes significant areas of native species but weed species are also widespread. In the upper reach of the South Creek riparian corridor dense weed growth, particularly Lantana (*Lantana camara*), is severely limiting the bio-diversity value of the creek environment.

3.2 Broad Reach Characteristics

The study area has been delineated into four reaches defined by their geomorphic characteristics. The reaches are:

1. South Creek Upper Reach (ATD 0.0km – ATD 0.90km);
2. South Creek Middle Reach (ATD 0.90km – ATD 1.98km);
3. South Creek Lower Reach (ATD 1.98km – ATD4.64km); and
4. Wheeler Creek.

The broad characteristics of these reaches are provided below and the reach extents are shown on **Figure 3.1**. Additional details on bank condition are provided in **Attachment 1** and a collection of photographs taken during field investigations is provided in **Attachment 2**.

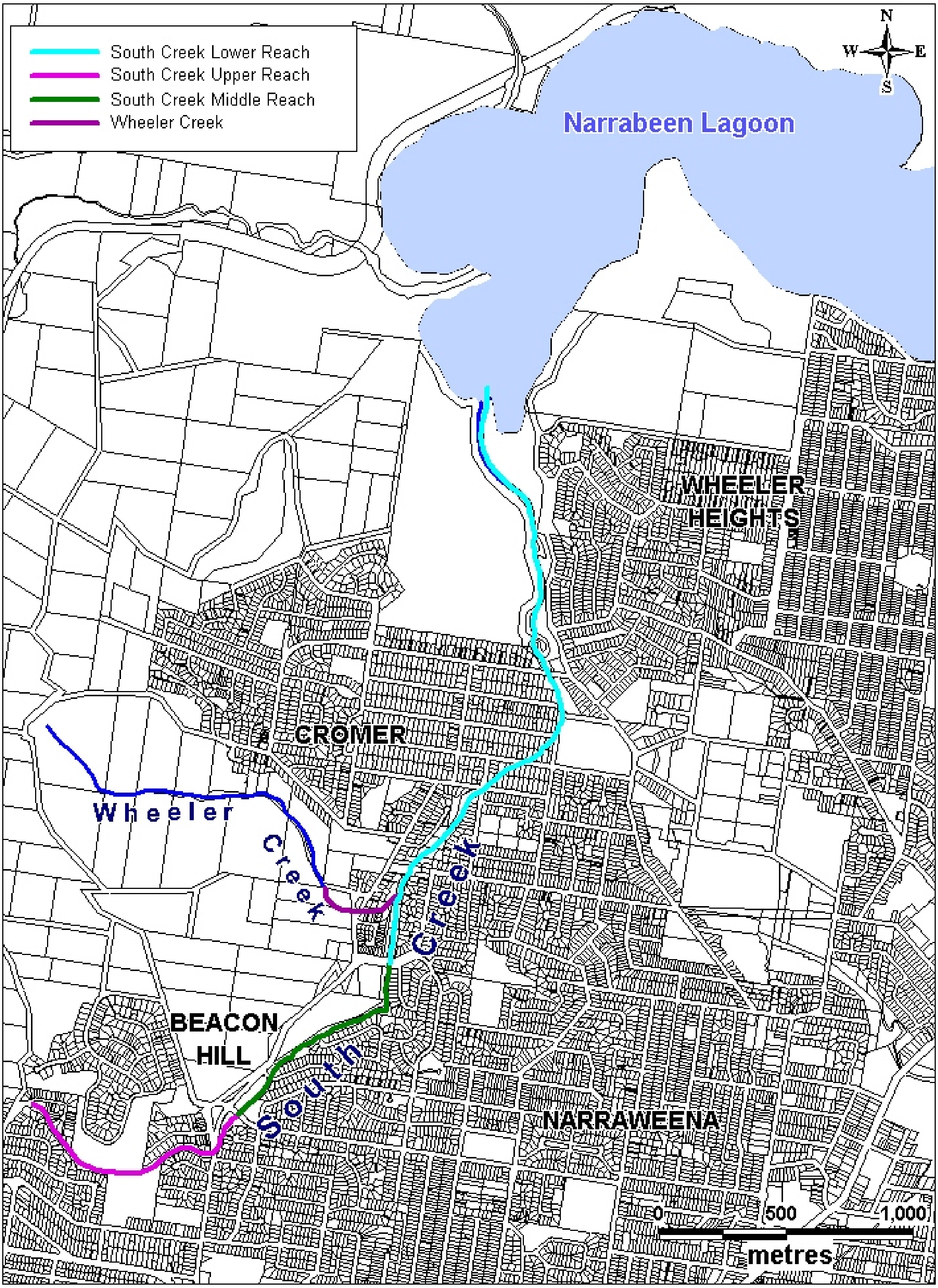

Figure 3.1 South Creek and Wheeler Creek Reaches

3.2.1 South Creek Upper Reach (ATD 0.0km ~ ATD 0.90km)

The upper reach has been defined as upstream of the first Willandra Road crossing (**Figure 3.1**).

The upper reach of South Creek is typified by a single well-defined channel, at times deeply incised. The bed slopes is on average almost 4% but frequent outcrops of bedrock are limiting the depth of incision and almost all of the instability is associated with lateral movement of the banks.

The vegetative cover is extensive but light limiting in many areas which is restricting the growth of ground cover species that could assist in reducing the erosion. In particular Lantana is prevalent, and although it can be a valuable species with its ability to reduce the velocity of main stream flows, it prevents any groundcover species becoming established. As a consequence local runoff and even moderately small creek flows are able to slowly but continuously erode areas of bank.

Access along the first 200 metres downstream of Brooker Avenue is impossible without slashing. However, thick sediment deposits in the creek bed are testimony to erosion in the upper-most areas of the catchment. A deep hole was noted at ATD 0.17km which may have been the result of a fallen tree that has since been removed.

Some bank protection work comprising a sandstone rock retaining wall west of the former Beacon Hill High School site has been constructed and appears to be in good condition.

A concrete encased service crossing at ATD 0.30km has been undermined and if left unattended is likely to lead to collapse of the service. Erosion at the bank where the crossing emerges is also occurring.

Elsewhere generally the creek is reworking sandy-silt deposits that form the creek banks. Frequent outcrops of bedrock appear to be controlling the bed grade but there is still considerable potential for erosion in the sections between the bedrock controlled reaches.

The area behind the former Beacon Hill High School site is of particular concern as the area appears to be frequently used, judging by the presence of compost heaps.

Along the section upstream of Willandra Road the creek enters a shallower reach characterised by low cascades and bedrock confining valley walls (ATD 0.66km ~ ATD 0.9km).

3.2.2 South Creek Middle Reach (ATD 0.90km ~ ATD 1.98km)

The middle reach of South Creek is considered to be the section between the first and second Willandra Road crossings (**Figure 3.1**).

The middle reach is characterised by an almost continuous outcropping of bed rock resulting in a continuous run of cascades and small waterfalls. The average bed slope through the reach is 7%. The sandstone bedrock is exposed along the creek bed and only small pockets of sandy sediment are present. The creek is very shallow with the right bank at times no more than 500mm high (ATD 1.25km). At some locations areas of cultivated lawn extend to the creek bank. The exception is the 200m long section between McIntosh Road and Alkira Circuit where the creek has become incised up to 3m deep and sandy silt of an unknown thickness forms most of the bank profile.

The middle reach is considered stable except for areas immediately downstream of McIntosh Road and Alkira Circuit where soils are resting on a steep bank. Dumped garden waste was noted at both of these locations at the time of inspection. This could contribute to bank instability by increasing the loading at the top of the bank and ultimately increasing the rate of slumping (see Figure 4.1). The garden waste would also contribute to elevated nutrient levels and the spread of weed species.

3.2.3 South Creek Lower Reach (ATD 1.98km ~ ATD4.64km)

The lower reach has been defined as the section downstream of the Willandra Road (lower) crossing (ATD 1.98km) (**Figure 3.1**). This reach is within the coastal floodplain which grades from an elevation of 8.5m AHD at Willandra Road to 0.5m at Narabeen Lagoon (ATD 4.64km). The average bed slope through the reach is 0.3%.

Whilst this reach has similar geomorphic characteristics along its length, the land use characteristics vary quite significantly. In the upper sections of this reach, residential development is immediately adjacent to the creek on the right bank and is set back from the creek on the left bank. Only minor instability issues were noted along this section with some sections of exposed bank due to limited vegetation cover. However, generally the vegetation cover was good but comprising of predominately weed species.

The section of this reach between Carcoola Road and Toronto Avenue has a wide riparian zone particularly due to the wetland area adjacent to St Mathews Farm Reserve. Proliferation of weeds and sedimentation was noted along this reach.

Immediately downstream of Toronto Avenue significant erosion was noted on the left bank, potentially undermining the bridge foundations and an exposed pipeline. In general the creek downstream of Toronto Ave was stable with only minor weed proliferation.

3.2.4 Wheeler Creek

Only the lower reach of Wheeler Creek between the confluence with South Creek and the Willandra Bungalows has been included in this management plan. This lower reach is within an alluvial system and displays similar characteristics to the South Creek lower reach with which it joins. Development of the catchment in the lower reaches has resulted in increased weed invasion potential and an increase in catchment-derived pollutants.

Immediately downstream of Little Willandra road only minor bank erosion was noted. Further downstream near the confluence with South Creek the banks were noted to be covered with dense weed growth and dumped garden waste was noted.

3.2.5 Soil Erodibility

Medium to coarse sandy soils dominate the creek banks in the upper and middle reaches with an increasing percentage of fine sands, silt, and organic matter in the lower reach. As noted elsewhere in this report the lack of established ground cover species in the upper and middle reaches is allowing the supply of sediment to the lower reaches to continue. While this is in part a natural phenomenon in sandstone catchments, the rate of erosion is increased due to increases in the peak flow rate and volume of runoff, associated with the urban development of the catchment.

Estimates of sediment yield vary greatly and without long term sampling it is impossible to accurately predict the base sediment load being transported. Williams (1972) reported soil loss of between 0.17 and 4.32 tonnes/ha/yr from sandstone hills in NSW with slopes varying from 3^0 to 25^0. The median value was 1.44t/ha/yr.

Further work reported by Humphreys and Mitchell (1983) for soil movement on Sydney Basin sandstone hillslopes indicated average soil loss rates ranging from 0.25~0.86 tonnes/ha/year for coarse grained soils probably not that dissimilar to the sandy soils of the South Creek catchment. Applying the average rates reported to the South Creek catchment there would be an expected sediment load ranging from 180 tonnes 630 tonnes annually reaching Narrabeen Lagoon. For unconsolidated sediments this tonnage would approximate to between $120m^3$ and $420m^3$.

Sediment loads currently delivered to Narrabeen Lagoon during a typical rainfall period (28/2/95 – 6/3/95) were determined by the AQUALM catchment runoff model as part of the Narrabeen Lagoon Estuary Processes Study (WBM, 2001). Under the current developed state, South Creek was estimated to convey 79 tonnes to the Lagoon during this period, and an average annual load of approximately 1075 tonnes.

While an estimate of the possible sediment load coming from an undeveloped South Creek catchment is not within the scope of this plan it is likely to be at the lower end of the undeveloped estimated range shown above (Williams, 1972 & Humphreys and Mitchell, 1983). This is significantly lower than the loads calculated for the developed catchment (WBM, 2001). Hence a sustainable bank management plan should seek to restrict the rate of erosion to rates consistent pre-development rates rather than attempting to halt erosion altogether. Proposed measures are described in **Section 5**.

3.3 Sediment – Flow Balance

For alluvial streams several empirical relationships linking discharge with channel gradient, width, depth, and the type of soil forming the channel have been established. In these relationships discharge is measured as either the mean annual flood discharge (Q_{ma}) or mean annual discharge (Q_m).

The “formative” discharge or “dominant” discharge is often considered as the “bank-full” discharge in alluvial streams. However, this is not always the case as local factors may have a significant influence. Typically local factors which may affect the formative flow are localised changes in sediment type and size, vegetation and channel gradient.

For stream management the mean annual flood discharge should be used as the absolute minimum discharge when designing any stream training or bank protection works. However, the preferred minimum discharge to be used is the 5 Year ARI flow and ideally the 10 Year ARI flow. For works designed to protect major infrastructure a 20 Year ARI flood or greater would be considered appropriate. Designing to a greater flood standard is not usually economically viable as even small increases in flood velocity will result in significant increases in the mass and extent of protective works required.

4. BANK MANAGEMENT MEASURES

4.1 Bank Erosion

Bank erosion can be both a natural process and a process triggered or enhanced by anthropogenic influences. Bank erosion is often a result of a combination of processes and therefore indicative of one or more of the geomorphologic processes that include:

- Stream metamorphosis,
- Stream bed degradation,
- Planform Processes (Meander Processes), and
- Stream Avulsion.

However bank erosion can also be a process in its own right. Bank erosion can on occasion be the result of a purely local process and can be dealt with as such.

The mechanism of bank failure will generally involve more than one failure mode. The most common failure modes involve mass failure such as;

a. Collapse following undermining,
b. Slumping (sloughing),
c. Rotational or slip circle failure,

or initial detachment of individual particles involving

d. Attrition or,
e. Fretting

Other modes of failure include;

f. Erosion by overland flow entering or leaving the main channel creating a headward erosion gully, and
g. Tunnel erosion (piping failure).

Some typical failure modes are illustrated below in **Figures 4.1, 4.2 and 4.3**.

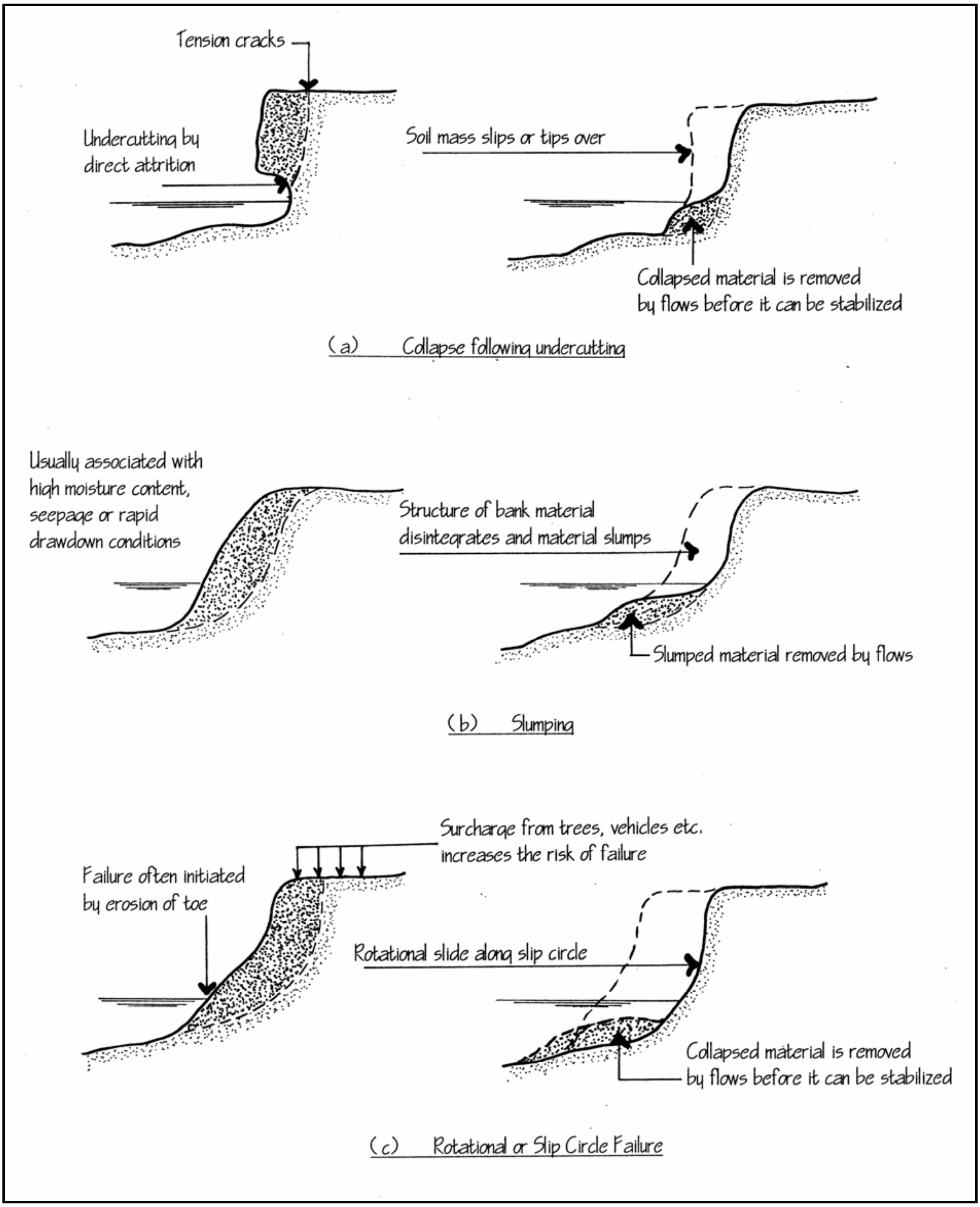

Figure 4.1 Bank Failure Modes – Mass Failure

(Source: Standing Committee on River and Catchments, 2001)

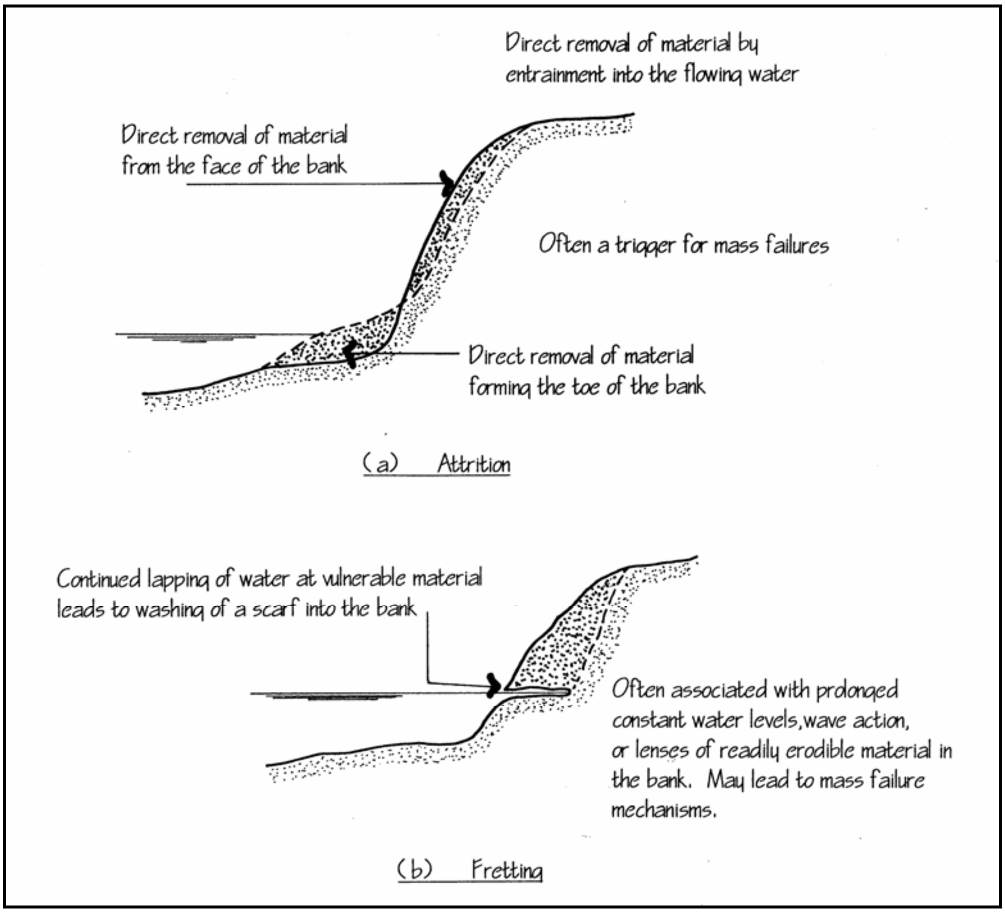

Figure 4.2 Bank Failure Modes – Detachment of Individual Particles

(Source: Standing Committee on River and Catchments, 2001)

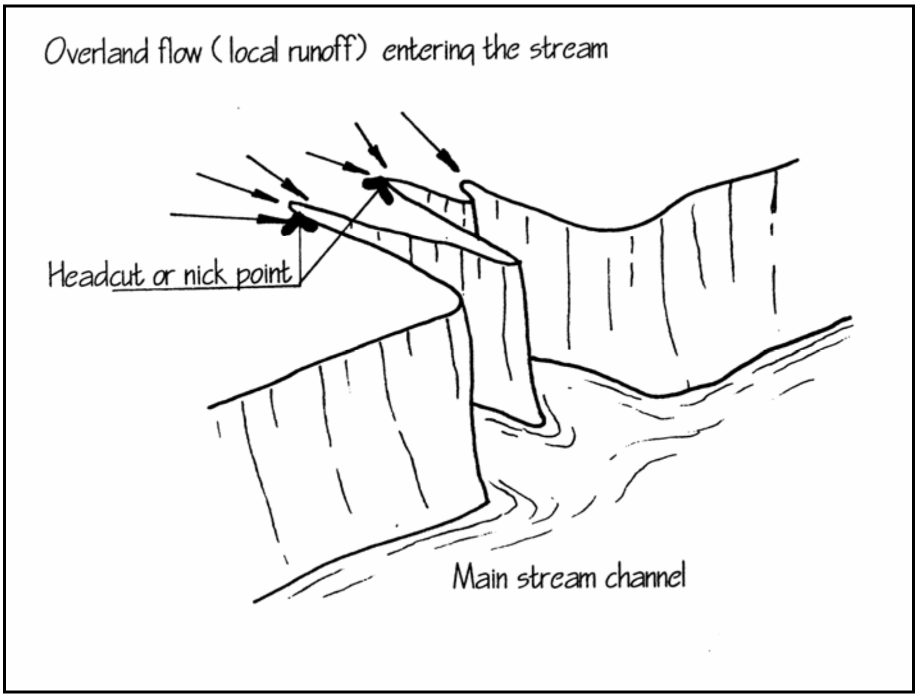

Figure 4.3 Bank Failure Modes – Erosion from Lateral Overland Flow

(Source: Standing Committee on River and Catchments, 2001)

Causes of Bank Erosion

Factors contributing to bank erosion within the study reach include stream flow, bank material, bank vegetative cover, channel obstructions and in some cases surcharge loading on the top of the bank.

Stream Flow

Stream flow is nearly always a contributing factor in bank erosion. The relative importance in the bank erosion process is dependent upon velocity, upstream alignment, turbulence and secondary currents. Stream flow can lead to attrition or undermining and typically contributes to mass failure by removing the supporting material at the toe of the bank. Episodic erosion is related to the frequency and duration of flows which have sufficient energy to mobilize the bed or bank material. The effect of a single flood may itself be insufficient to cause an irreversible change but may provide the conditions (ie removal/damage to bank vegetation) to allow smaller subsequent floods to scour the stream bed and/or banks.

Bank Material

The presence of a softer or unconsolidated and more readily erodible layer of bank material can lead to undermining or fretting. The removal of supporting bank material then results in a mass failure. The importance of the presence of a more readily erodible layer is greatest when the layer is close to the normal water line and subjected to both stream velocity and wave action.

Flow Obstructions

Obstructions may include trees, stabilized gravel bars, footbridges or road abutments or any other objects which either divert flow towards the bank or increase flow velocities adjacent to the bank which exceed the scour threshold value of the bank material. This may lead to undermining or attrition of the bank with subsequent mass failure.

Surcharge

Loads on top of the bank can contribute to mass failure. Typically surcharging arises from filling, roads, buildings or occasionally large trees. Vibration from irrigation pumps may also reduce soil strength leading to collapse of the bank.

Vegetation

Appropriate vegetation assists in reducing erosion risk by;

- binding the soil structure,
- providing a barrier between the soil and the flowing water,
- reducing the velocity of channel flow; and
- reducing the effects of waves.

Where protective vegetation has been reduced or removed bank scour is generally present to some extent. There are areas in South Creek where this has occurred and/or ground cover species have not become established and in these locations it is considered to be a major factor in bank instability.

Velocity is a product of many of the other variables listed and can be a primary indicator in assessing the viability of stream management works. Quoted velocities usually refer to the mean velocity at a given cross section and this can have important ramifications for creek management. The velocity varies both horizontally and vertically across a section; with the maximum point velocity usually ranging from +25% to +50% of the mean velocity (Chow, 1959). As South Creek is fairly steep with high velocities, velocity is an important consideration in the design of river bank protection works.

The type and distribution of bed and bank material is a product of the catchment geology, land uses and management practices and the carrying capacity of the river. The change in particle size along the river system is closely related to the channel geometry and flow variables such as velocity. The reduction in particle size with increasing distance downstream is caused by particle abrasion, hydraulic sorting and chemical weathering. This is noticeable in South Creek where cobbles and small boulders were noted in the creek bed upstream of the Willandra Road (ATD 0.88km) are virtually absent at the Toronto Avenue Bridge (ATD 3.45km).

The geologic structure and composition of bed and bank material are also important in the development of channel shape. In general, a channel with fine material will have a greater depth than a channel with coarse material all other factors being equal.

The sediment discharge also affects the channel shape with streams carrying finer sediment (with lower settling velocities) having a greater load and generally a larger channel width/depth ratio.

4.2 Bank Stabilisation Techniques Overview

Management strategies may include both interventionist (structural) techniques or non-structural techniques, such as changes in land use practices. Non-structural techniques would form part of long term strategies, the effects of which may not be noticed for 10 years or more.

Structural strategies include bed and bank management techniques, although it should be noted that implementation of a bed control technique will always have implications for bank condition and vice versa.

As noted in Section 3.2.5, the sediment in the banks is primarily sandy. Previous studies undertaken by cardno have identified that without viable ground cover bank erosion in sandy soils will often continue unless structural measures are used.

Apart from two notable sites at ATD 0.40km and 1.825km, the overriding management issue for South Creek is the control of progressive bank retreat due to fretting and attrition with some attendant slumping. This is likely to be the result of changes in the flow-sediment balance due to changes in land use in the catchment. It is likely that due to increased catchment development there has been an increase in flow velocities and volume resulting in channel erosion and no deposition in some locations and in the wider channel areas (such as St Mathews Farm) excess sedimentation is occurring.

To manage the progressive bank retreat it is expected that the management strategy for the creek will include predominantly bank management techniques focussed on re-vegetation with suitable species and supplemented where necessary by vegetation reinforcement matting and/or limited rock work where it is considered unlikely that vegetation can be established and remain viable in the long term.

Bank management techniques include bank protection techniques and bank stabilisation techniques. Bank protection techniques are those which aim to physically protect the bank material from the direct action of flowing water, while bank stabilisation techniques aim to stabilize the bank material by increasing its strength to resist failure. Many techniques perform both these functions.

Bank protection techniques are appropriate against the bank failure modes described as "attrition" and "fretting". By preventing the removal of material from the toe of the bank they can be effective in preventing mass failures by collapse, sloughing or rotational failure.

Bank stabilisation techniques can increase the stability of the bank material by;

- surface or subsurface drainage to reduce the water content in the bank,
- battering to decrease the bank slope,
- incorporating a stabilizing medium such as soil-cement,
- establishing vegetation to bind the bank material,
- providing mass support at the toe of the bank (eg rock rip-rap, soil confinement, gabions),
- removing surcharge from the top or face of the bank (buildings, trees, vehicle access).

The various techniques available may also be also be divided into hard structural, soft structural or non-structural techniques.

Typical **hard structural techniques** include;

- placed rock armouring,
- rock rip-rap revetment,
- concrete armouring including articulated concrete block mattresses revetment,
- rock filled wire baskets (gabions and mattresses),
- soil confinement,
- groynes and retards,
- retaining walls (timber, concrete, steel sheet piling).

Typical **soft structural techniques** include,

- re-vegetation using artificial reinforcement mats to provide increased stability,
- tree planting,
- tree stabilisation when used with rocks or packed earth,
- soil confinement when used with re-vegetation,
- groynes and retards when used with re-vegetation

Non structural techniques typically include,

- exclusion fencing,
- tree removal or lopping, and
- snag management/brushing,

Other management techniques available but which do not afford direct protection to the bank include;

- relocation of assets under threat,
- prohibition or control and policing of threatening activities (e.g. uncontrolled access down a river bank), and
- bank survey/monitoring.

4.3 Suitable Bank Management Techniques

The techniques listed in this report and particularly those nominated for use at selected sites have been chosen on the basis of the condition of the creek when inspected, the level of analysis undertaken, and the performance of the techniques in comparable catchments.

Measures considered suitable for application at various locations along South Creek and Wheeler Creek include:

- Bank battering with re-vegetation
- Vegetation management
- Fencing
- Rock rip-rap
- Hard timber or Ecolog bank toe protection
- Gabions and reno mattresses, and
- Bed excavation.

Appropriate management of the creek banks will;

- protect existing assets under threat,
- provide increased stability of property boundaries,
- improve public safety, and
- improve riparian habitat.

4.3.1 Bank Battering (Technique 1)

Battering is simply the process of excavating the over-steepened bank to a slope that is significantly less than the natural repose angle of the material forming the bank. The battered slope would normally be vegetated, and often in conjunction with top-soil and a bio-degradable matting, to assist in the re-vegetation process. Unless protection is provided at the toe of the bank and below levels normally affected by 6 monthly or yearly flows then battering will usually only provide a short term solution. As a stand-alone technique it is best suited for use on intermittent flowing streams. Battering is often the first step in preparing the bank as part of soil confinement as discussed for Techniques 3 and 4.

4.3.2 Re-vegetation (Technique 2a)

Re-vegetation is only successful as a stand-alone technique where suitable conditions already exist and the exposed bank has resulted from an abnormal set of circumstances such as a sequence of significant floods where the intervening time between floods has been less than the natural recovery time for damaged vegetation.

The known exceptions are exotic species and have not therefore been considered for inclusion in the bank management strategy. The value of vegetation in combating bank erosion will be in reducing the strength of the currents flowing against the bank to values that are approaching, and preferably less than the scour threshold velocity for the soil. It may be noted that even velocities of 1m/s would be sufficient to scour the low cohesive sandy soils that constitute most of the vulnerable eroding banks in the catchment. For vegetation to be effective in arresting erosion in the South Creek system it must include extensive dense ground cover species that can tolerate frequent submergence. To this end vegetation management should include a careful review and on-going monitoring of light limiting species overhanging the ground cover. Recent studies in the Wyong River and Ourimbah Creek catchments (Cardno Lawson Treloar, 2006) concluded that despite extensive lower, middle, and upper storey species along the stream verges, without viable ground cover bank erosion in sandy soils would continue unless structural measures were used.

A similar situation is considered to exist in the South Creek catchment.

4.3.3 Vegetation Reinforcement (Technique 2b)

3-Dimensional Erosion Control Mats

3-Dimensional Erosion Control Mats are supplied as rolls of light weight polyamide or polyethylene matting. The mat is usually about 18mm thick and is characterised by an open mesh of fibres forming an upper cuspated surface with an array of pockets to trap soil particles while allowing vegetative root systems to grow down through the matting. The matting is highly flexible with a 3 dimensional drape quality which allows it to conform to, and maintain close contact with the soil surface. A wide variety of proprietary products are available but not all have the same durability or robustness. Products which retain their structural integrity when cut are preferred to alternatives which feature a top and bottom mesh enclosing a mass of loose fibres as the latter tend to disintegrate when damaged by cutting or tearing.

When correctly installed and well vegetated the "reinforced vegetation (grass)" has been shown to be able to withstand a velocity of 4.5m/s for 12 hours (CIRIA, 1985). The matting has been successfully used in stream restoration work in Australia, America and Europe and when combined with vegetation would be expected to find application as an erosion control technique in the South Creek catchment.

Bio-degradable Mats

A variety of bio-degradable mats are commercially available. Most are manufactured from coarse natural fibres such as coconut fibre with either a close or open weave. They are used to provide temporary sacrificial cover for re-vegetated areas while the new plantings become established. Typical applications include holding down seeded straw or brushing while self germination occurs. There is evidence of hessian matting employed along parts of South Creek in the past.

Geotextiles

A geotextile is a permeable fabric manufactured from synthetic material (usually polypropylene, polyester or polyamide (nylon)) and maybe non-woven, woven or knitted (Hausmann, 1990). It is supplied on a roll and is available in widths from about 2 metres to 5 metres.

In coarse grained soils, such as medium sized sand and coarser particles, woven geotextiles may give satisfactory performance but needle punched non–woven geotextiles are the most common and most widely used in river engineering applications. Non-woven geotextiles are suitable for use with all soil types. They are available in a range of weights and corresponding thicknesses, permeabilities and burst strengths.

A typical general purpose geotextile and one which would be suitable for the majority of stream work on the South Creek system would have a mass of approximately 250g/m^2 to 280g/m^2. Lighter geotextiles maybe used in non-critical locations or as a permanent erosion control mat which is thin enough to allow grass to penetrate (*e.g.* Bidim A12 or A14). Heavy geotextiles or double thickness geotextiles are recommended where it is used under sharp rocks or gabion baskets.

4.3.4 Cellular Soil Confinement – Reinforced Earth Retaining Wall (Technique 3)

This technique involves the use of a proprietary cellular product that is secured to a prepared bank face or is stacked in horizontal layers. The main advantages of soil confinement mats are their compactness and light weight making them easy to transport to remote sites, the ability to utilize on site soils (sand and gravel are particularly suited), their flexibility and tolerance to some bed and bank unevenness, and their compatibility with vegetation.

The system is manufactured from either woven coir yarn or high density polyethylene (HDPE). The woven coir yarn product is marketed as Coirweb™ and has a life expectancy of 5 to 7 years. It is not suitable for use in stacked horizontal layers. The HDPE product is marketed as Ecocell® and Geoweb® and both are suitable for permanent installations.

The HDPE mat works by containing the backfill material within a cell approximately 200mm x 240mm and 200mm deep and both shields the backfill from direct water currents as well as providing a stable environment in which vegetation can be established. Mats with larger cells and/or different cell depths are also available. The woven coir yarn product is only available as a 150mm deep cell that is 400mm x 400mm.

Two possible variations of soil confinement have been presented in this report. One variation is to use Coirweb™ and the second variation uses Ecocell™ or an equivalent product.

The indicative cost for protecting a minimum 50m of 2m high bank using the Coirweb is $22,000. However the Coirweb has a maximum life expectancy of 7 years and in circumstances where the bank is predominantly sand and mature vegetation is unlikely to stabilise the bank then substantial repair/maintenance would be required. The alternative of using Ecocell which is manufactured from HDPE has a life expectancy of 30 years or more. The additional cost for 50m of bank (150m of bank face) is $2,000.

4.3.5 Cellular Soil Confinement – Reinforced Earth Slope (Technique 4)

A high density polyethylene (HDPE) cellular confinement mat is laid over a prepared surface, typically a battered bank. The cells are filled with a granular material although all soil types may be used. Vegetation should be used if sand, silts and clays are used as backfilling.

The technique provides protection against surface erosion / rilling. The sloping bank should not be steeper than about 26^0 from the horizontal. For steeper slopes additional stakes and anchor lines (polypropylene or stainless steel) connected to buried anchors at the top of the slope should be used to secure the matting. A slope stability analysis for banks steeper than 26^0 is recommended.

4.3.6 Bio-reinforced Earth retaining Wall / Bank (Technique 5)

A geo-grid is used to construct a reinforced earth bank in front of, or to replace the eroding bank. Suitable deep rooting vegetation is sandwiched between successive layer of geo-grid as the bank is constructed. A lightweight geo-grid or geo-textile is used to face the bank. Where necessary the geo facing is cut to permit the vegetation root stock to grow and cover the bank.

Reinforced earth bank may be near vertical or sloping. A concrete or timber crib wall may be used in lieu of reinforced earth. Where crib walling is used the lower lifts are usually filled with rock (cobble size or larger) if the wall is below water level or subject to wave action.

The technique provides bank protection against undermining, piping, and slumping failure modes.

4.3.7 Tree Management (Technique 6)

The technique is used to reduce the risk of localised bank stability and may include:

- Lopping or trimming of trees that have been undermined or are leaning precariously to remove public safety threat.
- Reducing the risk of tree collapse and resulting exposure of unprotected stream bank , or to reduce the surcharge load on a bank weakened by over steepening or undermining.
- Tree planting on suitable low bank terraces to assist in binding the soil and reducing the risk of erosion.

The technique is however limited by the risk of localised rock protection placed around the base of the tree being outflanked if more general erosion occurs over a wider front, and/or newly planted trees may be lost if high flows occur before they become sufficiently well established.

4.3.8 Rip-rap Armouring (Technique 7)

Rock rip-rap is placed against a prepared bank to provide a physical barrier between the bank and the flowing water. Bank maybe battered before placing the rip-rap. A filter layer, either a non-woven geo-textile or a well graded rock layer is used to limit any leaching of the fine bank material. Large rock boulders may be placed in lieu of dumping and spreading smaller rock. Broken concrete slabs are sometimes used but usually ineffectually. Specially designed concrete blocks maybe used but they make the project expensive. Maybe constructed with either a buried toe apron (cut-off) or a self-launching apron.

The technique is used to improve slope stability and to provide instant protection to an eroding bank and is commonly used in conjunction with bank battering. Depending on the shape and size of the rock works can withstand high velocities for prolonged periods.

4.3.9 Gabion Retaining Wall (Technique 8)

Gabions are wire baskets that have been filled with small rock. They have been commonly used in the past to overcome the problems of obtaining large “quarry run” rock. The main advantages of wire baskets are the lightness and ease of transport when collapsed, the capacity to conform a range of “squared” or sloping bank profiles, and the ability when filled to provide a large unit mass to overcome stream re-mobilization forces. However, they are difficult to cover with vegetation except by creeping ground covers, have an “un-natural” geometric appearance, and tend to allow increases in near bank stream velocities and hence scour potential. In high streams with large coarse mobile sediment loads gabions are prone to wire abrasion failure. There is also a tendency for litter and flood debris to be caught on the wire as well as potential danger to the public arising from sharp wire. The technique nonetheless can be very useful in some circumstances and has been employed to stabilise an area of the South Creek at approximately ATD2.06km.

The technique provides immediate protection and increased stability to eroding banks. It is suitable for addressing a wide range of bank failure modes including fretting, direct attrition, and undermining to sloughing (mass failure). Drawbacks of the technique include premature failure by wire breakage due to high sediment loads carried by the stream, vandalism, public safety concern where wire breaks or by creation of steep vertical drops. Failure often occurs due to toe scour and the system should nearly always include a deep cut off wall or self launching apron.

4.3.10 Dredging (Technique 9)

Dredging a river or creek can be useful in situations where an increase in the flood carrying capacity of the stream is required or to minimise siltation in downstream reaches. Dredging is undertaken using heavy earth moving machinery from either the bank or from within the stream bed.

The technique can be financially self supporting where there is a continual supply of sediment and a market for the dredged material. It can however have severe environmental consequences by completely destroying in-stream habitat and it may result in major and potentially irreversible changes in the stream processes. Any dredging should therefore be carefully planned and monitored for any unforseen consequences in both the upstream and downstream reaches so that remedial action can be taken at the earliest opportunity. As a general rule, dredging should not lower the stream bed below the overall gradient through the reach.

4.3.11 Minor Grade Control (Technique 10)

Headward erosion in a stream bed can result in unstable banks due to over steepening, and an increased sediment supply to downstream reaches which may result in bank erosion as the stream adjusts to the changes in the sediment supply- water balance.

Grade control structures can vary widely from rock chutes to concrete cut-off walls. Typically, in ecologically sensitive streams grade control is achieved by constructing check weirs, rock chutes, or log weirs. In each case the structure should be well embedded into the stream bank so as to reduce the risk of seepage flows eroding the bank and out flanking the structure. The structures should generally be limited to less than 1m above the stream bed and protection provided at the toe of the structure to prevent a plunge pool developing that would otherwise destabilise the structure.

4.3.12 Fencing (Technique 11)

Fencing can be either temporary, usually steel “star pickets” with several stands of wire and/or farm mesh fencing (Ringlok® or similar), or a more substantial permanent structure. In the context of this report permanent fencing of a more substantial nature has only been considered in view of the likely long term benefits of continued exclusion of human access to the creek except at properly constructed locations. The type of fencing envisaged would comprise primarily vertical slats to deter access. The fencing should be located several metres back from the top of the high bank. The set back would however be dependent upon what can realistically be achieved at any particular site based on the co-operation of the landholder, the existing ecological value of the vegetation, its potential for recovery if in a degraded condition, and the potential progression of any active bank erosion.

Fencing at the rear of the former Beacon Hill High School site is considered a key component in managing the creek in that area. However, fencing is an adjunct to other techniques rather than a stand alone option.

Further information and diagrams of the various techniques is provided in **Attachment 3**.

5. BANK MANAGEMENT STRATEGY

5.1 Implementation Plan

The implementation plan for bank management works has been provided in a summarised table of works in **Table 5.1**. Sites have been identified by chainage as this provides a unique identifier and immediately places the site in the context of its location with other sites. These chainages are also shown on site notes in **Attachment 1** and the photographic montage in **Attachment 2**.

5.2 Work Priorities

Areas for attention have been rated as high, moderate or low depending upon the assessed risk for further rapid bank erosion and the threat to public infrastructure or buildings.

5.3 Design of Bank Management Works

Specific designs have not been prepared for the various sites requiring attention using structural / hard engineering techniques. When designing bank protection works care is required to ensure that the extent of works is not likely to cause further instability either upstream or downstream of the works site. The assessment should at the very least consider the overall alignment of creek flows through the reach, the likelihood of generating flow eddies adjacent to the works, and any changes in flow velocities. In the latter case, increase in flow velocities close to the creek bank induced by smooth hard bank protection works may significantly increase the risk of bank toe scour.

5.4 Monitoring

It is recommended that a monitoring programme be established at pre-determined creek sections which allows a quick field assessment of bank movement using either a tape measure or range finder. Hand held GPS units are not considered sufficiently accurate for monitoring on the scale of South Creek. A comparison of surveys for each year following Spring or Autumn will assist in identifying creek behaviour and may provide early warning of potential sudden shifts in bank alignment during subsequent floods.

Table 5.1 Bank Management Plan Action List

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Very High	Undercutting of concrete weir/service crossing	6,7,8	ATD 0.40km	Technique 7 – Rock rip-rap. Site is subjected to high hydraulic forces therefore soft engineering techniques unlikely to provide a long term solution. Alternatives: Technique 8 (Gabions). Would work but broken wire can be hazardous. Technique 3 (Cellular reinforced earth wall if filled with stone.) Technique 8 (Bio-reinforced wall) Would only be useful on the banks when well clear of the weir.
High	Undercutting of Toronto Avenue bridge Structure and services	77-2	ATD 3.46km	Erosion on the left bank undercutting the bridge structure and services crossing the creek. Due to threat to infrastructure the erosion should be stabilised using rock rip rap (Technique 7) or a gabion wall (Technique 8).
High	Headward erosion of creek bed	63	ATD 2.55km	A small drop (approx. 300mm) in the creek bed appears to be migrating upstream unless it encounters bedrock. Upstream migration of the drop will increase bank instability further adding to the potential for erosion and sediment being transported to the lower reaches. The potential for sediment generation is far greater than the apparent significance of the drop based on size. Stabilise drop using a rock chute or log weir. (Technique 10 – Minor Grade Control). Regular monitoring will still be required to check stability and effectiveness of weir.

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
High	Exposed creek bank.	61,62,63,64	ATD 2.52~2.59km	When inspected the right bank had been stripped of vegetation but no replacement planting or re-vegetation commenced. Re-vegetation of creek banks should always be staged and interim protection provided while waiting re-planting. Technique 2 (Reinforced Vegetation). Bio-degradable matting could be used on the upper bank providing the mature vegetation community will still admit sufficient sunlight to maintain a dense healthy groundcover.
High	Bank undercut and large tree de-stabilised.	36,37	ATD 1.83km	Bank has been undercut on outside bend and tree is adding to bank instability due to surcharge load. Support tree by re-placing soil and protecting re-instated bank with large rocks (Technique 7 – Rip Rap Armouring). Alternatively use cellular reinforced earth wall (Technique 3 – Cellular Reinforced Earth). Gabions (Technique 8 – Gabion Retaining Wall) would work structurally but are not favoured.
Medium to High	Eroding vertical bank with trees being endangered.	34,35	ATD 1.84km ~1.96km.	Bank appears to be slowly but steadily retreating. Battering the bank would result in loss of the trees therefore techniques that can provide a steep but stable bank face (Techniques 3 – Reinforced Earth or 5 – Bio Reinforced Earth) are preferred. Waterway area should be maintained.

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Medium to High	Extensive siltation of creek and dense growth of Typha is restricting hydraulic capacity of creek and culverts. May eventually lead to destabilization of the creek banks.	65,66,67,68,69	ATD2.7km ~ 2.90km.	Creek bed needs to be dredged and a control program implemented to eradicate or at least limit the extent of Typha growing in the creek bed. Technique 9 - Dredging.
Medium	Weed infestation		ATD 0.17~0.20km	Staged removal and re-planting. Use bio-degradable matting to assist the re-establishment of native species.
Medium	Unprotected sandy terrace subjected to frequent flow	11,12	ATD 0.49~0.53km	Technique 2 – reinforced vegetation. Permanent matting reinforcement, recommended as area is light limited which will make it difficult to establish and maintain dense ground cover.
Medium	Exposed sandy soil at piped outlet.	38,39	ATD 1.83km	Local stormwater pipe is discharging to an unlined channel with a deep sandy bed. Intermittent flows would permit a cellular confinement mat to be used to stabilize the channel (Technique 4 – Cellular Reinforced Earth Slope). Moderate priority due to small area.
Medium	Stormwater pipe outlet apron partially collapsed.	47,48,49	ATD 2.27km	Large diameter pipe discharges onto an apron that has been undermined and partially collapsed. Repair apron and stabilise with rock rip-rap (Technique 7).

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Medium	Extensive silt deposits in the creek bed have been stabilized with vegetation including many weed species. The potential for further siltation is considered significant.	72,73,74	ATD 3.05km~3.30km	Extent of dredging (Technique 9) will be partly dependent on flood risk and instability of the silt deposits and the creek banks. Any dredging and vegetation removal / replacement should be done in a carefully staged manner to reduce the risk of de-stabilisation of the creek and sediment slugs moving downstream during high flows.
Low to Medium	Banks are characterised by significant patches of poor quality vegetation and exposed areas.		ATD2.0km~2.2km	Staged removal and re-planting. Use bio-degradable matting to assist the re-establishment of native species where there will be sufficient sunlight to maintain a dense ground cover when vegetation matures. Otherwise use permanent matting to reinforce new vegetation.
Low	Deep scour on tributary	1,2	ATD 0.15km	Backfill and re-vegetate.
Low	Stormwater outlet undercut	4	ATD 0.20km	Technique 7 – Rock rip-rap.
Low	Broken stormwater pipe.	14	ATD 0.50km	Replace / repair broken pipe, cover and re-vegetate area.
Low	Sparse groundcover and relic erosion features.	16	ATD 0.78~0.88km	Monitor. Stabilise using reinforced vegetation (Technique 2) as required. Avoid use of biodegradable matting if area is light limited.
Low	Potential bank slips	23,24	ATD 1.05km	Bank condition could not be assessed due to steep slope and thick vegetation. Monitor for rock falls. Clear rock and vegetation debris from outlet area as necessary.
Low	Potentially unstable bank	27	ATD 1.27km	Bank appears overly steep. Depth of soil/vegetation cover unknown. Monitor regular and stabilise using Techniques 2 (Reinforced Vegetation) or 3 (Cellular Reinforced Earth Retaining Wall) if necessary.

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Low	Banks are characterised by significant patches of poor quality vegetation and exposed areas.		ATD2.18km~2.27km	Staged removal and re-planting. Use bio-degradable matting to assist the re-establishment of native species where there will be sufficient sunlight to maintain a dense ground cover when vegetation matures. Otherwise use permanent matting to reinforce new vegetation.
Low	Unstable sandy deposits in creek bed.	50	ATD2.32km	Remove and or stabilize deposits using reinforced vegetation reinforced with permanent matting (Technique 2 – Reinforced Vegetation). Bio-degradable matting will disintegrate too quickly and is considered unlikely to provide long term assistance especially under high flow conditions.
Low	Banks are characterised by patches of poor quality vegetation and minor isolated occurrences of bank erosion.	53,54,55	ATD2.40km2.52km	Staged removal and re-planting. Use bio-degradable matting to assist the re-establishment of native species where there will be sufficient sunlight to maintain a dense ground cover when vegetation matures. Otherwise use permanent matting to reinforce new vegetation.

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Very Low to Low	Weed management		ATD 3.6km ~ 4.6km	This reach of the creek passes across a wide flat floodplain. Creek flow is sluggish and in general vegetation lines the low banks. The does not appear to be the need for significant structural works or bank repair along this reach. The primary management control required is to monitor the general condition of the creek including stability of, and public safety at the weir, and implement staged removal of weeds and re-plant as necessary. The need to reinforce any new vegetation planting along this reach is not regarded as important except in the areas close to Toronto Avenue where higher velocity flows and relatively steeper and higher banks exist.
Very Low	Washout behind stormwater pipe headwall	15	ATDS 0.71km	Monitor. Stabilise using Technique 2 (Reinforced Vegetation) or Technique 7 (Rip Rap Armouring) as appropriate if and when required.
Very Low	Minor instability due to access to GPT.		ATD 0.91km	Monitor. If instability worsens consider using cellular mat backfilled with cobbles. (Variation of Technique 4).
Very Low	Weed management		ATD 1.1km~ 1.2km	Monitor and implement staged removal and re-planting as necessary.
Very Low	Potential right bank instability	23,24	ATD 1.2km~ 1.25km	Bank height is less than 1m with expected high velocity flow over bedrock. When inspected the reach appeared stable but should be checked after significant high flows.
Very Low	Weed management	27, 28, 29	ATD 1.3km~1.77km	Monitor and implement staged removal and re-planting as necessary.
Very Low	Vertical rock wall	9,10	ATD 0.41~0.45km	Monitor for undercutting at base of wall.

Priority	Description	Photo Reference	Location	Suggested Management Technique and Comment
Very Low	Gabion retaining wall.		ATD2.18km	Monitor for signs of undercutting at base of wall. In long term consider replacing with Techniques 3 (Cellular Reinforced Earth Retaining Wall) or 5 (Bio Reinforced Earth) to provide a more natural bank environment free of discontinuities.
Very Low	Weed management	76	ATD 3.4km	Monitor and implement staged removal and re-planting as necessary.

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ATTACHMENT 1

Stream Bank Survey and Investigations

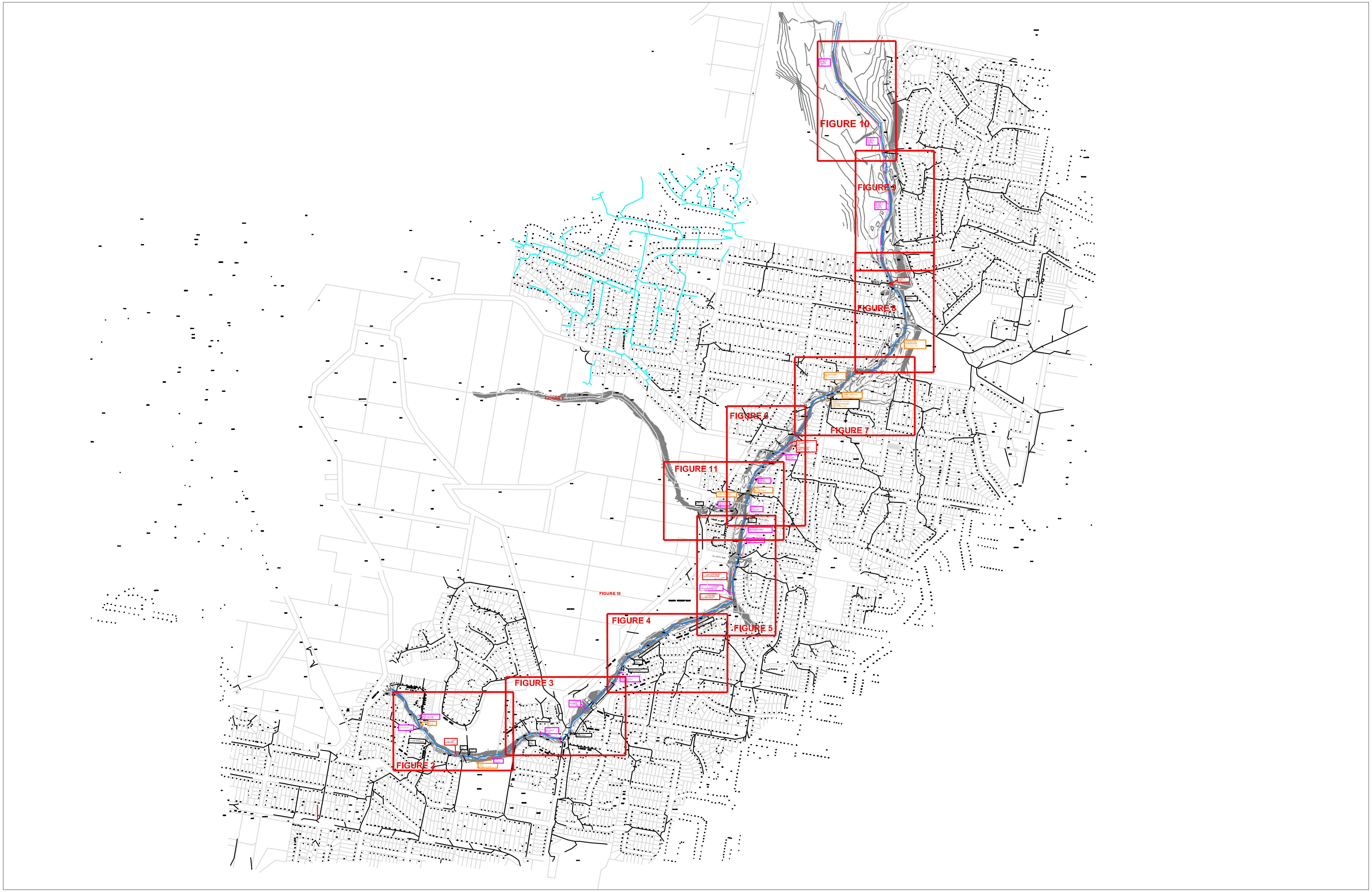
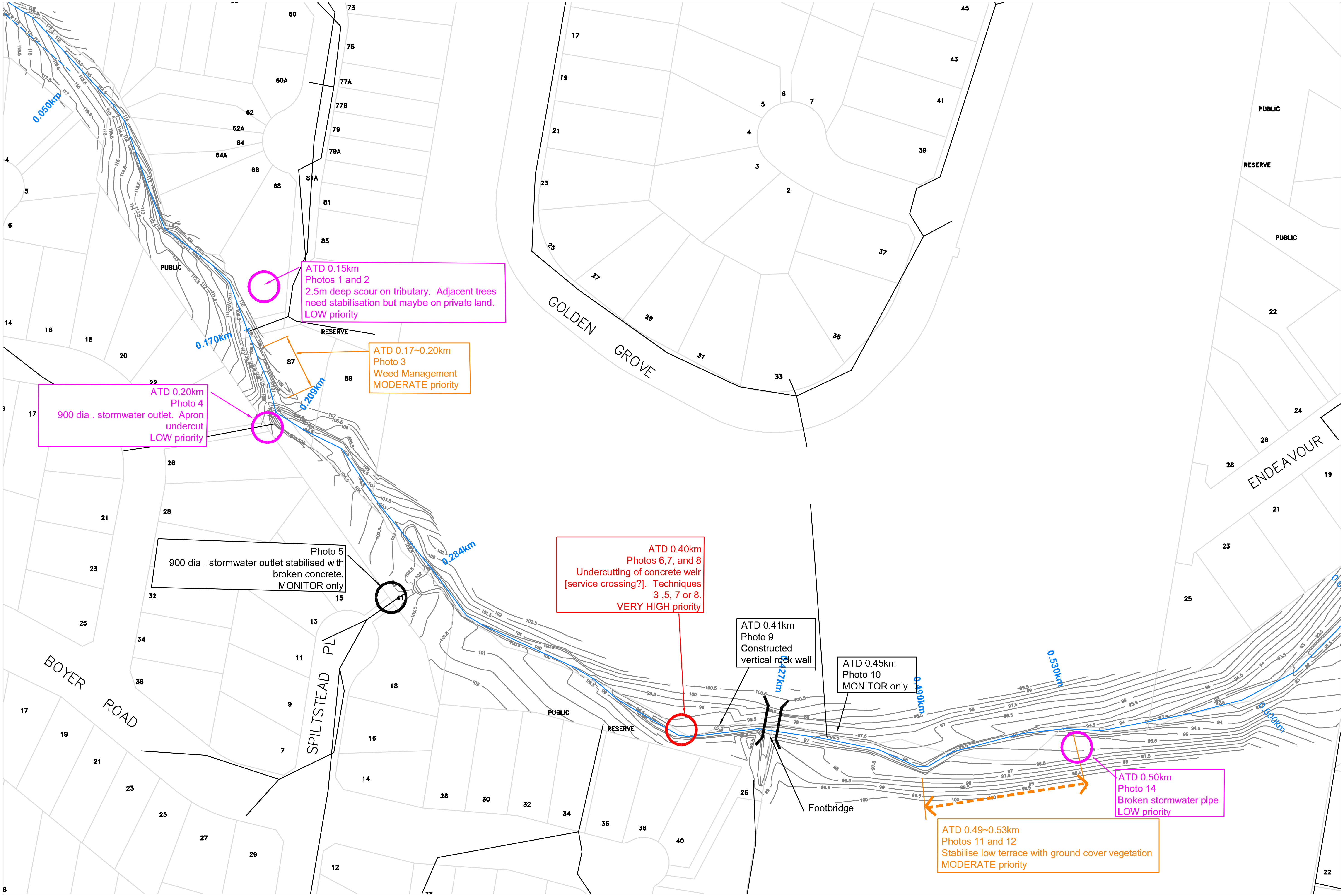


FIGURE 1
KEY PLAN
SOUTH CREEK BANK MANAGEMENT PLAN



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4 February 2008

FIGURE 2
ATD 0.02KM TO ATD 0.60KM
SOUTH CREEK BANK MANAGEMENT PLAN

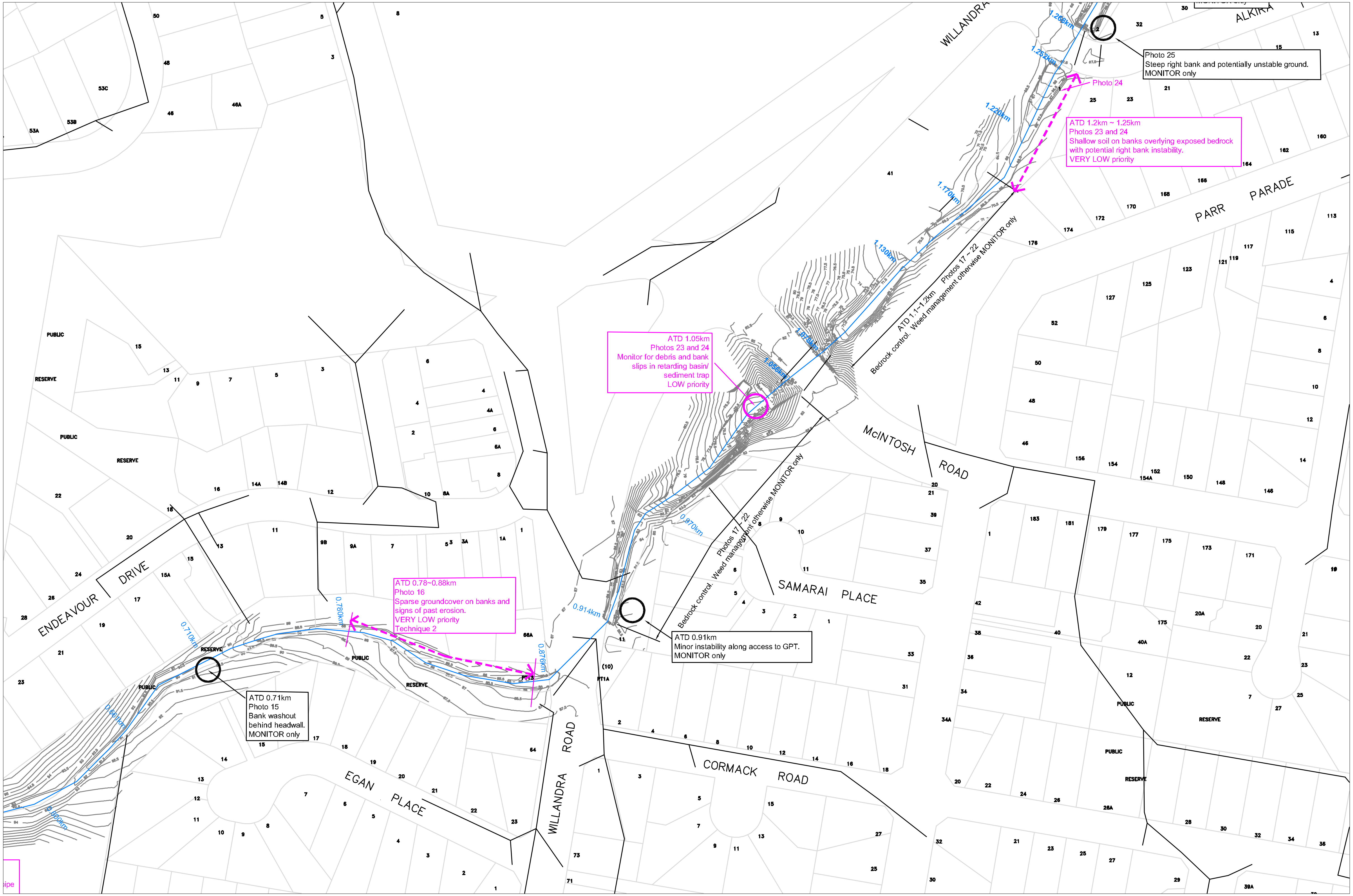

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FIGURE 3
ATD 0.60KM TO ATD 1.17KM
SOUTH CREEK BANK MANAGEMENT PLAN

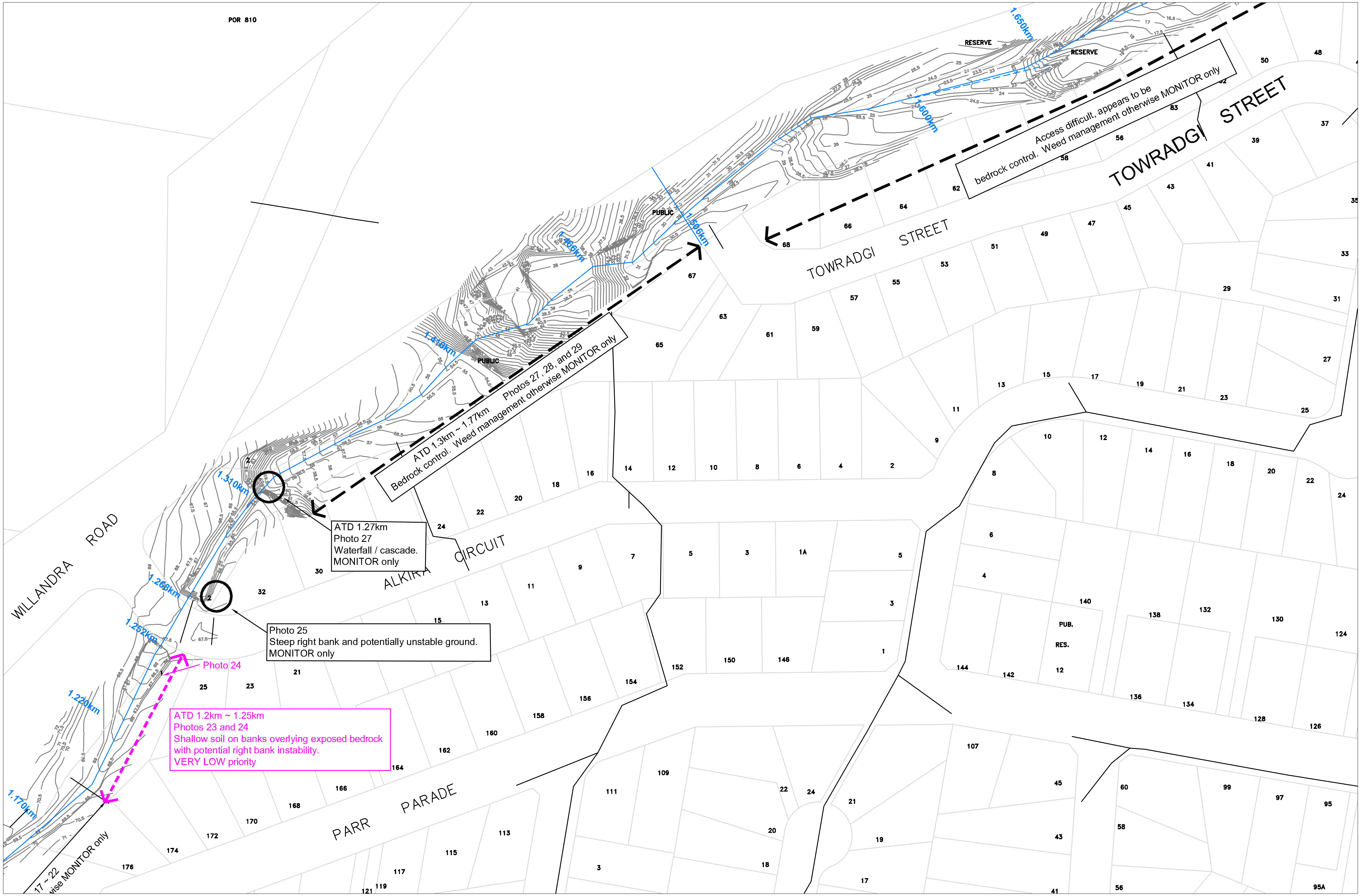

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FIGURE 4
ATD 1.17KM TO ATD 1.65KM
SOUTH CREEK BANK MANAGEMENT PLAN

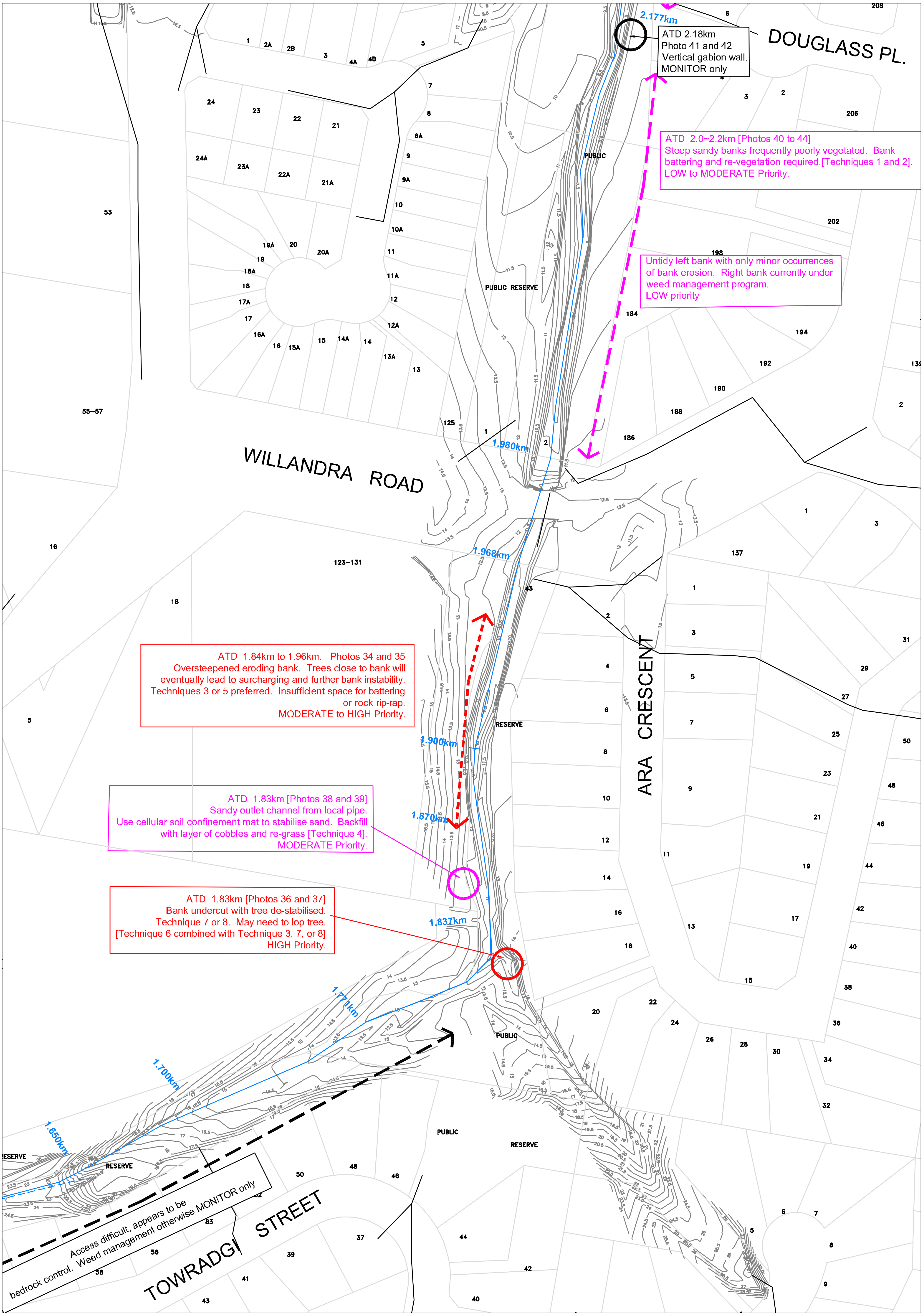

FIGURE 5

ATD 1.65KM TO ATD 2.18KM
SOUTH CREEK BANK MANAGEMENT PLAN

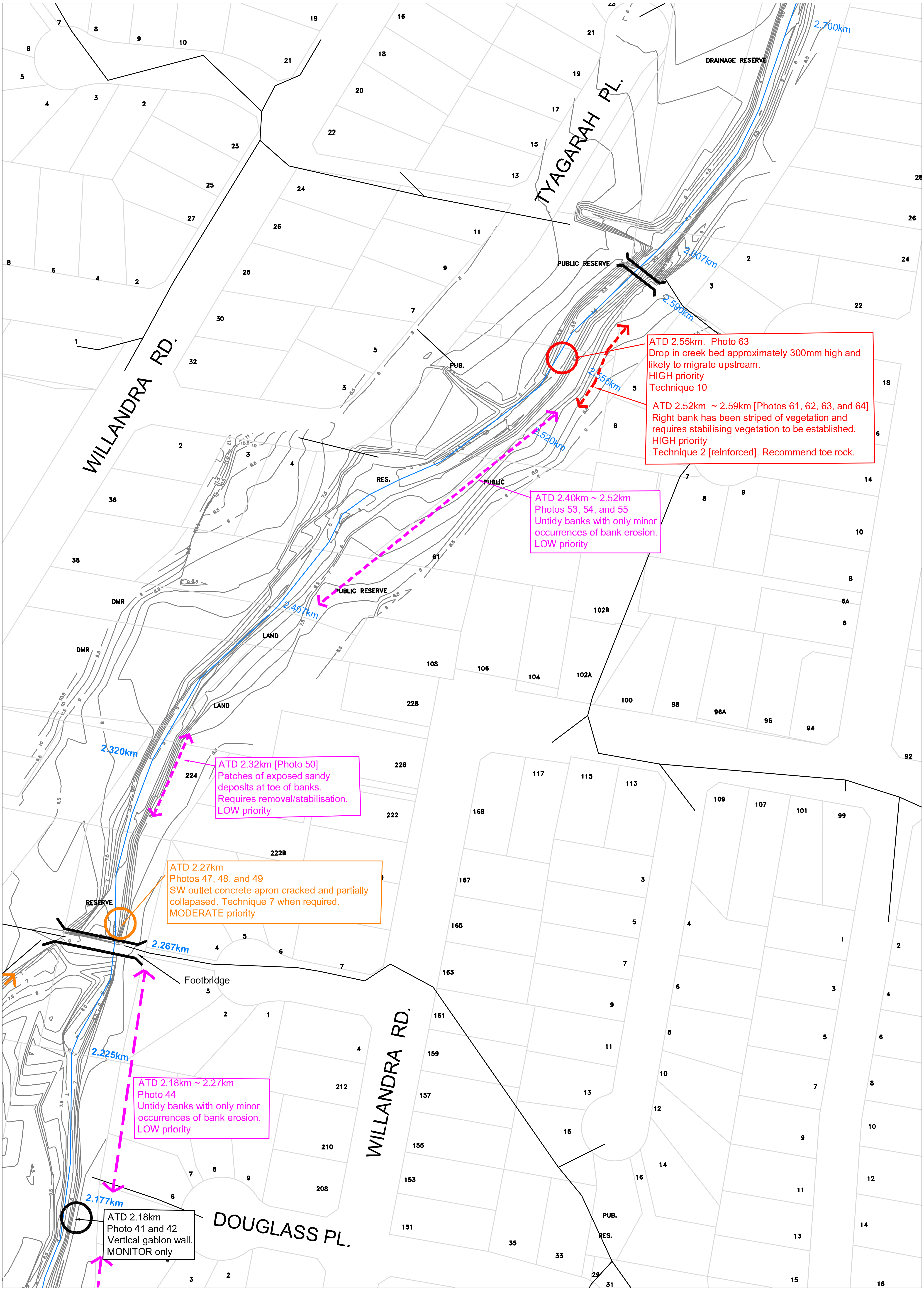

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FIGURE 6

ATD 2.18KM TO ATD 2.70KM

SOUTH CREEK BANK MANAGEMENT PLAN

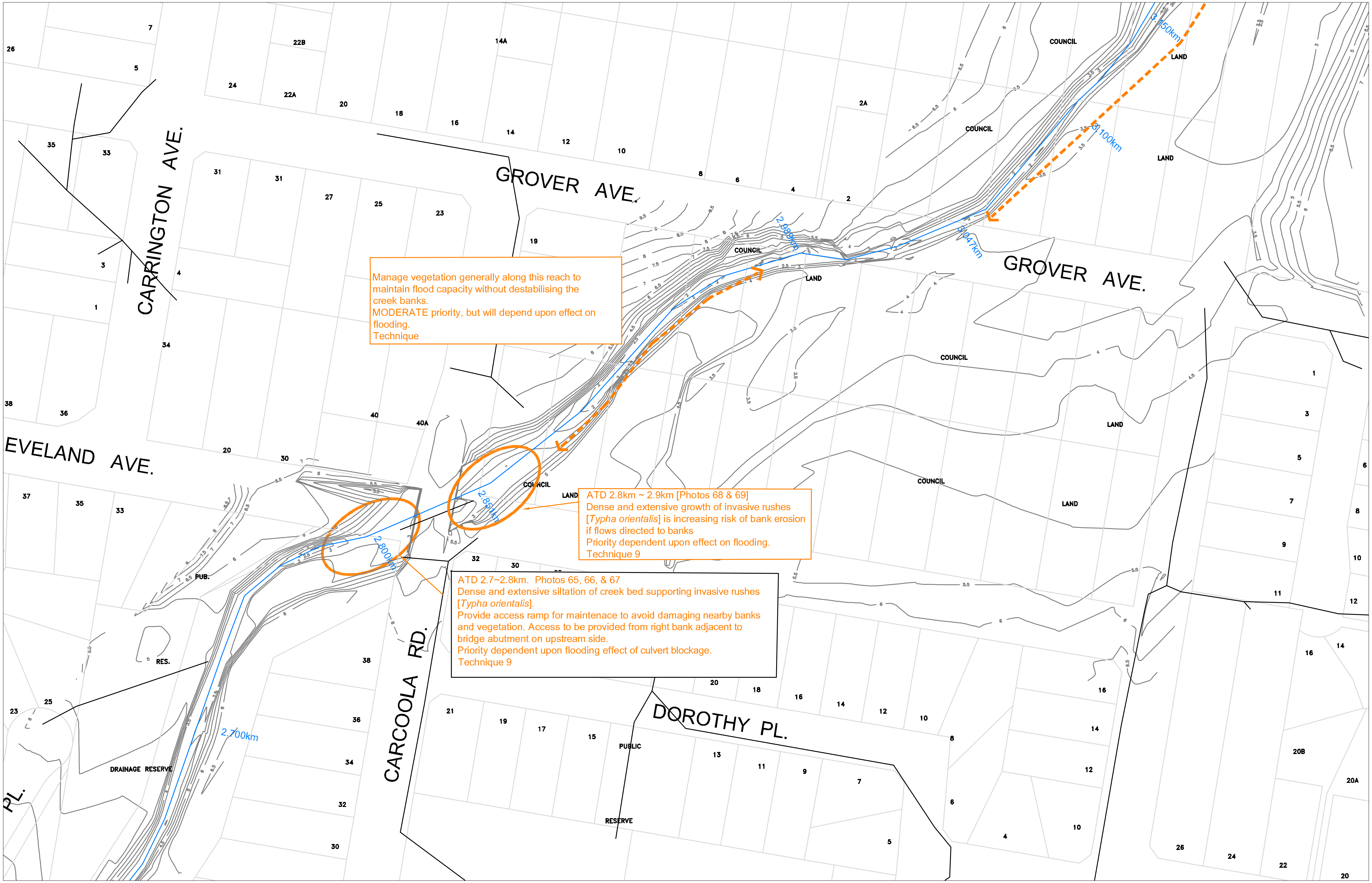

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FIGURE 7
ATD 2.70KM TO ATD 3.15KM
SOUTH CREEK BANK MANAGEMENT PLAN

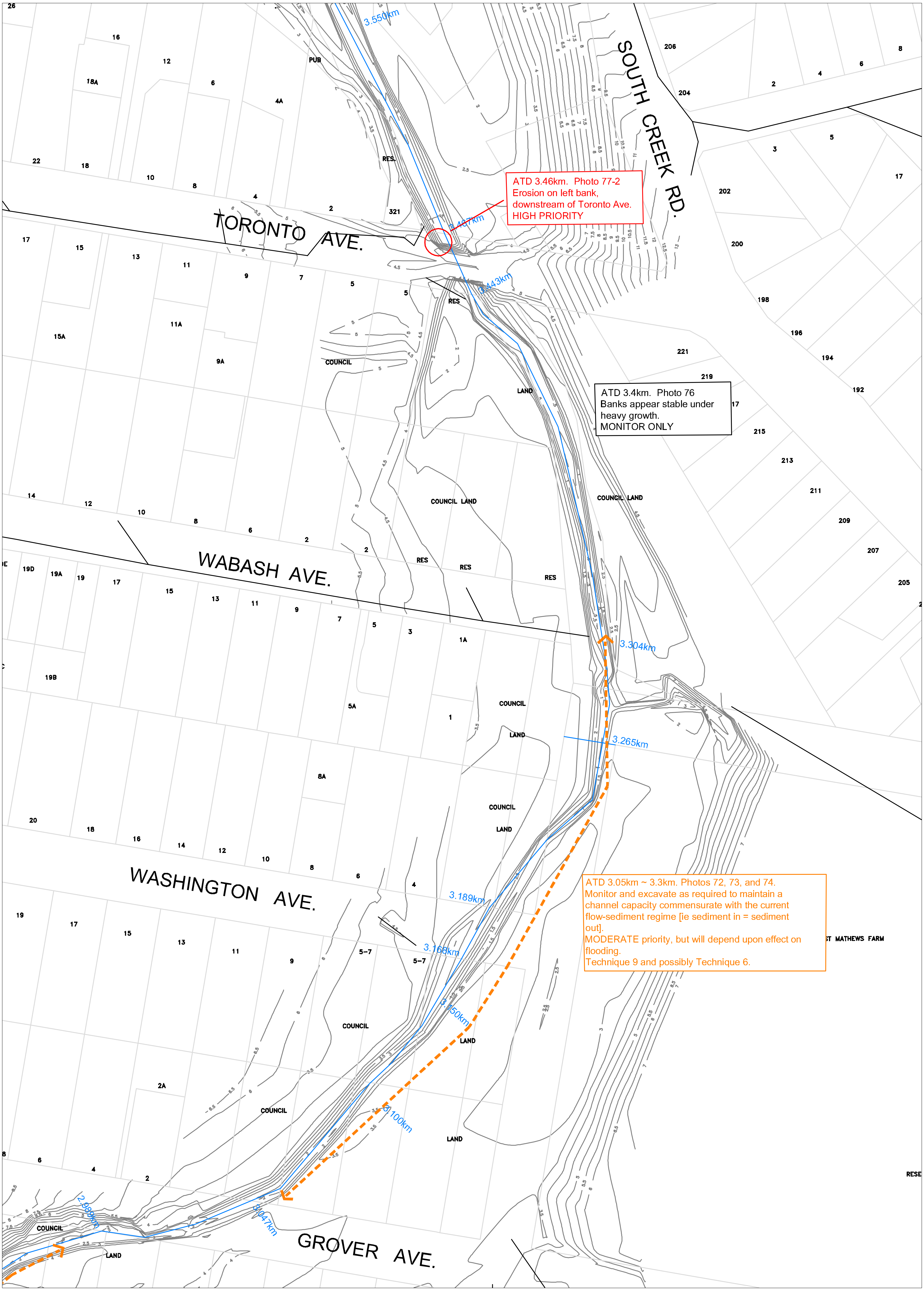

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FIGURE 8
ATD 3.00KM TO ATD 3.55KM
SOUTH CREEK BANK MANAGEMENT PLAN

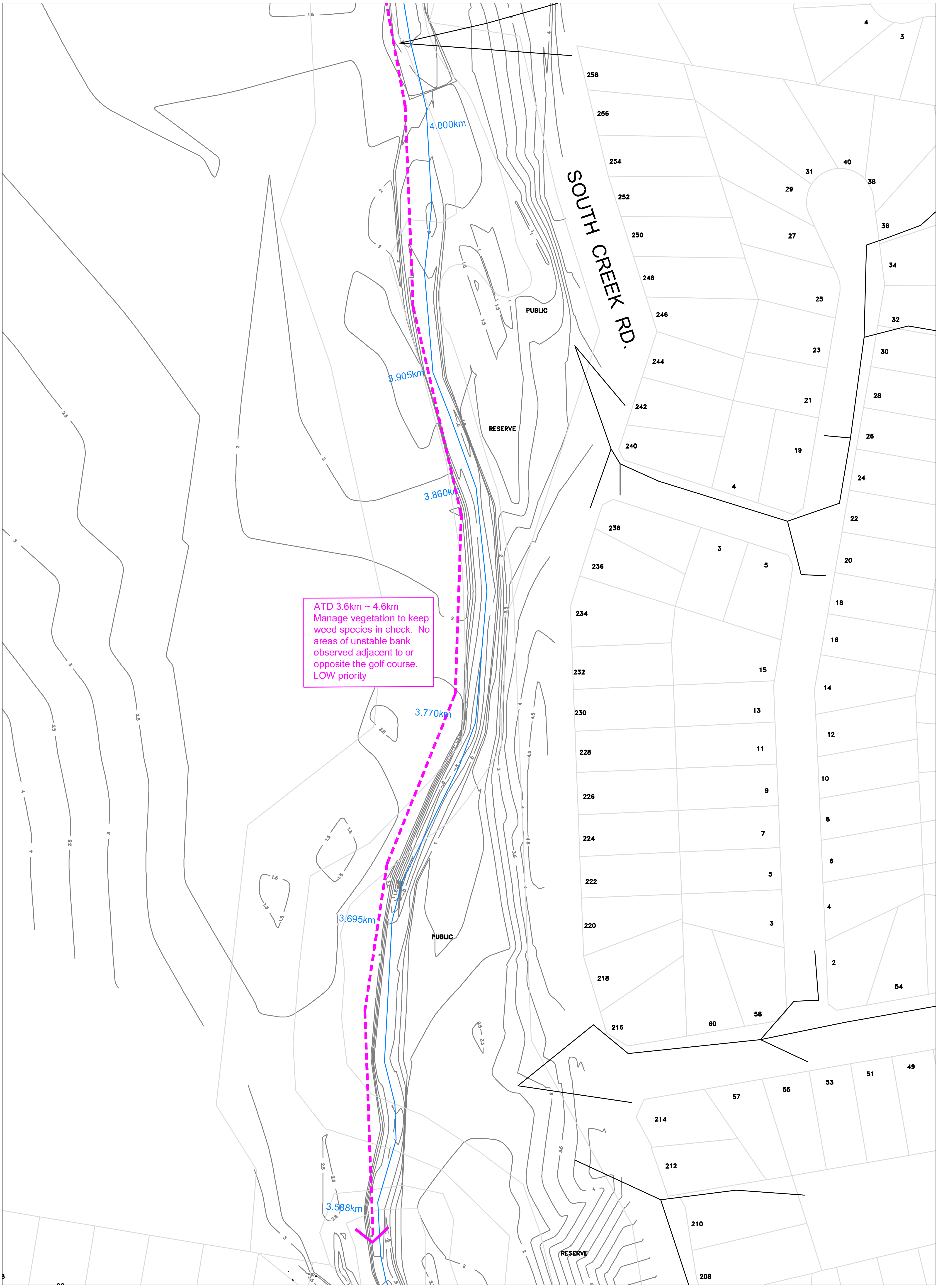

FIGURE 9
ATD 3.55KM TO ATD 4.05KM
SOUTH CREEK BANK MANAGEMENT PLAN

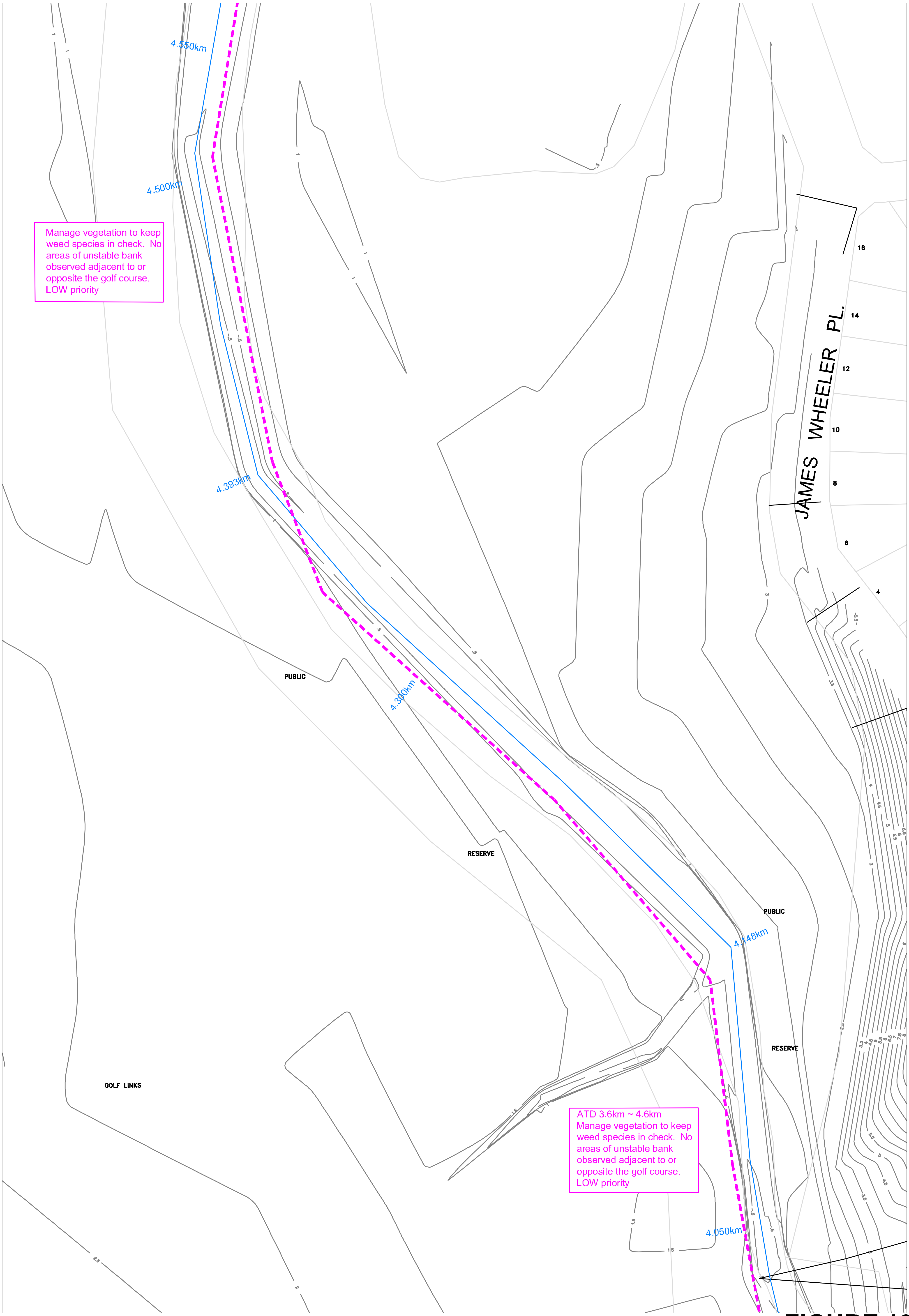

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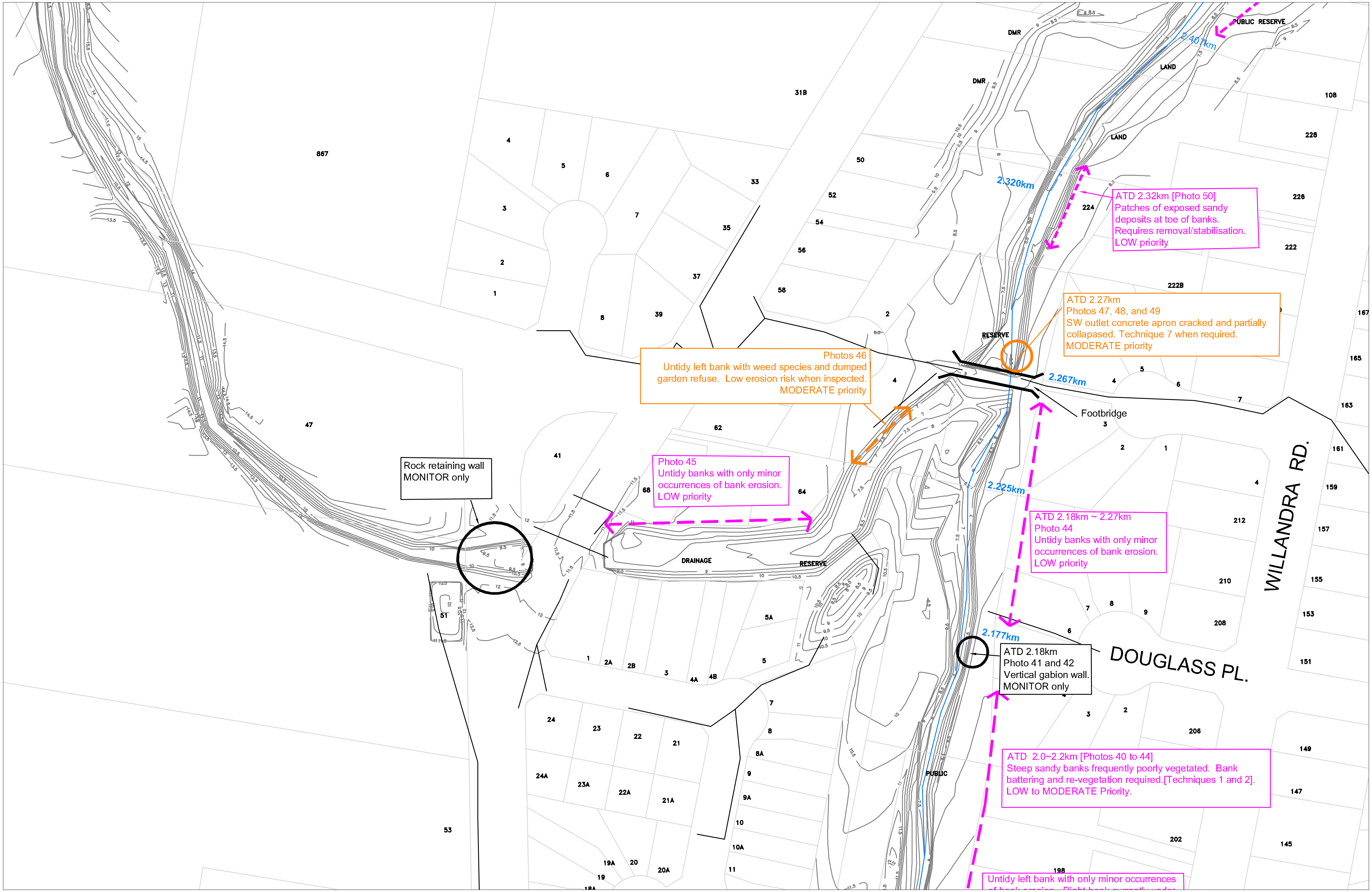
FIGURE 10

ATD 4.05KM TO ATD 4.55KM

SOUTH CREEK BANK MANAGEMENT PLAN



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4 February 2008

FIGURE 11
Lower Wheelers Creek
SOUTH CREEK BANK MANAGEMENT PLAN

ATTACHMENT 2

Creek Photo Survey (2005)

South Creek – Photo survey [July 2005]

Photo 1 Looking upstream and across
Ref #0049

Photo 2 Looking upstream and across
Ref #0050

ATD 0.170km

Left tributary from Brooker Ave, 2.5m deep scour bowl possibly initiated by loss of tree.
Refer also photos #50.
Machinery access difficult.

Tree requires support.
Peg observed. Scour maybe in private property but is not affecting buildings.

Management Priority:
Low
Stabilise tree with rock and soil backfill. Applicable techniques:
4, 5, 6.

Photo 3 Looking downstream. Confluence area of left and right tributaries.
Right tributary: sandy banks / pocket floodplains
Both left and right tributaries inaccessible along creek reserve.
Ref #0052 & #0051

ATD 0.185km

No stabilisation works required except following weed removal.

Management Priority
Moderate

Monitor and weed management.

Photo 4 Looking upstream and across
Ref #0048

ATD 0.209 km

900dia. RCP SW outlet. Concrete apron with embedded rock spalls. Apron undercut. Concrete on banks downstream of headwall.
Creek appears to be stable in this reach.

Management Priority
Very Low
Monitor only. If increased undercutting observed repair with un-grouted rock spalls or confinement mat backfilled with cobbles. Technique ?

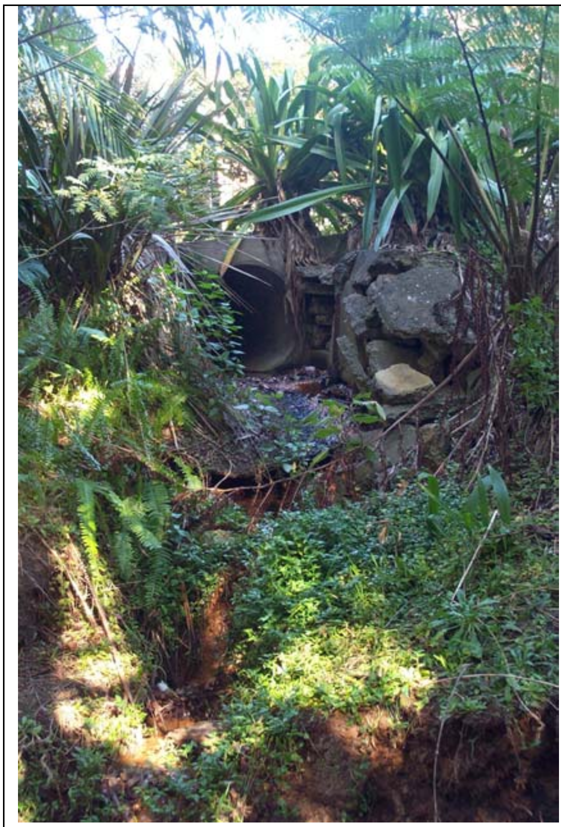
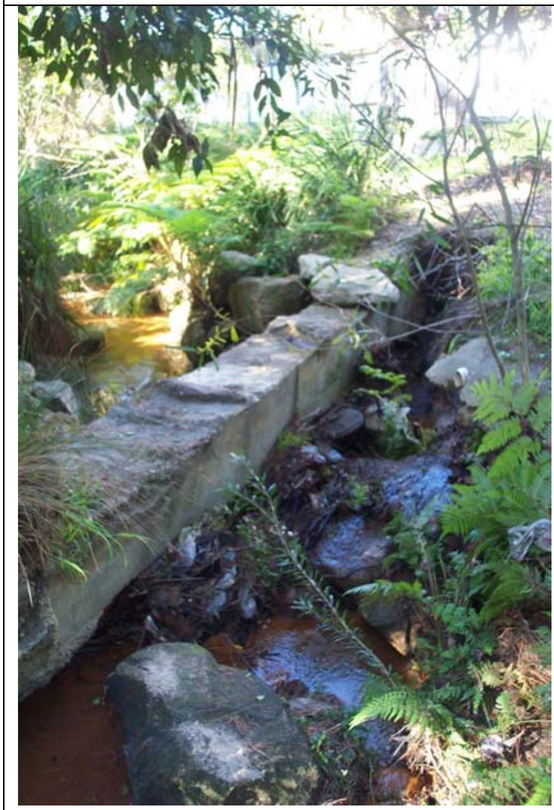
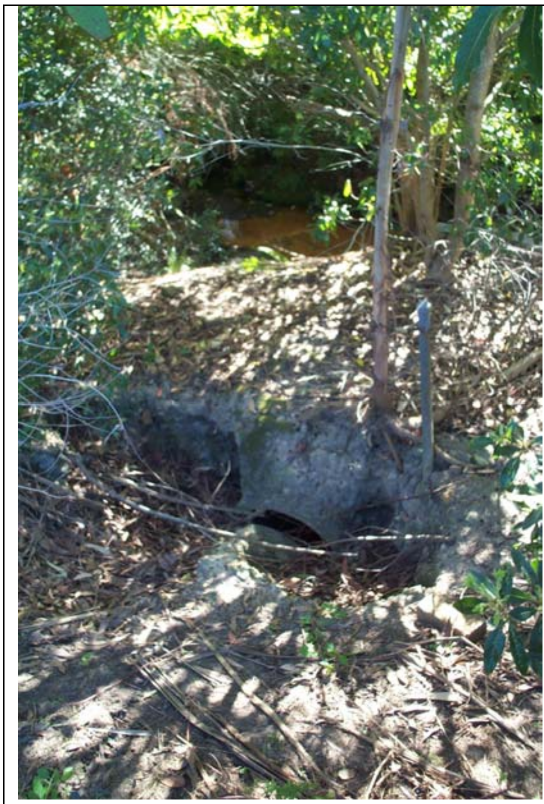
 **Photo 5** Looking upstream and across Ref #0047	**ATD 0.284 km** 900dia RCP SW outlet. Broken concrete used for wingwall. Outlet appears to be stable but is unsightly. Rock armouring in lieu of broken concrete would be preferred.	Management Priority **Very Low** Monitor only.
 **Photo 6** Looking upstream Ref #0044	**ATD 0.300 km** Placed rock boulders on right bank downstream of concrete weir [protecting a service crossing?]. Low flow passes under weir. Scour hole on right bank upstream of weir Weir/bank undercut on left bank for approx. 15m. Likely to eventually cause failure/cracking of weir. Vegetation includes: Bracken on left bank Young castor oil tree Palms Conifer [sp?] Small waterfall ≈30m upstream of weir.	Management Priority **Very High** Stabilisation using rock or equivalent required. Techniques 4, 5, or 6.

 **Photo 7** Looking upstream and across (Ref #0045)		
 **Photo 8** Looking upstream and across (Ref #0046)		
 **Photo 9** Looking upstream (Ref #0043)	**ATD 0.427 km** Upstream of school / footbridge. Placed rock boulders on right bank extend upstream to concrete weir. Rock wall appears to be stable. Lomandra planted behind rock wall Tree ferns on right bank.	Management Priority **Monitor only** Monitor only for signs of bank instability every 1 to 2 years or after large flood.
 **Photo 10** Looking upstream (Ref #0042)	**ATD 0.460 km** Adjacent to school. Low banks, exposed but appear reasonably stable. Scrub includes significant quantities of Pittosporum undulatum.	Management Priority **VERY LOW** Monitor only for signs of bank instability every 1 to 2 years or after large flood.

 **Photo 11** Looking upstream Ref #0040  **Photo 12** Looking downstream Ref #0041	**ATD 0.490 km** Adjacent to school. Plastic covered compost heap. Galv. Steel posts [fence line?] Bank 1.5m High composed of sandy silt. Evidence of frequent access by students resulting in loss of ground cover on Lower terrace. Regeneration of ground cover vegetation needed to stabilise area and reduce sediment loss. Exposed Low vertical bank is vulnerable to erosion.	Management Priority: **HIGH** Re-vegetate banks/Lower terrace using shade tolerant species. Use fencing or other barrier to protect vegetation. Techniques 1,2, 3.
 **Photo 13** Looking upstream Ref #0039	**ATD ≈ 0.510km** Cascade pool sequence bed rock outcrops Banks 1.5m and steep Good tree cover, minimal ground cover Pocket floodplain on right bank.	Management Priority: **Moderate** Re-vegetate banks/Lower terrace using shade tolerant species. Techniques 1,2, 3.

 **Photo 14** Broken stormwater pipe from school grounds Ref #0053	**ATD ≈ 0.530km** Broken SW pipe on right bank coming from school. Approx. 100m d/s of footbridge. Soil washing into pipe has formed a sink hole but quantity of soil lost does not appear to be large.	Management Priority**:** **Low** Repair pipe to limit erosion and sediment transport. Responsibility maybe NSW Government – school drain.
 **Photo 15** Looking upstream Ref #0054	**ATD 0.710km** SW pipe outlet. Orange-brown discharge coming from pipe. Limited washout of bank behind headwall may lead to future instability of outlet. 2.4m length of RCP aligned with right creek bank 15m d/s of outlet but doesn't appear to be causing problems.	Management Priority: **Monitor** Test and monitor discharge from SW drain. Monitor headwall stability. Use techniques 4, 5 or 6 if future stabilisation is required.
 **Photo 16** Looking downstream Ref #0055	**ATD ≈ 0.780km** Between school and Willandra Road the creek is generally stable with sandy pockets and frequent bedrock outcrops and small waterfalls /cascades. Bare banks do not appear to be causing a significant problem.	Management Priority: **VERY LOW** Monitor bare banks. Use toe rocks and battering with vegetation if banks show signs of active erosion. Technique ?

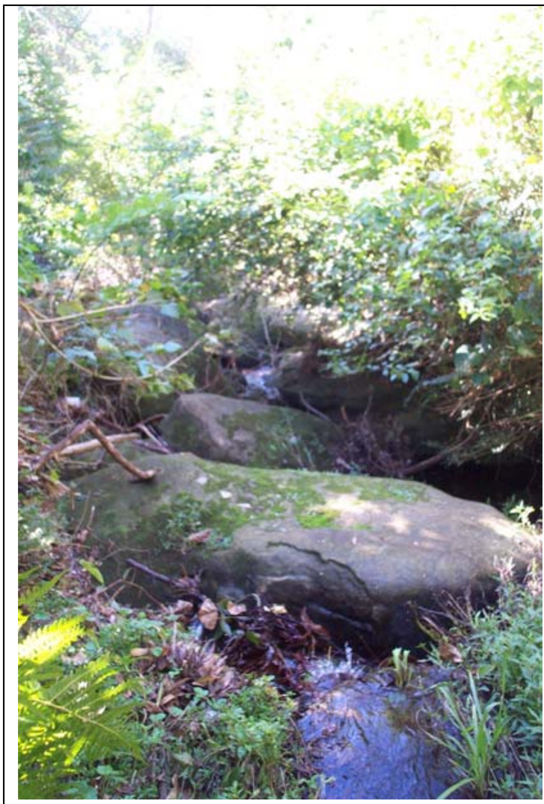
 **Photo 17** Looking downstream Ref #0056	**ATD ≈ 0.970km** Downstream of Little Willandra Road GPT. Reach characterised by multiple rock waterfalls and pools. Area appeared stable when inspected [August 2005].	Management Priority: **Monitor** only.
 **Photo 18** Looking downstream Ref #0057	**ATD ≈0.980km** Downstream of McIntosh Rd. GPT. Area appeared stable when inspected [August 2005].	Management Priority: **Monitor** only

 **Photo 19** Looking downstream along sediment trap (Ref #0058)	**ATD 1.130km** Offline sediment trap / WQ pond on left bank downstream of McIntosh Rd.	Management Priority: **Monitor** only Monitor inlet and outlets for blockages.
 **Photo 20** Looking upstream to diversion weir. (Ref #0059)	**ATD 1.130km** Creek adjacent to WQ pond. Rock bed. Area appeared stable when inspected [August 2005].	Management Priority: **Monitor** only
 **Photo 21** View downstream to adjacent to sed. trap. (Ref #0060)	**ATD 1.160km** Creek adjacent to WQ pond. Rock bed. Area appeared stable when inspected [August 2005].	Management Priority: **Monitor** only
 **Photo 22** View downstream beyond sediment trap. Ref #0061	**ATD 1.170km** Creek adjacent to WQ pond. Rock bed.	Management Priority: **Monitor** only

 **Photo 23** View upstream from near Alkira Circuit. Ref #0062	**ATD ≈1.220km** Creek running over exposed bedrock. Low right bank and shallow soil showing some scour at the edges but not considered significant.	Management Priority: **Low** Monitor only at this stage. Use techniques 2 or 4 or variations should work be required in future.
 **Photo 24** View upstream from near Alkira Circuit. Ref #0063/64	**ATD ≈1.230km** Creek running over exposed bedrock. Some scour at toe of bank but not considered significant.	Management Priority: **LOW** Monitor only. Use techniques 2 or 4 or variations should work be required in future.
 **Photo 25** View downstream at Alkira Circuit. Ref #0065	**ATD 1.268km** Downstream side of Alkira Circuit. Unstable fill on right bank	Management Priority: **Moderate** Use techniques 2 or 4 or variations to stabilise bank/fill.
 **Photo 26** View downstream at Alkira Circuit Ref #0066	**ATD 1.268km** Left bank exposed but appears stable.	Management Priority: **Monitor** only.

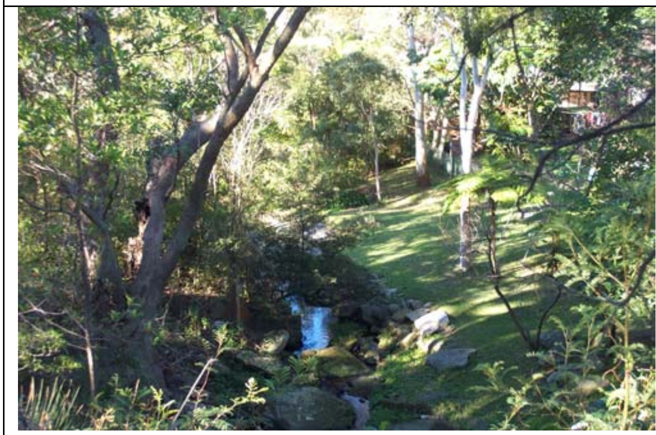
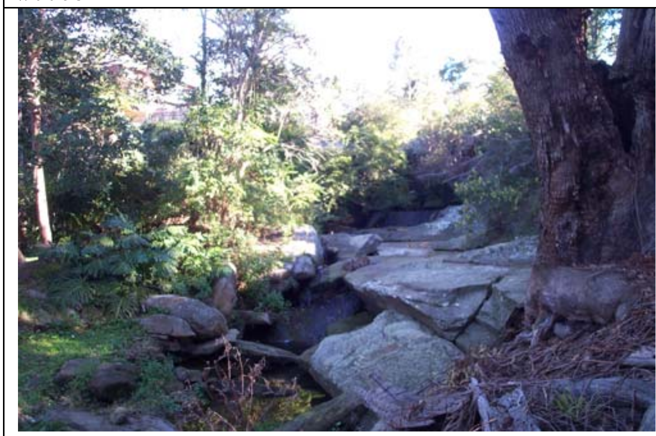
 **Photo 27** View downstream from head of waterfall Ref #0067	**ATD 1.310km** Waterfall appears stable.  **Photo 31** Water dragon at head of waterfall Ref #0072	Management Priority: **Monitor** only. Use techniques 2 or 4 or variations should work be required in future.
 **Photo 28** View downstream at bottom of waterfall. Ref #0068	**ATD 1.450km** Shallow soil overlying bedrock forms creek banks and floodplains. Low exposed bank could erode in High floods but appears stable when inspected in August 2005.	Management Priority: **Monitor** only. Use techniques 2 or 4 or variations should work be required in future.
 **Photo 29** View upstream towards waterfall. Ref #0069	**ATD 1.460km** Waterfall appears stable when inspected in august 2005.	Management Priority: **Monitor** only.
 **Photo 30** View downstream Ref #0070 and #0071	**ATD 1.500km** Creek is confined by outcropping bedrock and is considered stable.	Management Priority: **Monitor** only for unstable debris that may wash downstream and block culverts.

 **Photo 32** Retarding basin outlet tower at McIntosh Road. Ref #0073	**ATD 1.056 km** Difficult to assess bank stability due to thick vegetation.	**Priority: VERY LOW** Monitor only for debris that may wash into outlet tower and excessive sediment deposits.
 **Photo 33** Retarding basin sed. basin outlet Ref #0074	ATD 1.056 km Sediment trap outlet within retarding basin.	**Priority: VERY LOW** Monitor only for debris and sediment that may block outlets.
 **Photo 34** View upstream behind Willandra Village Ref #0075	**ATD 1.890km** Incised alluvial creek. Left bank is actively retreating towards trees located between 0.5 and 1.5m from top of bank. Right bank appears to be stable.	Management Priority **HIGH** Refer beLow

 **Photo 35** View downstream behind Willandra Village Ref #0076	**ATD 1.870km** Erosion of left bank likely to be due to runoff and seepage from mown area as well as creek fLows. Bank material is silty sand. Improved SW outlets are required for both the UPVC pipe and larger SW drains terminating up to 20m from the creek bank.	Management Priority **HIGH** For left bank: Technique 4 or 5 with bank re-vegetation. Limited opportunity for bank battering due to trees. If tree set back is sufficient use Technique 1 together with 2, 4, or 5. Technique 3 is also applicable. Recommend toe rocks be used on right bank in conjunction with left bank works.
 **Photo 36** View upstream behind Willandra Village Ref #0077	**ATD 1.825 km** Confluence area. Undercut right bank, tree de-stabilised. Tributary fLow is undercutting bank on outside bend and de-stabilising tree.	Management Priority **URGENT** Use technique 4 or 5 to stabilise tree and right bank but maintain similar waterway area. May need to lop tree [technique 7].
 **Photo 37** View upstream behind Willandra Village Ref #0080	**ATD 1.825 km** Confluence area. Undercut right bank. If tree falls further significant scour is likely on both banks due to deflected fLows.	Management Priority **URGENT** Refer to above.

 **Photo 38** View upstream behind Willandra Village Ref #0078	**ATD 1.837 km** Willandra Village SW outlet and channel. Outlet channel appears stable but is bare of vegetation. Deep sandy deposits near creek are mobile.	Management Priority **MODERATE** Recommend rock lining or other form of stabilised vegetation to stabilise sandy deposits. Techniques 2 or 11.
 **Photo 39** View upstream behind Willandra Village Ref #0079	**ATD 1.837 km** Willandra Village SW outlet channel to creek.	Management Priority **MODERATE** Refer to comments above.
 **Photo 40** View downstream Ref #0081	ATD 1.98 km Reach between Willandra Road and Douglass Place. Typical of conditions where area has been invaded by weed species and frequent patches of bank are exposed.	Management Priority **LOW to MODERATE** Refer to comments above.

 **Photo 41** View downstream. Gabion wall on right bank Ref #0082	**ATD 2.177 km** Gabion retaining wall. **ATD 2.177 km** Gabion retaining wall.	Management Priority **MONITOR** for signs of undercutting along toe of wall. For long term consider replacing by a vegetated retaining wall system [Techniques 3 or 5].
 **Photo 42** View upstream from gabion retaining wall. Ref #0083		
 **Photo 44** View downstream Ref #0085	**ATD 2.206 km** Typical of reach where area characterised by weed species and patches of exposed bank.	Management Priority **LOW** Staged clearing of weed species. Technique 2.

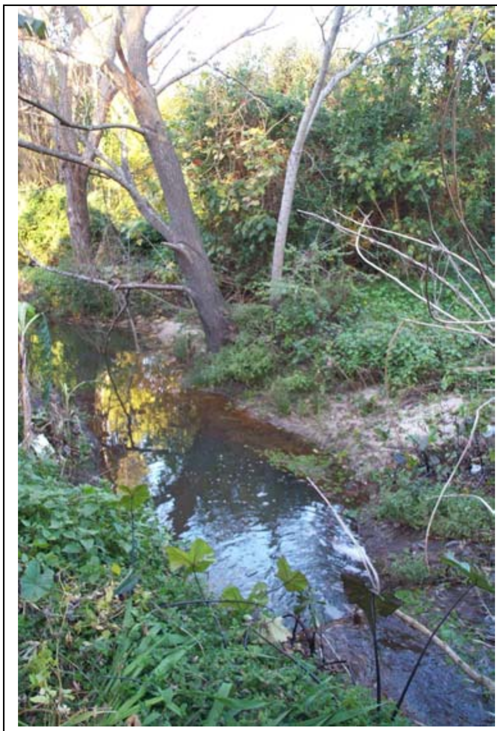
 **Photo 45** Wheeler's Creek – view upstream Ref #0086	**ATD 2.225km** View from 30m upstream of footbridge at ATD 2.267 km. Steep untidy bank littered with garden refuse.	Management Priority **MODERATE** Staged clearing of weed species. Technique 2.
 **Photo 46** View upstream from footbridge Ref #0087	**ATD 2.266 km** Prolific amount of lantana.	Management Priority **LOW** Staged clearing of weed species. Technique 2.
 **Photo 47** View downstream from footbridge. Ref #0088	**ATD 2.267 km** Broken concrete apron at outlet on right bank. Tree lopped on left bank.	Management Priority **LOW** Monitor only at this stage. Use rock boulders to stabilise bank if scouring occurs.

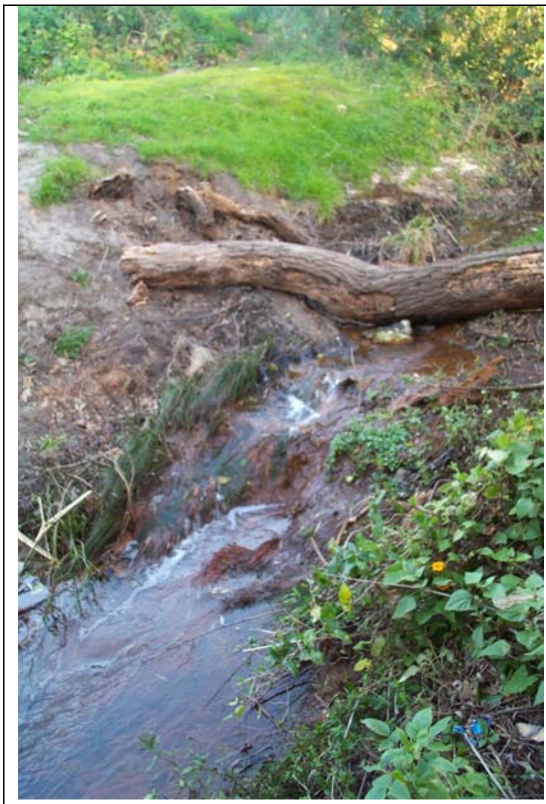
 **Photo 48** View upstream towards footbridge [See also photo 47 and 49]. Ref #0089	**ATD 2.267 km** Lopped trees. Banks stable. Broken concrete apron at SW outlet on right bank. Evidence of some bush re-generation work.	Management Priority **LOW** Monitor only at this stage. Use rock boulders to stabilise bank if scouring occurs. Staged clearing of weed species. Technique 2.
 **Photo 49** View downstream from footbridge [See also photo 47]. Ref #0089	**ATD 2.267 km** Recently lopped tree on left bank. Banks are stable.	Management Priority **LOW** Monitor only at this stage. Use rock boulders to stabilise bank if scouring occurs. Staged clearing of weed species. Technique 2.
 **Photo 50** View upstream about 10m upstream of pipeline. Ref #0090	**ATD 2.32km** 5~6m eroding on opposite left bank. Low level sandy terrace with ineffective ground cover [Creeping Solomon].	Management Priority **LOW** Staged clearing of weed species. Stabilise silt deposits in creek bed where they are not unduly obstructing flow leading to an unacceptable flood risk. Technique 2.

 **Photo 51** View upstream [≈ 10m upstream of pipeline crossing] Ref #0091	**ATD 2.32km** Left bank – sandy pocket bench and Coral Tree.	Management Priority **LOW** Staged clearing of weed species. Stabilise silt deposits in creek bed where they are not unduly obstructing flow leading to an unacceptable flood risk. Technique 2.
 **Photo 52** View downstream Ref #0092	**ATD 2.510 km** Weed infested sandy terrace on right bank. Fallen trees. Thick Lantana on left bank and unstable sandy deposits about 1m thick.	Management Priority **MODERATE** Staged clearing of weed species. Some woody vegetation that has become stabilised is deflecting flows onto the banks and should be thinned/removed in a planned way. Technique 2.
 **Photo 53** View downstream from sandy bench. Ref #0093	**ATD 2.520 km** Open woodland type vegetation. Litter in creek includes car tyre. Cootamundra wattle.	Management Priority **MODERATE** Staged clearing of weed species. Some woody vegetation that has become stabilised is deflecting flows onto the banks and should be thinned/removed in a planned way. Technique 2.

 **Photo 54** View downstream from sandy terrace. Ref #0094	**ATD 2.520 km** Fallen trees deflecting flow onto sandy bank. Lantana established on attached sandy bar [left bank].	Management Priority **MODERATE** Staged clearing of weed species. Some woody vegetation that has become stabilised is deflecting flows onto the banks and should be thinned/removed in a planned way. Technique 2.
 **Photo 55** View downstream. Ref #0096	**ATD 2.320 km** Silt fence at top of right bank regeneration /weeding has occurred at top of bank. Broken concrete litters the bank. Right bank is steep and eroding over about 5m. Vegetated attached sandy bar on left bank.	Management Priority **LOW** Staged clearing of weed species. Some woody vegetation that has become stabilised is deflecting flows onto the banks and should be thinned/removed in a planned way. Technique 2.
 **Photo 56** View downstream to pipeline crossing. Ref #0097	ATD km Vegetated but unstable sandy bar attached to left bank includes back channel next to left bank.	Management Priority **LOW** Staged clearing of weed species. Stabilise silt deposits in creek bed where they are not unduly obstructing flow leading to an unacceptable flood risk. Technique 2.

 **Photo 57** View upstream – matches Photo 58. Ref #0098	**ATD 2.450 km** Complex geomorphic configuration includes pools, drops, a chute, a mid-stream bar creating a low level flood channel on right bank and attached low level bar/delta on left bank.	Management Priority **MONITOR** Staged clearing of weed species. Stabilise silt deposits in creek bed where they are not unduly obstructing flow leading to an unacceptable flood risk. Technique 2.
 **Photo 58** View upstream – matches Photos 57 and 59 Ref #0099		
 **Photo 59** View upstream – matches Photo 58 Ref #0100		

 **Photo 60** 300mm High drop. View downstream. Ref #0101  **Photo 61** Ref #0102	**ATD ≈ 2.555km** Recent clearing on right bank included castor oil trees but has left bank Highly vulnerable to erosion. [Photo #102]. 300mm drop in creek bed is likely to migrate upstream and should be stabilised. Difficult to assess stability of left bank due to vegetative cover but appears stable. Stabilising matting or equivalent required when removing bank vegetation.	Management Priority: Drop: **HIGH** Left bank: **URGENT** Employ Technique 10 [drop] and Technique 2 [Bank].
 **Photo 62** Ref #0103	**ATD ≈ 2.555km** Refer to comments for Photo #102.	Management Priority: Left bank: **URGENT** Employ Technique 2.

 Photo 63 Approx. 300mm drop. Ref #1004	**ATD ≈ 2.555km** Drop in creek bed is likely to migrate upstream and should be stabilised.	Management Priority: **HIGH** Employ Technique 2.
 **Photo 64** View upstream from footbridge at ATD 2.590 km Ref #1005	ATD 2.590 km Exposed right bank after weed removal [August 2005]	Management Priority: **URGENT** Employ Technique 2.
 **Photo 65** View upstream from Carcoola Bridge showing dense vegetation in creek bed.	**ATD 2.75km** Failure to maintain sufficient capacity in the creek channel will lead to further sedimentation and ultimately a widening manifested as bank erosion.	Management Priority: **HIGH** Employ Technique 9 [Dredging] together with staged weed removal.

<table>
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<td>
Photo 66 View at upstream side of Carcoola rd bridge.</td>
<td rowspan="3">ATD 2.80km

Failure to maintain sufficient capacity in the creek channel will lead to further sedimentation and ultimately a widening manifested as bank erosion.</td>
<td rowspan="3">Management Priority:
HIGH

Employ Technique 9 [Dredging] together with staged weed removal.</td>
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<td>
Photo 67 Sediment deposit at Carcoola Road.</td>
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<td>
Photo 68 Dense vegetation in creek bed downstream of Carcoola Rd.</td>
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 **Photo 69** View downstream of Carcoola Rd. showing dense vegetation in creek bed.  **Photo 70** Unconsolidated sediment deposits downstream of Carcoola Rd. Ref #41	**ATD 2.85km** Failure to maintain sufficient capacity in the creek channel will lead to further sedimentation and ultimately a widening manifested as bank erosion.	Management Priority: **HIGH** Employ Technique 9 [Dredging] together with staged weed removal.
 **Photo 71** Placed rock bank stabilisation at Grover Ave. Ref #2367	**ATD 2.97km** Good use of placed rock boulder technique as an alternative to rip-rap [Technique 7]. There is a need to monitor the toe of the rock wall to check for scour and possible destabilisation.	Management Priority: **MONITOR** for undercutting along toe of wall. Use rock rip is scouring becomes evident [Technique 7].

Photo 72 Creek channel adjacent to natural sediment basin.
Ref #31

Photo 73 Stabilised sediment deposits opposite St Matthews Farm reserve.
Ref #35

Photo 74 Stabilised sediment deposits opposite St Matthews Farm reserve.
Ref #37

ATD 3.05 to 3.25km

This area is acting as a sediment basin and has been reducing the amount of sediment transported further downstream. However it s effectiveness is probably diminishing as much of the sediment is stabilised with vegetation. There is now a danger that further sedimentation may result in the creek channel moving laterally into paleo sedimentary deposits rather than re-working the more recent deposits.

Management Priority:
MODERATE

Monitor and excavate to maintain adequate waterway commensurate with a stable channel for the estimated water-sediment regime.

May require dredging [Technique 9] and/or tree management [Technique 6] depending on flood risk and how much flow is being deflected onto vulnerable creek banks.

 **Photo 75** View downstream to Toronto Ave from near Wabash Ave. Ref #2355	**ATD 3.31km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.
 **Photo 76** View upstream from Toronto Ave. Ref #2348	**ATD 3.44km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.
 **Photo 77-1** View downstream from Toronto Ave.	**ATD 3.47km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.

 **Photo 77-2** View downstream from Toronto Ave, erosion on left bank.	**ATD 3.47km** Site inspection was undertaken in May 2007 after heavy rainfall in April 2007. Erosion was noted on the left bank around the footings of the Toronto Ave bridge.	Management Priority: **HIGH** Employ Technique 7 [Rock Rip Rap] or Technique 8 [Gabions] to protect bridge foundations, infrastructure and services.
 **Photo 78** Wooden crossing downstream of Toronto Rd. Ref #2351	**ATD 3.5km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.
 **Photo 79** View upstream along left riparian edge adjacent to golf course.	Approx. ATD 3.65km Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.

 **Photo 80** Typical vegetation on the right bank opposite the golf course	**Approx. ATD 3.8km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Staged clearing of weed species. Technique 2 as required.
 **Photo 81** Management practice at golf course.	**Approx. ATD 3.9km**	Management Priority: **LOW** [monitor only] Monitor for weed species and remove as necessary.
 **Photo 82** Swampy edge of creek opposite golf course.	**Approx. ATD 3.9km**	Management Priority: **LOW** [monitor only] Monitor for weed species and remove as necessary.

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<td>
Photo 83 View upstream from the weir.</td>
<td rowspan="3">ATD 4.01km

Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.</td>
<td rowspan="3">Management Priority:
LOW [monitor only]

Monitor condition of weir and for signs or erosion on the banks after heavy flooding.

Periodically check for signs of bank erosion due to human access. Fence or plant out to discourage access if required.</td>
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<td>
Photo 84 View downstream from the weir.</td>
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<td>
Photo 85 Weir.</td>
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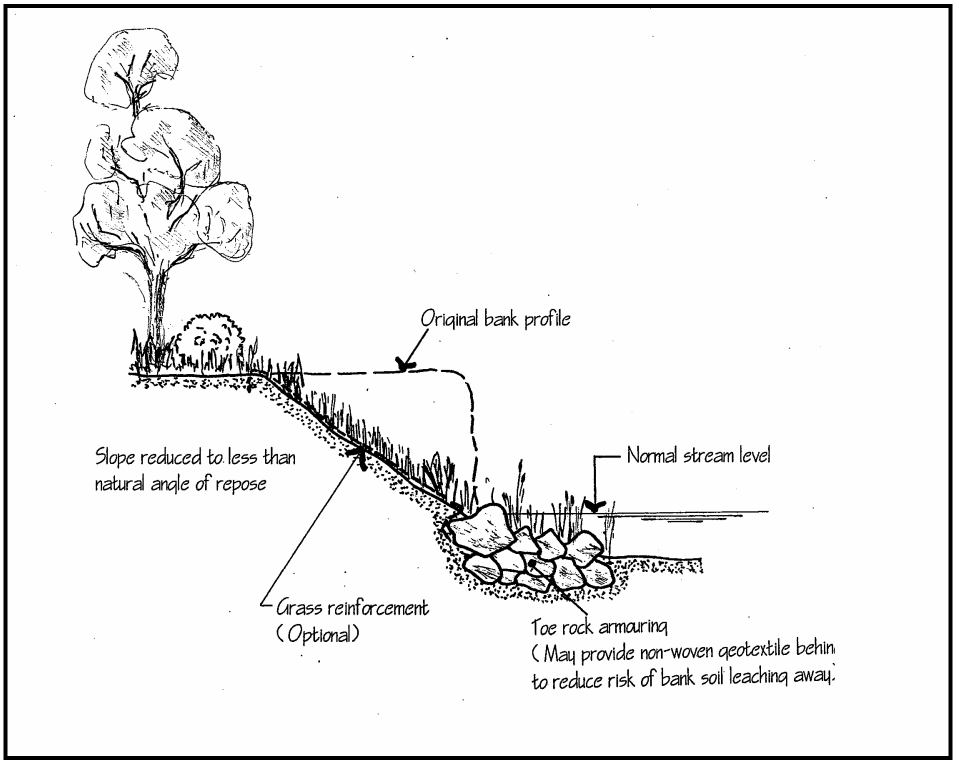
 **Photo 83** View downstream from the left bank. Typical condition of the lagoon reach over the last few hundred metres. Ref #	**ATD 4.20km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Monitor for weed species and remove as necessary.
 **Photo 84** View upstream from the left bank. Typical condition of the lagoon reach over the last few hundred metres. Ref #	**ATD 4.39km** Creek appears to be generally stable however weed removal and re-vegetation activities should be carefully planned and executed using an alternate strip removal technique [Technique 2B] to minimise the risk of locally high flood velocities and erosion.	Management Priority: **LOW** [monitor only] Monitor for weed species and remove as necessary.

ATTACHMENT 3

Creek Management Techniques

Technique 1: BANK BATTERING



Description: A stream bank is excavated to reduce the steepness of the face. The bank face is then normally re-vegetated. Frequently rock is placed along the toe to reduce the risk of toe scour.

Variations: Technique may only be applied to the upper bank with other techniques, such as rip-rap being used to protect the lower bank.

Application: Used to improve slope stability thus preventing mass failure. Maximum effectiveness is achieved in situations where the stream flow against the bank is not continuous.

Limitations: Toe scour often remains a problem especially where it is difficult to establish suitable vegetation.

Advantages

- Simple to implement
- Reduces fretting and attrition by allowing vegetation to establish on the bank face.

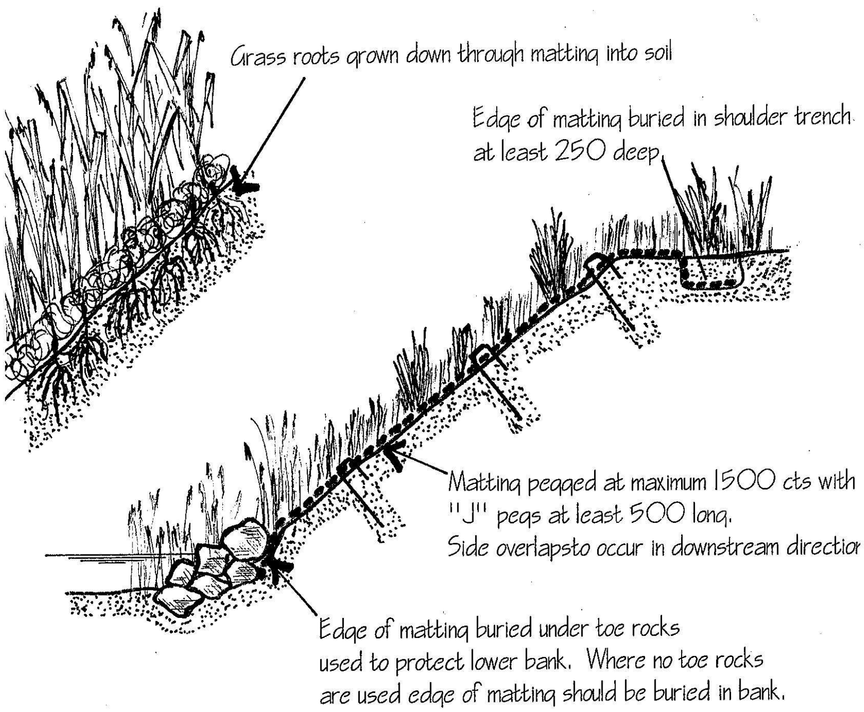
Disadvantages

- Not suitable for high velocity flows unless a suitable permanent reinforcement mat is used.
- Vulnerable until vegetation is established. Reinforcement matting can reduce the risk
- Generally ineffective below water.

Indicative Capital Cost: Low assuming there is good access for machinery. Cost is in low to medium range if toe rock protection is used.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 2%pa to 5%pa of the capital cost.

Technique 2: REINFORCED VEGETATION [GRASS]



Description: Herbaceous vegetation, usually grass, is planted into a soil covered permanent matting [high density polyethylene [HDPE] which is secured to prepared bank using mild steel pegs. Frequently rock is placed along the toe to reduce the risk of toe scour.

Variations: Technique may only be applied to the upper bank with other techniques, such as rip-rap, being used to protect the lower bank.

Application: Used to improve slope stability thus preventing mass failure. Commonly used in conjunction with bank battering. Maximum effectiveness is achieved in situations where the stream flow against the bank is not continuous although scour resistance is improved by the matting.

Limitations: Toe scour often remains a problem especially where it is difficult to establish suitable vegetation.

Advantages

- Simple to implement
- Reduces fretting and attrition by allowing vegetation to establish on the bank face.
- When properly used and maintained can withstand moderately high velocities [3m/s to 4 m/s] for several hours with minimal damage.

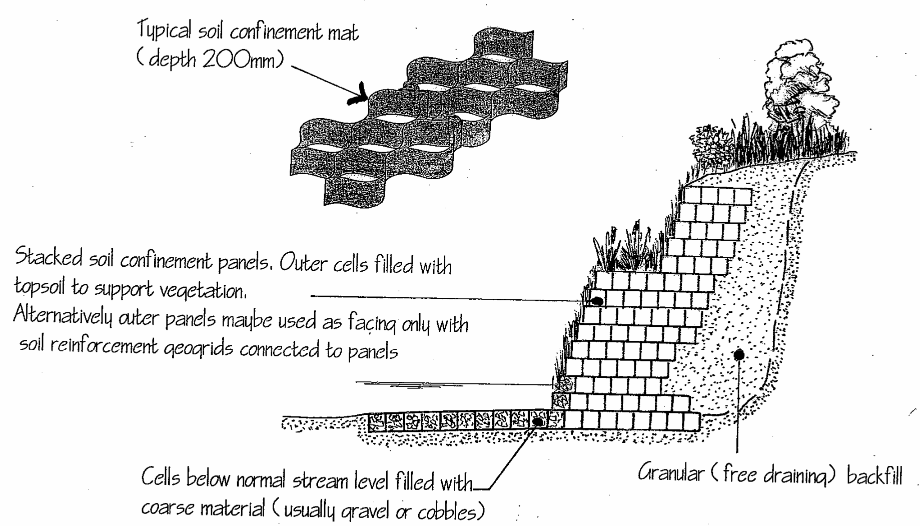
Disadvantages

- Not suitable for high velocity flows unless a suitable permanent reinforcement mat is used.
- Vulnerable until vegetation is established.
- Generally ineffective below water.

Indicative Capital Cost: Low to medium assuming there is good access for machinery. Cost is in medium range if toe rock protection is used.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 2.5%pa to 5%pa of the capital cost.

Technique 3: CELLULAR REINFORCED EARTH – RETAINING WALL



Description: A high density polyethylene [HDPE] cellular confinement mat is used in layers to construct a reinforced earth bank in front of, or to replace the eroding bank. The exposed cells are either filled with gravel or cobbles or suitable deep rooting vegetation to resist scour. The cellular mat is usually black but can be coloured to reduce the initial visual impact.

Variations: The cellular mat may comprise a single layer secured to the face of a sloping bank. The sloping bank should not be steeper than about 30^{0} from the horizontal unless multi-layers of matting are used. Hooked anchor stakes and /or cables anchored to the top of the are required where the matting is used on a sloping surface. .

Application:
Provides bank protection against undermining, piping, and slumping failure modes.

Limitations: May increase bank pore pressure unless permeable layers are introduced to act as weep holes.

Advantages

- Suitable for a wide range of bank conditions and soil types.
- Provides protection while vegetation is becoming established.
- Flexible system that can yield and rebound under stress.
- Does not require specialised equipment.
- Does not normally require rip rap at the toe.

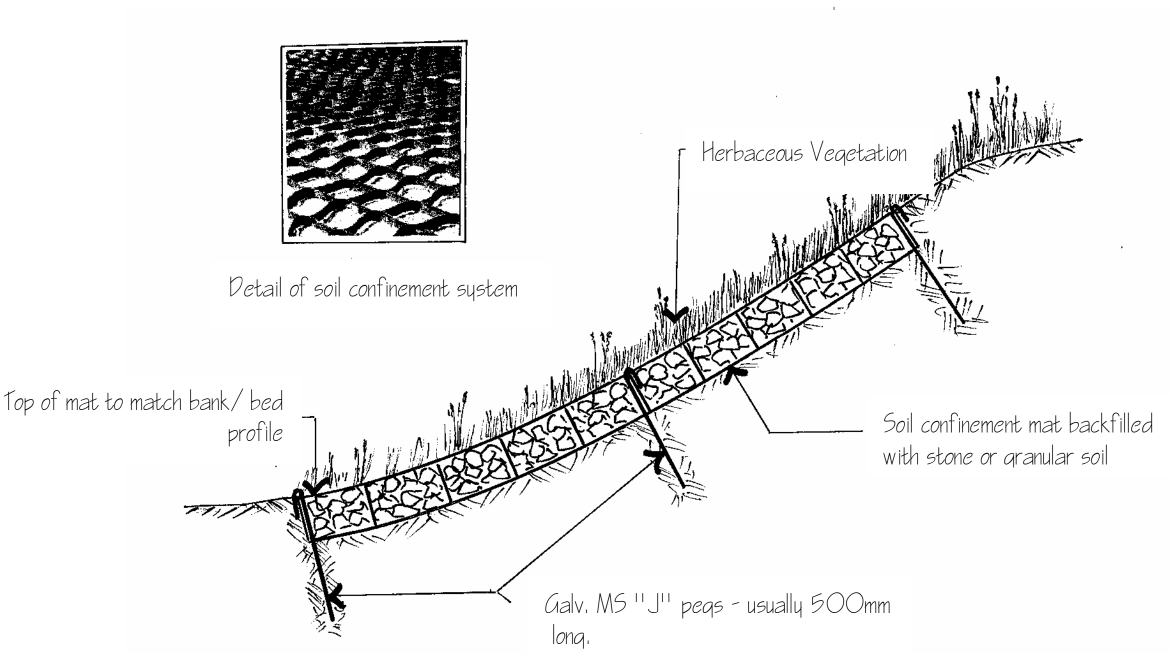
Disadvantages

- Labour intensive [placement of vegetation. Cost maybe reduced if seed broadcast over the finished face.
- Maybe visually unattractive until vegetation is established.

Indicative Capital Cost: Medium assuming there is good access for machinery. .

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 1.5% pa to 3% pa of the capital cost. Maybe 5% pa or higher if used as a single layer on a sloping surface in a harsh environment.

Technique 4: CELLULAR REINFORCED EARTH SLOPE



Description: A high density polyethylene [HDPE] cellular confinement mat is laid over a prepared surface. Typically the cells are 200mm deep and filled with a granular material although all soil types may be used. Vegetation should be used if sand, silts and clays are used as backfilling.

Variations: The cellular mat is usually black but can be coloured to reduce the initial visual impact. Cells with perforated walls to improve drainage of heavy soils are also available.
Wire mattresses [“Reno” mattresses] maybe used in lieu of cellular mat.

Application: Provides bank protection against surface erosion / rilling. The sloping bank should not be steeper than about 26^0 from the horizontal. For steeper slopes additional stakes and anchor lines [polypropylene or stainless steel] connected to buried anchors at the top of the slope should be used to secure the matting. A slope stability analysis for banks steeper than 26^0 is recommended.

Limitations: Generally limited to slopes flatter than 26^0 [1V:3H]. At steeper slopes deeper cells are required to avoid washout of backfill and ties to buried anchors maybe required for stability.

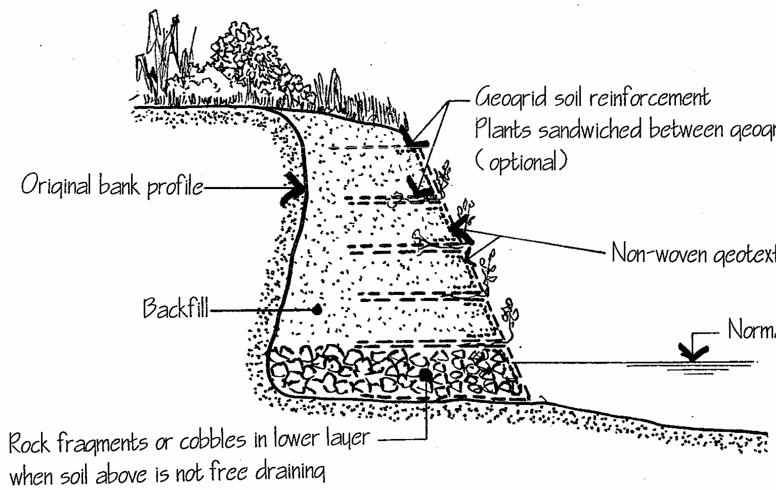
Advantages
- Suitable for a wide range of bank conditions and soil types.
- Does not require specialised equipment.
- Provides protection while vegetation is becoming established.
- Flexible system that can yield and rebound under stress.
- Top edges of cells only are visible and are readily covered by spreading vegetation.

Disadvantages
- Labour intensive [placement of vegetation. Cost maybe reduced if seed broadcast over the finished face.
- Cannot easily be placed under water.

Indicative Capital Cost: Medium assuming there is good access for machinery and bank is not steep.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 1.5% pa to 3% pa of the capital cost. Maybe 5% pa or higher if used in a harsh environment.

Technique 5: BIO-REINFORCED EARTH



Description: A geo-grid is used to construct a reinforced earth bank in front of, or to replace the eroding bank. Suitable deep rooting vegetation is sandwiched between successive layer of geo-grid as the bank is constructed. A lightweight geo-grid or geo-textile is used to face the bank. Where necessary the geo facing is cut to permit the vegetation root stock to grow and cover the bank.

Variations: Reinforced earth bank may be near vertical or sloping. A concrete or timber crib wall may be used in lieu of reinforced earth. Where crib walling is used the lower lifts are usually filled with rock [cobble size or larger] if the wall is below water level or subject to wave action.

Application:
Provides bank protection against undermining, piping, and slumping failure modes.

Limitations: Requires a supply of suitable vegetative material. Toe scour may occur especially where the reinforced bank is terminated above the low water line. Rock armouring can reduce the risk of toe scour.

Advantages

- Suitable for a wide range of bank conditions.
- Provides protection while vegetation is becoming established.
- Flexible system that can yield and rebound under stress.
- Does not require specialised equipment.

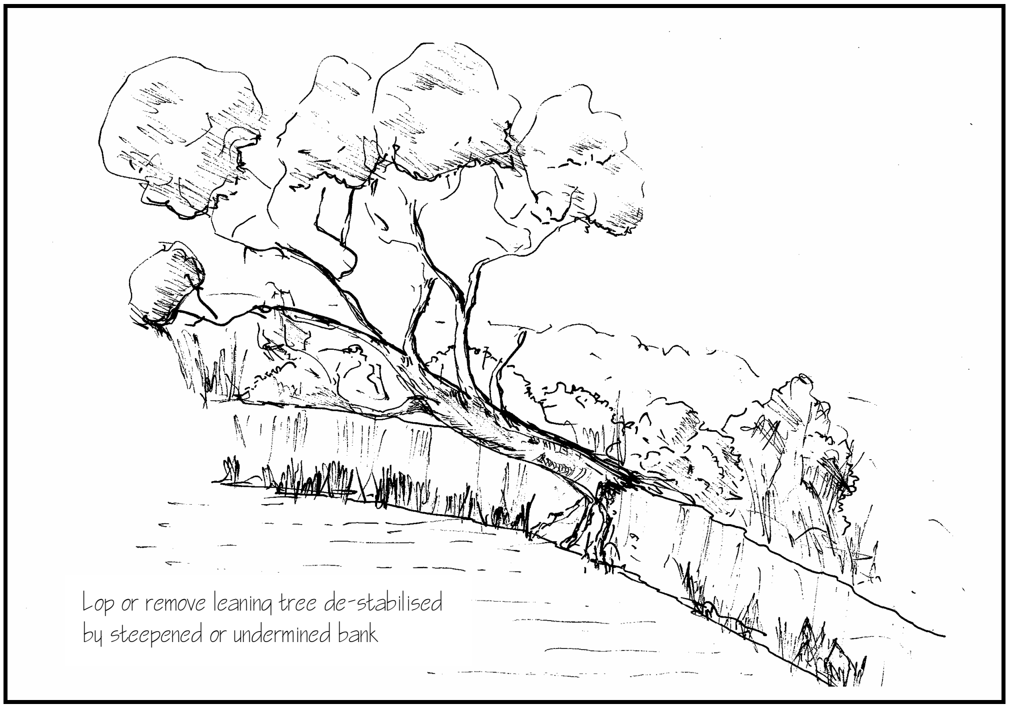
Disadvantages

- Labour intensive [placement of vegetation.
- Geotextile facing is prone to degradation if exposed to UV light for prolonged periods.

Indicative Capital Cost: Medium assuming there is good access for machinery. Cost can be high if rock protection along the toe is also required and/or coffer dams are required to enable construction.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 1.5% pa to 3%pa of the capital cost.

Technique 6: TREE MANAGEMENT



Description
Includes the following**:**

- Lopping or trimming of trees that have been undermined or are leaning precariously to remove public safety threat.
- Reducing the risk of tree collapse and resulting exposure of unprotected stream bank , or to reduce the surcharge load on a bank weakened by over steepening or undermining.
- Tree planting on suitable low bank terraces to assist in binding the soil and reducing the risk of erosion.

Application: Used to increase bank stability in localised areas.

Limitations:

- Localised rock protection placed around the base of the tree may be outflanked if more general erosion occurs over a wider front.
- Newly planted trees may be lost if high flows occur before they become sufficiently well established.

Advantages

- Improves/maintains riparian habitat.
- Low cost and may therefore attract funding from a wider variety of sources.

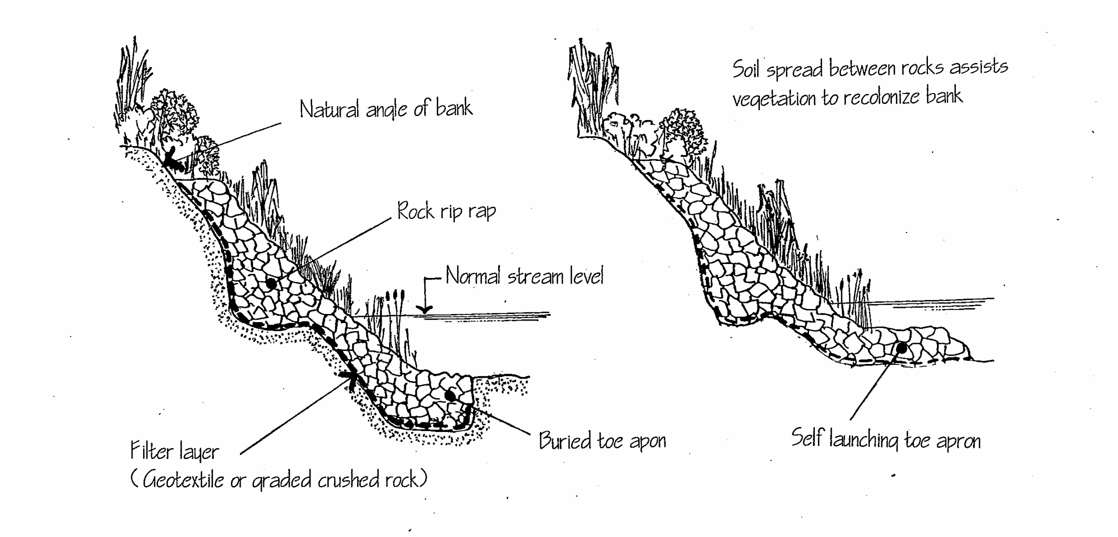
Disadvantages

- May require temporary hard structural protective measures to assist in establishing trees in areas of frequent and/or high flows.
- Newly planted trees or thinning or trees may create corridors of high velocity flow leading to unexpected scour.

Indicative Capital Cost: Low.

Indicative Re-current Cost: Dependent upon climate, growth rate of trees, and extent of re-colonisation by self seeding but usually in the range of 5% to 15% pa.

Technique 7: RIP-RAP ARMOURING



Description: Rock rip-rap is placed against a prepared bank to provide a physical barrier between the bank and the flowing water. Bank maybe battered before placing the rip-rap. A filter layer, either a non-woven geo-textile or a well graded rock layer is used to limit any leaching of the fine bank material.

Variations: Large rock boulders may be placed in lieu of dumping and spreading smaller rock. Broken concrete slabs are sometimes used but usually ineffectually. Specially designed concrete blocks maybe used but they make the project expensive. Maybe constructed with either a buried toe apron [cut-off] or a self-launching apron.

Application: Used to improve slope stability and to provide instant protection to an eroding bank. Commonly used in conjunction with bank battering. Depending on the shape and size of the rock works can withstand high velocities for prolonged periods.

Limitations:

- Application in severe hydraulic conditions may be limited by the available rock.
- Where the stream is prone to bed scour the rock maybe de-stabilised by undermining of the toe.
- Suitable access required for machinery to deliver and place the rock.

Advantages

- Simple to implement and a near permanent solution.
- Flexible
- Low maintenance
- Compatible with re-vegetation.
- Can be placed below water.

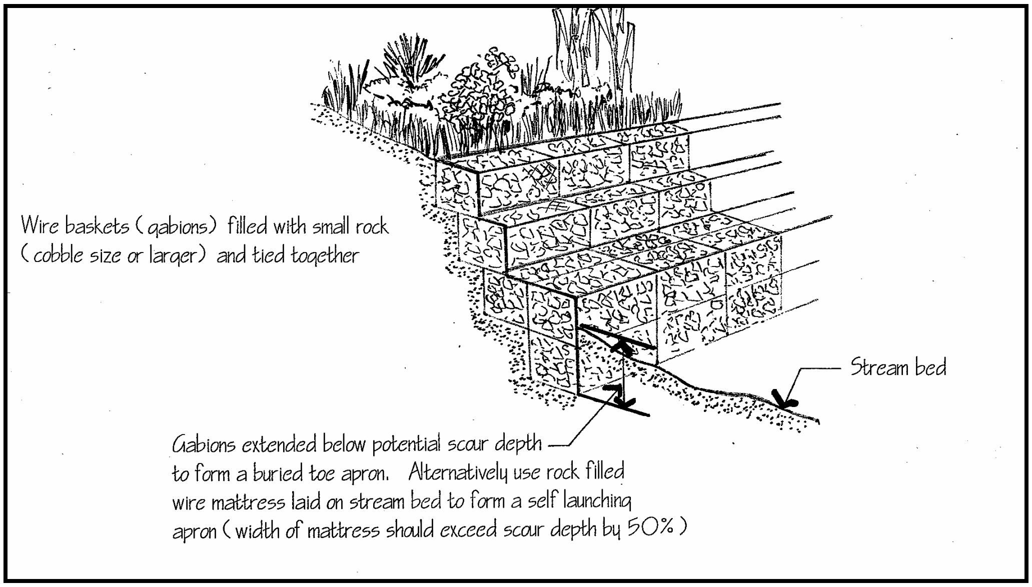
Disadvantages

- Cost maybe high if suitable rock is unavailable and concrete blocks are used.
- Visually harsh until vegetation is established.

Indicative Capital Cost: Usually low to medium depending on the availability of rock. Cost is high to very high if specially designed concrete blocks are used.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 0.5%pa to 2%pa of the capital cost.

Technique 8: GABION RETAINING WALL



Description: Gabion wire baskets or mattresses are filled with rock or river cobbles and laid adjacent to or on the stream bank.

Variations: Bank may be battered before placing the gabions. The exposed gabions may be filed with earth to assist in establishing a vegetative cover. Maybe constructed with either a buried toe apron [cut-off] or a self-launching apron. Mattresses are usually used to form the self-launching apron.

Application: Provides immediate protection and increased stability to eroding banks. Suitable for addressing a wide range of bank failure modes including fretting, direct attrition, and undermining to sloughing [mass failure].

Limitations:
- Subject to premature failure by wire breakage due to high sediment loads carried by the stream.
- Often subject to vandalism.
- May be of public safety concern where wire breaks or by creation of steep vertical drops.
- Where the stream is prone to bed scour the gabion wall maybe de-stabilised by undermining of the toe.
- Suitable access required for machinery to deliver the rock infill.

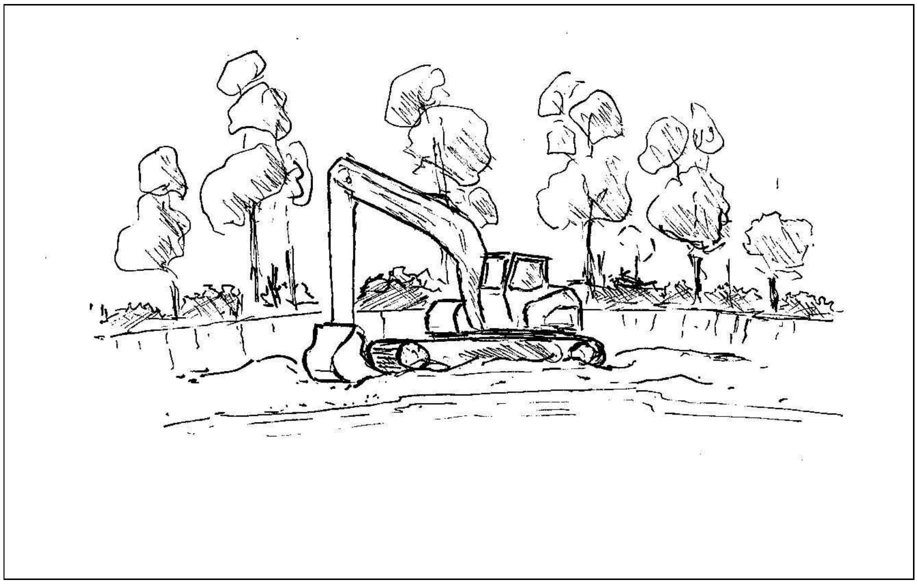
Advantages
- Commonly understood by contractors and requires no specialised machinery.
- Provides immediate protection where suitable rock is available.
- Low maintenance if used where stream sediment loads are low.
- Can withstand high velocities for prolonged periods providing sediment and debris loads are small.

Disadvantages
- Requires a sacrificial facing when sediment and/or debris loads are moderate to high.
- Visually harsh.
- Limited Flexibility
- Limited compatibility with re-vegetation. Requires infilling of rock interstices to enable vegetation to establish.

Indicative Capital Cost: Medium to high depending on the availability and method of lacing the rock infill.

Indicative Re-current Cost: Dependent upon frequency of flooding/submergence but may range from 1.5%pa to 3%pa of the capital cost. Re-current cost will be 5% to 10% pa if used where high velocities and high sediment loads are present.

Technique 9: DREDGING



Description: Dredging a river or creek can be useful in situations where an increase in the flood carrying capacity of the stream is required or to minimise siltation in downstream reaches. Dredging is undertaken using heavy earth moving machinery from either the bank or from within the stream bed.

The technique can be financially self supporting where there is a continual supply of sediment and a market for the dredged material. It can however have severe environmental consequences by completely destroying in-stream habitat and it may result in major and potentially irreversible changes in the stream processes. Any dredging should therefore be carefully planned and monitored for any unforseen consequences in both the upstream and downstream reaches so that remedial action can be taken at the earliest opportunity. As a general rule, dredging should not lower the stream bed below the overall gradient through the reach.

Application: Use where sediment has become stabilised by vegetation that is reducing the median flood carrying capacity of the stream.

Limitations:

- Dredging should only occur after a rigorous analysis of the consequences of removing the sediment.

Advantages

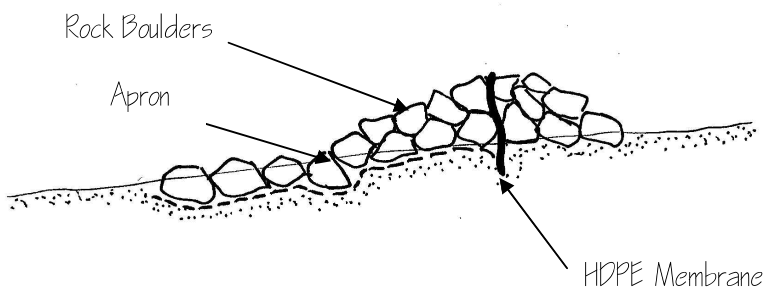
- Provides immediate increase in flood carrying capacity..
- Readily used in conjunction with other techniques

Disadvantages

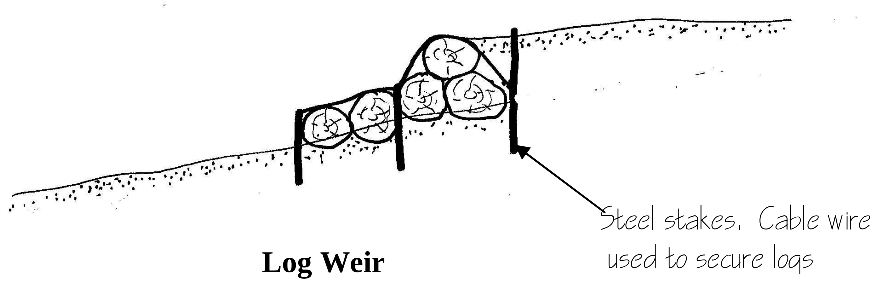
- Can have severe and/or unforeseen consequences for stream stability.
- On going monitoring required of up-stream and downstream reaches.
- Destroys in-stream habitiat.

Indicative Capital Cost: Medium depending on the availability and method of access. Can be very low if the sediment has a re-sale value.
Indicative Re-current Cost: Dependent upon frequency of de-silting required. Cost can be high if sediments contain toxins.

Technique 10: MINOR GRADE CONTROL



Rock Chute/Check Weir



Log Weir

Description: Placed rock boulders or hardwood logs are placed across the stream bed and embedded into the banks to locally reduce the effective stream grade. Check weirs are constructed on the stream bed and permit the deposition of sediment which gradually reduces the stream bed. When used as weirs they act by reducing the upstream movement of the nick point or head gully in the stream bed

Variations:. Gabion baskets, stacked vehicles tyres [Ecoflex®] or cellular confinement matting [Ecocell®] can also be used. Concrete headwalls also sometimes used but mostly in irrigation canals.

Application: Provides immediate protection and increased stability to bed erosion. Will assist in arresting bank erosion where this is due to over steepening of the banks due to stream degradation.

Limitations:
- Suitable only for low level drops.
- May create a public safety concern where the crest of the weir or drop is used as an informal creek crossing.

Advantages
- Provides immediate protection.
- Readily used in conjunction with other techniques
- Can incorporate or act as a fish ladder.

Disadvantages
- Log system requires regular monitoring and maintenance.

Indicative Capital Cost: Medium to high depending on the availability and method of lacing the rock infill. **Indicative Re-current Cost**: Dependent upon frequency of flooding/submergence but may range from 1.5%pa to 3%pa of the capital cost. Re-current cost will be 5% to 10% pa if used where high velocities and high sediment loads are present.