15. Geomorphology

This chapter provides a summary of the results of the fluvial geomorphic assessment undertaken for the Project. A copy of the full assessment report is provided in Appendix I.

15.1 Methodology

The potential impact of the construction and operation of the Project on the stability and geomorphic values of the waterways intersected along the pipeline was assessed by:

- Undertaking a review of applicable legislation, policies and guidelines;
- Undertaking an assessment of existing information to classify and define the waterways at crossing locations using waterway crossing classification descriptions;
- Defining the type of waterways at each crossing location based on the River Styles® framework (Brierley and Fryirs 2005) (Section 15.1.1);
- Undertaking an assessment of geomorphic condition based on Outhet and Cook (2004), dividing stream geomorphic condition into Good, Moderate or Poor condition (Section 15.1.2);
- Undertaking a geomorphic field investigation where key information concerning the morphology of each waterway crossed by the pipeline, including:
  - Channel form and instream morphology;
  - Bed and bank stability;
  - Nature of bed and bank sediments;
  - Channel controls;
  - Adjoining landuses;
  - Features indicative of flow levels (*e.g.,* debris); and
  - Nature and location of any existing infrastructure.

  The field assessment encompassed all identified major and moderate named and unnamed waterway crossings. Additionally, a selection of Minor Waterways and Drainage Lines were also investigated to verify the range of geomorphic types and condition of these waterways as determined through the desktop assessment; and
- Based on the understanding of the form, stability and geomorphic condition of waterways at crossing locations, an assessment of the impacts and risks associated with the preferred crossing method (trenching) was undertaken.

15.1.1 Waterway identification and classification

An assessment of existing information (GIS data and aerial imagery) was undertaken to classify and preliminarily define the geomorphic type and condition of waterways at crossing locations as detailed below.

The method for waterway classification at each crossing location was undertaken in general accordance with the parameters set out in Table 15.1.

Table 15.1 Waterway crossing classification descriptions

Waterway Classification	Catchment Area (ha)	Stream Order*	Valley/Channel Definition
Drainage Line	< 100	Unmapped to first order	No defined channel and valley floor fill < 10 m wide.
Minor Creek	100 to 500	First to second order	Defined channel < 5 m wide or valley floor fill 10 to 20 m wide.
Moderate Creek	500 to 2,000	Second to third order	Defined channel 5 to 10 m wide or valley floor fill 20 to 50 m wide.
Major Creek/River	> 2,000	Third order and higher	Defined channel > 10 m wide or valley floor fill > 50 m wide.

* Based on Department of Lands 1:25,000 drainage layer

15.1.2 Waterway Types and Geomorphic Condition

The type of waterways at each crossing location was defined based on the River Styles framework (Brierley and Fryirs, 2005).

Assessment of geomorphic condition was based on Outhet and Cook (2004) who describe a rapid method of condition assessment that frames geomorphic condition in the context of natural and human induced variability and divide stream condition into three broad categories: The characteristics relating to each of the categories of geomorphic condition are outlined below (based on Outhet and Cook 2004).

Good Condition – must contain all of the following characteristics:

- River character and behaviour is similar to the pre-development state presenting a high potential for ecological diversity;
- Minimal alteration to catchment controls such as sediment supply and the hydrological regime allowing fast recovery from natural disturbance; or
- Relatively intact and effective vegetation coverage dominated by native species, giving resistance to natural disturbance and accelerated erosion.

Moderate Condition – contains one or more of the following characteristics:

- Localised degradation of river character and behaviour, typically marked by modified patterns of geomorphic units; or
- Patchy effective vegetation coverage allowing some localised accelerated erosion.

Poor Condition – contains one or more of the following characteristics:

- Abnormal or accelerated geomorphic instability (reaches are prone to accelerated and/or inappropriate patterns or rates of planform change and/or bank and bed erosion);
- Excessively high volumes of sediment inputs which blanket the bed, reducing flow diversity; or
- Absent or geomorphologically ineffective coverage by vegetation (allowing most locations to have accelerated rates of erosion).

15.1.3 Determination of crossing method and impact assessment

The crossing method for each waterways was determined based on the classifications above, the field assessment and the recommendations for crossings provided by NOW as follows:

- Crossings of waterways/riparian land should be underbored or attached to existing structures (such as bridges) to avoid direct impacts on the aquatic and riparian environment, where:
  - there is permanent flow in the waterway; or
  - there is existing native riparian vegetation; or
  - the creek is in good natural condition; or
  - there is a potential fish passage Class 1 or 2.
- The NOW recommends that underboring commence from the outer edge of the riparian land and that it is bored for the full width of the watercourse and riparian land;
- Trenching may be an option if:
  - the waterway is a dry intermittent creek;
  - the native riparian vegetation has previously been cleared; and
  - there are no watercourse instability issues.
- If there are areas of the existing creek instability below the pipeline route the creek crossing needs to be designed so as to ensure for the future stability of the waterways and reduce risk to the pipeline itself.

The potential impact to the waterways has been assessed against the worst-case-scenario, that being that the waterway would be crossed by trenching. This was applied to all 138 waterways and despite most "major" waterways being crossed by HDD as the proposed measure (see Table 6.4 [Section 6 – Project Description]), during the impact assessment, some of these waterways have been identified as suitable for trenching or alternative crossing methods. Further support of trenching for some permanently flowing waterways is required in the form of aquatic ecology surveys and geotechnical surveys which would be undertaken prior to construction.

There are a number of available methods for constructing waterway crossings, depending on environmental and engineering constraints. For the environmental impact assessment, it has been assumed that most waterways with permanent flowing water ("major waterways") would be crossed by HDD, with all other waterways crossed by open cut trenching, unless there are sensitive waterways or associated environments. Table 6.4 (Section 6 – Project Description) describes the proposed waterway crossings for the project. Further aquatic ecology surveys and geotechnical investigations will determine the final method of crossing during detailed design.

This assessment therefore considers the potential impacts associated with the trenching method on waterway stability for all waterways as a base case scenario.

As a base case, all waterways have been assessed for the suitability for trenching as a crossing method. Where it is determined that trenching would not be a feasible crossing method, an alternative method has been identified (i.e. HDD or anchored pipeline).

15.2 Existing environment

15.2.1 Waterway identification and classification

A total of 138 waterway crossings were identified along the pipeline alignment. Table 15.2 describes the classification of the waterway crossings.

Table 15.2 Classification of waterway crossings along the pipeline alignment

Waterway classification	Crossing identification code	Waterway name
12 waterway crossings classified as major creeks/rivers	W3	Kelly's Creek
	W52	Paddys River
	W56	Uringalla Creek
	W57	Back Creek
	W69	Jaorimin Creek
	W84	Narambulla Creek
	W108	Boxers Creek
	W120	Kenmore Creek
	W105, W106, W119, W131	Wollondilly River
8 waterway crossings classified as moderate creeks (6 named)	W14	Medway Rivulet
	W22	Black Bobs Creek
	W95	Osborns Creek
	W122, W123, W124	Kenmore Creek
25 waterway crossings classified as minor creeks (3 named)	W19	Wells Creek
	W27	Long Swamp Creek
	W81	Lockyersleigh Creek
93 waterway crossings classified as drainage lines, all unnamed	All unnamed	All unnamed

15.2.2 Waterway types

The waterways inspected for the purposes of this assessment are predominately set within a rural or semi-rural land use context and have been modified over time by land clearance, the construction of the gas pipelines and other agricultural practices. Most waterways are ephemeral in nature and flows were observed at only some of the Moderate and Major Creeks/Rivers the time of the site inspections.

Table 15.3 provides a summary description of the eight broad waterway types observed during the field inspection. Examples of the waterway types are provided in Figure 15.1 to Figure 15.4 below.

Table 15.3 Summary of the waterway types observed (out of 138 total waterway crossings)

Waterway type	Description and Field observations	Number observed	Classification
Headwater Systems	Steep gradient channels. Bedrock dominated. Little deposits of sediments within channel. Floodplains non-existent. Channel may slowly erode the valley wall if it consists of weathered bedrock or colluvium. Many of the headwater systems had relatively undefined flow paths. Flows at crossing points largely derived from hillslope sheet flow.	43	Drainage lines
Confined Systems	Single, symmetrical channel. Often in bedrock controlled, irregular v or u shaped valleys. Channel geometry and sinuosity is valley controlled. Bed composed of bedrock, boulder, cobble and gravel. May also transport sand. Subject to very slow rates of change.	1	Moderate Creek (W95)
Valley Fill Systems	Minor waterways are generally typical of valley fill systems. Characterised by relatively flat, unincised valley floor surface. Substrates comprised of alluvial fine silts and muds. Flows lose their velocity and competence as they spread over an intact valley floor and deposit sediment load.	57	Drainage lines or minor creeks
		1	Moderate creek (W124)
Channelised Fill System	More defined watercourse channel than the valley fill system. In some cases, waterways have been channelized or formed as a constructed drainage line. Likely they have been modified to convey flows to drain land for agricultural use.	20	Drainage lines or minor creeks
		1	Moderate creek (W121)
		1	Major creek (W108)
Chain of Ponds Systems	Series of symmetrical (sometimes irregular) ponds. Occur at irregular intervals along drainage line. Banks and pond beds composed of fine sand, mud and organic material. Ponds tend to retain water all year. During high flows sands and fine material is transported downstream. Often associated with lower gradients and lower flow velocity. Quite rare and fragile. Prone to channelization between ponds forming a continuous channel resulting in loss of aquatic habitat.	1	Major creek (W84)
Bedrock Controlled Fine Grained Systems	Single, trench-like, symmetrical channel. Low sinuosity with moderate lateral and vertical stability. Often bedrock floor. Valley width and alignment controls channel sinuosity and floodplain extents, creating discontinuous floodplains as the river migrates between valley margins. Cohesive fine-grained sediments dominate the bed and alluvial banks.	5	Major creeks/rivers (W52, W105, W106, W119, W131)

Waterway type	Description and Field observations	Number observed	Classification
Bedrock Controlled Sand Systems	Single, laterally stable, bedrock floored channel with a sandy bed. Some lateral movement can occur where discontinuous floodplains are formed as the channel crosses from valley margin to valley margin. Prone to enlargement through erosion.	1	Major creek (W69)
Low Sinuosity Fine Grained Systems	Low sinuosity channel with wide, continuous floodplains and relatively stable, cohesive banks due to fine-grained material. Bed consists of fine-grained sediments with some sand and gravel sections creating moderate hydraulic diversity within the channel. Low gradient and usually low energy allowing a build up of fine-grained sediment.	1	Minor creek
		5	Moderate creeks (W14, W22, W112, W122, W123)
		4	Major creeks (W3, W56, W57, W120)

Figure 15.1 Wollondilly River (W105) – Bedrock Controlled, Fine Grained – downstream view from proposed crossing point.

Figure 15.2 Jaorimin Creek (W69) – Bedrock Controlled, Sand – downstream view from proposed crossing point.

Figure 15.3 Paddy's River (W52) – Bedrock controlled, fine grained – upstream view from proposed crossing point.

Figure 15.4 Narumbulla Creek (W84) – Chain of ponds – downstream view from proposed crossing point.

15.2.3 Waterway existing condition

European land clearance has resulted in altered hydrological regimes which have had an impact on the morphological character of many of the waterways within the vicinity of the proposed pipeline route.

Prior to European land clearance, many of the waterways along the proposed route would have been either Chain of Ponds or Valley Fill waterway systems while now they exhibit an incised, channel form. Many of the waterways have significantly altered their form and some continue to exhibit signs of channel instabilities.

Additionally, the alignment follows the existing gas pipelines from approximately the Hume Highway through to Goulburn and as a result, the common waterway crossings, although generally stable, have been disturbed previously and lack native riparian vegetation coverage in the vicinity of the crossing locations.

Of the 138 waterway crossings:

- 31 of the waterway crossings were assessed to be in good condition. These are all Minor Creeks with Headwater and Valley Fill systems apart from the Major Creek/River crossing at W69 (Jaorimin Creek);
- 92 of the crossings were assessed to be in moderate condition, ten of which are classed as Major Creeks/Rivers and four as Moderate Creeks; and
- 15 of the crossing were assessed to be in poor condition, one of which is a Major Creek/River (W108, Boxers Creek) and four are Moderate Creeks.

15.2.4 Waterway stability

Most waterways along the pipeline route are considered to be relatively geomorphologically stable. This is a reflection of the landscapes and type of waterway systems the proposed pipeline traverses. Some waterways, however, displayed existing instabilities in the form of either headward erosion or bank erosion. A description of each is provided below.

Bed instability – Headward erosion

Headward erosion was evident downstream of four of the waterways assessed (W8, W20, W42 and W80).

Headward erosion ('headcut') is erosion which occurs along a channel in the opposite direction to water flows. This causes down cutting or incision of the bed of a stream and can alter the longitudinal profile of the waterway. Erosion can result in increased rates of sediment to be transported downstream.

Bank instability

Existing bank instabilities were evident at nine of the waterway crossings (W1, W14, W19, W42, W67, W69, W79, W108 and W111).

Many banks are irregular in shape indicating that erosion has occurred in the past. Banks are generally stable under the current flow regimes, many of which are stabilised by pasture grasses.

15.3 Impact assessment

15.3.1 Waterway crossing construction methods and impacts

There are a number of available methods for constructing waterway crossings, depending on environmental and engineering constraints. It is likely that all minor and moderate waterways would be crossed by open cut trenching (with or without flow diversion). The impact assessment therefore considers the potential impacts associated with the trenching method on waterway stability.

The major waterways have been identified as part of the assessment. Many of these waterways contain permanent flow. It has been determined that a number of crossings across major waterways would be undertaken by underboring (either by HDD or thrust boring). These include Paddys River (W52), Uringalla Creek (W56) / Back Creek (W57) confluence, Jaorimin Creek (W69) and the Wollondilly River (W105, W106, W119, W131). As such, the waterways themselves would not be directly impacted by the crossing work. The geomorphology assessment has however considered the potential impact to these waterways should trenching be used as the method for crossing as the worst case scenario. The crossing method of the major waterways may be further refined during the detailed design phase as further engineering and aquatic surveys are undertaken. In many cases, the geomorphic assessment indicates that waterways could be crossed by trenching; however detailed aquatic surveys and engineering surveys have not been undertaken to establish whether alternative methods are applicable.

Trenching

Standard open cut trenching is most often utilised in low flow, shallow or dry conditions. This technique involves setting up a stable work platform on each side of the watercourse and then excavating a trench. The trench is not completed until immediately prior to placement of the pipeline. Tie in points are located on high ground away from the banks. Pipes are then placed into the trench using slings from the excavators at either side of the waterway. The spoil from the watercourse bed and bank and trench spoil material are stored separately.

This crossing method may also be applied in sensitive streams where rapid construction is considered the best means of minimising environmental impacts. The primary risk of impact associated with trenching is the potential for release of high sediment loads during excavation and backfilling. If managed inappropriately, it could increase turbidity, impacting upon downstream water quality. Mitigation measures to reduce the environmental impact of trenching include, flow diversion, sediment capture devices and strict environmental management controls.

Where higher water volumes and flows are present, open trenching using streamflow diversion can be used. This technique typically involves creating a dry construction area within which to work by pumping around the area. Other diversion techniques include diverting the water flow through a flume pipe installed between the dams. Diverted flow is maintained at a flow rate and water quality, which would allow the downstream reaches of the waterway to continue to function.

Key construction activities include:

- Installation of sediment controls and flow diversions;
- Trench excavations and placement of the pipeline; and
- Reinstatement / revegetation.

Impacts associated with trenching may include:

- Disturbance to bed and banks of waterway channels;
- Disturbance to floodplains;
- Stream bed degradation;
- Stream bank erosion; and
- Scour potential from poor pipeline orientation:
  - The impact of erosion from bed and bank disturbance can include water quality impacts on the downstream environment. General construction activities (e.g. stockpiling of material, etc.) may lead to sedimentation issues.
  - Impacts to riparian and aquatic flora and fauna.
  - Disturbances or loss of native vegetation (including seedbank, instream and riparian vegetation).

15.3.2 Specific transfer pipeline route impacts on waterway geomorphology

Alteration of Channel Morphology

Trenching to lay the pipe would disrupt the bed and banks of waterways along the proposed pipeline alignment resulting in altered channel and floodplain morphology if appropriate mitigation is not implemented.

Stability

Site based assessments indicate that headward erosion and bank erosion is occurring in the vicinity of some waterway crossing locations along the alignment. These bed and bank instabilities may be further exacerbated by construction associated with laying of the transfer pipeline. This may:

- Increase the risk of headward erosion where headcuts are evident downstream. There is a risk that the pipeline would create bed instabilities leading to further channel incision in an upstream direction. An additional consequence of this may be the risk of exposing the pipeline asset in the future; and
- Initiate bank disturbance during trenching activities. If appropriate reinstatement is not implemented this may lead to increased bank erosion.

Works on waterways during construction of the Project also have the potential to increase bed and bank instabilities due to removal of existing instream and riparian vegetation and disturbance of the channel profile.

Table 15.4 summarises the general impact of the pipeline construction on waterway stability by waterway type and some specific waterway crossing locations where applicable.

Table 15.4 General impact of pipeline construction on waterway stability by waterway type

Waterway type	Waterway stability	Specific crossing locations (if applicable)	Potential construction impact
Headwater and Confined Systems	These systems are bounded by bedrock and are not prone to bed scour or bank erosion.	NA	Very stable channel and with appropriate treatment and rehabilitation the construction of the pipeline will have an extremely low risk of increased channel instabilities on these systems.
Valley Fill Systems	Do not have defined channels and therefore can't be subject to bed scour or bank erosion. These systems dissipate flows over a flat, broad area and are generally composed of cohesive fine grained sediments.	W132 W136	Exposure and disturbance from construction activities can destabilise the valley fill surface allowing a point where channelisation could start. With appropriate treatment the risk is low, however is considered moderate at locations where the pipeline alignment traverses along rather than across the valley surface.
	Stable landforms when intact. However disturbance can result in the incision of a channel within a fill surface leading to erosion and release of sediments downstream.	W8 W20 W42 W80	Headwater erosion was evident downstream of a number of waterway crossings. This poses risk of potential future exposure of the pipeline in the event of further upstream retreat of the headward erosion occurs.
		NA	Flow diversion structures may concentrate flows resulting in an increased potential for scour during run-off events and initiating channel development. Risk is low due to the relatively rapid construction requirements, limiting the need for flow diversion structures.
Channelised Fill Systems	Depth of channel incision is limited by underlying bedrock or by some downstream base level control, hence further vertical incision is limited. The banks of such systems can exhibit prolonged instability following the initial development of the	W1 W19 W79 W108 W111	Ongoing bank instability was identified at some locations where the pipeline crosses. Construction of the pipeline has a low to moderate risk of exacerbating bank instabilities in the immediate locality of these crossings.

Waterway type	Waterway stability	Specific crossing locations (if applicable)	Potential construction impact
	channel.		
Chain of Ponds Systems	Disturbance of pond connections can result in the incision of a channel within the connections that can lead to significant erosion, the release of sediments to downstream environments and the loss of the permanent pond environments.	W84	The crossing point at W84 is located in the middles of the pond, and therefore trenching activities and pipeline placement will not directly disturb a pond connection; however due to the sensitivity of the waterway type, careful planning and monitoring of the construction phase would be required. The upstream extent of the downstream connection will likely be used as a crossing point for vehicles and machinery; however it is at a point where the likelihood of channel development is low. Crossings by vehicles should only be undertaken if the crossing point is dry and the number of crossing should be minimised.
Bedrock Controlled Fine Grained and Bedrock Controlled Sand Systems	These systems have some capacity to adjust in response to disturbances, usually through localised bank erosion and/or bed degradation. Regular bedrock controls generally limit the extent of these responses. The extent and potential degree of these impacts will be site specific and need to be discussed individually.	W52	Channel scour potential during high flows is limited due to the dense channel vegetation and low channel depth which allows flood flows to readily dissipate across the floodplain. The risk of trenched pipeline construction to cause channel instabilities is low if standard mitigation measures are implemented.
		W69	A rock ford crossing downstream controls upstream channel bed and water levels in the pool. A steep drop off exists downstream of the ford crossing and banks are eroding, posing a risk the ford may fail in the future. This would lead to a drop in the bed level and water level of the pool, with a risk of exposing the pipeline in the future. The risk of causing channel instabilities is low if appropriate bank re-instatements are implemented and the pipeline is set at a depth below the influence of bed scour. However, the potential future failure of the ford downstream poses a risk to the pipeline and the stability of the channel at the crossing location.
		W105	There is a deep pool at this site (> 5m

Waterway type	Waterway stability	Specific crossing locations (if applicable)	Potential construction impact
			depth) inset within a broader macro-channel approximately 80m wide. Given the depth of the pool, a trenched pipeline at this crossing location is unlikely to be feasible. The current alternatives, subject to geotechnical and hydraulic investigations, are to either anchor the pipeline to the channel bed via concrete blocks or to use a Horizontal Directional Drill (HDD) method. Both these methods will result in minimal disturbance to the channel bed during the construction phase. With appropriate re-instatement and rehabilitation the risk of ongoing bank erosion is considered low.
		W106	Bed materials are mobilised infrequently under high magnitude flow events. Bedrock is exposed in the base of the low flow channel indicating the low flow channel is vertically stable. The low flow channel has the potential to move laterally across the entire width of the macro-channel invert over time and in response to high magnitude flow events. The exposure of bedrock in the low flow channel means that the pipe will be able to be inset within a bedrock trench and concrete encased. This construction method will need to be implemented across the entire width of the macro-channel to limit the exposure of the pipe through potential lateral adjustments of the low flow channel in the future. With appropriate flow diversions and bed and bank re-instatements, there is a low risk of causing channel instabilities at this site.
		W119	Banks are alluvial and are stable being well graded and grassed. Given the low water depths at this crossing site, a trenched crossing is feasible and will result in minimal long term disturbance to the channel bed and banks if constructed during low flow periods and appropriate flow diversions, sediment controls and bed and bank re-instatements are implemented. However, the bed of the channel is composed of fluvial gravels, sands and silts and excessive scour may

Waterway type	Waterway stability	Specific crossing locations (if applicable)	Potential construction impact
			expose the pipe during high magnitude flood events.
		W131	Banks are alluvial and, although near vertical, are stable and well vegetated with grasses. Given the depth of the pool a trenched pipeline at this crossing location is unlikely to be feasible. The current alternative, subject to geotechnical and hydraulic investigations, is to anchor the pipeline to the channel bed via concrete blocks. This will result in minimal disturbance to the channel bed during the construction phase, although banks will be excavated to transition the pipe into and out of the channel. However, with appropriate re-instatement and rehabilitation the risk of ongoing bank erosion is considered low.
Low Sinuosity Fine Grained Systems	These systems are generally stable due to the bed and banks of the channel being composed of cohesive fine, grained sediments. As a result most of these systems along the alignment are stable at the proposed pipeline crossing locations. With appropriate treatment and rehabilitation the risk of bed and bank erosion posed by pipeline construction is generally low.	W14	The exception of the stable system is waterway crossing W14 where ongoing bank instability was evident at the crossing location. Construction of the pipeline has a low to moderate risk of exacerbating bank instabilities in the immediate locality of this crossing.

15.4 Summary of results

Eight broad waterway types were identified along the pipeline route. These include headwater systems, confined systems, valley fill systems, channelised fill systems, chain of ponds systems, bedrock controlled by fine grained systems, bedrock controlled by sand systems and low sinuosity fine grained systems.

Most waterways along the pipeline route are considered to be relatively geomorphologically stable. This is a reflection of the landscapes and type of waterway systems the proposed pipeline traverses. Some waterways, however, displayed existing instabilities in the form of either headward erosion or bank erosion.

A number of potential impacts have been identified concerning the construction and operational phases of the Project. For this report, these are concerned with the impact that construction of the pipeline has on the form and stability of the potential 138 waterways crossed by the pipeline. Waterway assessments indicated that the bulk of waterways are Drainage Lines or Minor Creeks and are relatively stable. Hence, with appropriate construction practices, re-instatements and rehabilitation, the impact of pipeline construction on waterway form and stability will be low. Nevertheless, some waterway crossing sites exhibit existing instabilities and/or sensitivities for which additional mitigation measures have been provided below. With adoption of these additional measures, the overall impact of pipeline construction on waterway form and stability would be low.

15.5 Mitigation measures

15.5.1 General construction impact mitigation measures

A range of measures are commonly used to mitigate potential impacts on the surface water environments and waterway stability. These measures are outlined below and should be incorporated into a CEMP.

Erosion and sediment control measures

The following standard erosion and sediment control measures would be implemented during construction:

- Erosion and sediment control measures would be established prior to construction;
- Erosion and sediment control measures would be regularly inspected, particularly following rainfall events, to ensure their ongoing functionality;
- Vegetation clearance would be avoided where possible to protect soils from erosion. If clearance cannot be avoided, the area of vegetation cleared at any one time should be minimised;
- Reinstatement of vegetation as quickly as practicable after construction;
- All stockpiled material would be stored in bunded areas and kept away from waterways and floodplains to avoid sediment entering the waterway;
- Diversion drains and bunds would be established during construction works to manage site runoff and minimise the transport of sediment from the construction site into the waterway; and
- Preferably a waterway would be crossed on a straight portion of the waterway to avoid the risk of erosion. Where this is not possible bank stability works should be implemented. The details of the specific bank stability works at each waterway crossing would be detailed in the CEMP after detailed design has been completed but would typically be comprised of soft engineering techniques to rectify bank cuts and improve stability. The waterways that may require specific bank stability or bed stability works are identified in Table 15.5.

Timing of construction

The timing of construction can help to reduce the potential impacts associated with the construction of the pipeline across the waterways. Specific measures include:

- Waterway crossings would be avoided during periods of heavy rainfall and flooding; and

- Contingency plans to address heavy rainfall and flood events during construction would be included in a CEMP. The contingency plan should address:
  - Limiting stormwater entering excavation areas;
  - Enhancement of controls when heavy rain is forecast;
  - Siting of facilities;
  - Clean up procedures;
  - A flood warning system for crossings on Major waterways; and
  - Procedures for limiting loss of spoil and other hazardous materials.

Minimise site disturbance

Actions to be taken to avoid site-based disturbance during the construction period would include:

- Minimising the width and effective footprint of works across waterways;
- Controlling the route used by machinery into and out of the works site;
- Avoiding the need for access of heavy machinery to the bed of the waterways as works would be undertaken from the top of the banks where possible; and
- Avoiding disturbance of surrounding banks by machinery or other construction works.

Depth of pipeline at waterway crossings

When installing the pipeline

- Depending on depth to bedrock, provide a minimum of 1 metre from the top of the pipe to the bed of the channel for Moderate Creeks, Minor Creeks and Drainage Lines;
- Depending of depth to bedrock, provide a minimum of 2 ms from the top of the pipe to the bed of the channel for Major Creeks; and
- For Valley Fill and Chain of Ponds systems, the minimum depth should be maintained across the entire width of the valley to reduce the risk of exposure of the pipe in the event a channel develops in the valley fill surfaces in the future.

Stream flow diversion measures

Stream flow diversion measures would be implemented during construction where high water volumes and flows are present and unavoidable. Specific measures for stream flow diversion are described in Chapter 6.

Reinstate profile and stability

Rehabilitation actions to reinstate the creek profile and promote stability in disturbed waterways would include:

- Replace sediments in order they were removed;
- Reshape according to current profile;
- Design recommendations informed by the geotechnical investigation to address the potential for differential settlements in areas containing soft or compressible soil types.
- Reinstating bank soils over pipeline with a soil-rock mix (~100-300 mm), jute matting and re-grassing to reduce risk of bank erosion; and

- Reinstating bed and banks with rock in erosion sensitive areas to protect from bank erosion.

15.5.2 Specific construction mitigation measures

In addition to the standard management requirements that would be expected during construction, some waterways may require additional mitigation measures to ensure adequate protection. These measures are outlined in Table 15.5.

As discussed in Section 15.3.1 above, the major waterways have been identified as part of the assessment. It has been determined that a number of crossings across major waterways would be undertaken by underboring (either by HDD or thrust boring). The geomorphology assessment has however considered the potential impact to these waterways should trenching be used as the method for crossing as the worst case scenario. The crossing method of the major waterways may be further refined during the detailed design phase as further engineering and aquatic surveys are undertaken. Thus the specific mitigation measures provided below relate to potential impacts to individual waterways should trenching be used to cross the waterway. In many cases, the geomorphic assessment indicates that waterways could be crossed by trenching; however detailed aquatic surveys and engineering surveys have not been undertaken to establish whether alternative methods are applicable.

Table 15.5 Specific waterway mitigation measures recommendations

Waterway Type	Waterway Crossings	Potential Impact	Recommended Mitigation
Valley Fill	All	Concentration of drainage due to flow diversions and/or soil disturbance leading to channel development.	◗ Avoid or limit the use of flow diversions during construction phase. ◗ Undertake construction during dry conditions to limit soil disturbance and need for flow diversions. ◗ Ensure final landform merges to pre-existing surface levels to avoid changes in flow distribution across valley fill surface. ◗ Implement rehabilitation measures immediately following construction.
	W132 to W136	Pipeline traverses longitudinally along valley fill surface increasing the risk of scour and channel development.	As per above and including: ◗ Limit the extent of open trench exposed at any time. ◗ Provide emergency bunding (sand bags) to divert flows from open trench in the event rainfall is forecasted during construction. ◗ Rehabilitate completed works and disturbed areas with a surface rock (50 to 100 mm) and soil mixture, jute matting and revegetation immediately following construction.
	W8, W20, W42 and W80	Retreat of existing downstream headward erosion leading to	◗ Set pipeline at a depth below the invert of the developed channel downstream; and/or

Waterway Type	Waterway Crossings	Potential Impact	Recommended Mitigation
		exposure of pipeline in the future.	◗ Monitor headward erosion and install stabilisation works in the event exposure of the pipeline is imminent.
Channelised Fill	W1, W19, W79, W108 and W111	Exacerbation of existing channel instabilities.	◗ Provide rock protection to disturbed banks ensuring the protection merges to existing surfaces and the risk of outflanking by existing upstream or downstream erosion is minimised.
Chain of Ponds	W84	Disturbance of downstream pond connection through vehicular movements	◗ Install a temporary causeway for construction composed of loose rock (100 to 200 mm). This shall be underlain by a geotextile to allow removal of rock following cessation of construction activities in the area. ◗ Undertake construction during dry conditions to limit soil disturbance.
Bedrock Controlled Fine Grained	W105	.Deep pool limiting feasibility of a trenched crossing.	◗ Subject to geotechnical and hydraulic investigations, anchor the pipeline to the channel bed or use Horizontal Directional Drilling (HDD) methods.
	W106	Exposure of pipe through lateral movement of low flow channel in the future	◗ Inset pipe within bedrock across entire width of the macro-channel.
	W119	Bed scour and pipe exposure during high flow events.	◗ Undertake geotechnical and hydraulic investigations to determine potential scour depth at crossing site. Set pipe below this depth and provide appropriate protection
	W131	Deep pool limiting feasibility of a trenched crossing.	◗ Subject to geotechnical and hydraulic investigations, anchor the pipeline to the channel bed via concrete blocks.
Bedrock Controlled Sand	W69	Bed scour and pipe exposure during high flow events.	◗ Undertake geotechnical and hydraulic investigations to determine potential scour depth at crossing site. Set pipe below this depth and provide appropriate protection.
		Failure of downstream ford leading to exposure of pipe and channel instability at crossing site.	◗ Given the ford will be likely to be used as a crossing for vehicles during construction, it is recommended that the ford be upgraded through construction of a rock dissipation ramp and provision of rock bank protection immediately downstream of the ford.

Waterway Type	Waterway Crossings	Potential Impact	Recommended Mitigation
Low Sinuosity Fine Grained	W14	Exacerbation of existing channel instabilities.	◗ Provide rock protection to disturbed banks ensuring the protection merges to existing surfaces and the risk of outflanking by existing upstream or downstream erosion is minimised.

15.5.3 Operational management measures

Additional requirements may need to be addressed during the operational phase of the Proposal in order to minimise the impact on the surface water environment: These would include:

- Monitoring of the downstream bed stability of the waterway where erosion has been identified as a key concern to ensure that mitigation is appropriate to protect the asset and prevent waterway degradation;
- The restriction of vehicles access during inspections in sensitive areas (*e.g.*, waterways) as much as possible; and
- All inspections portals, valves, *etc*. are not installed in the vicinity of the waterway crossings as they may be inundated during periods of high flow.