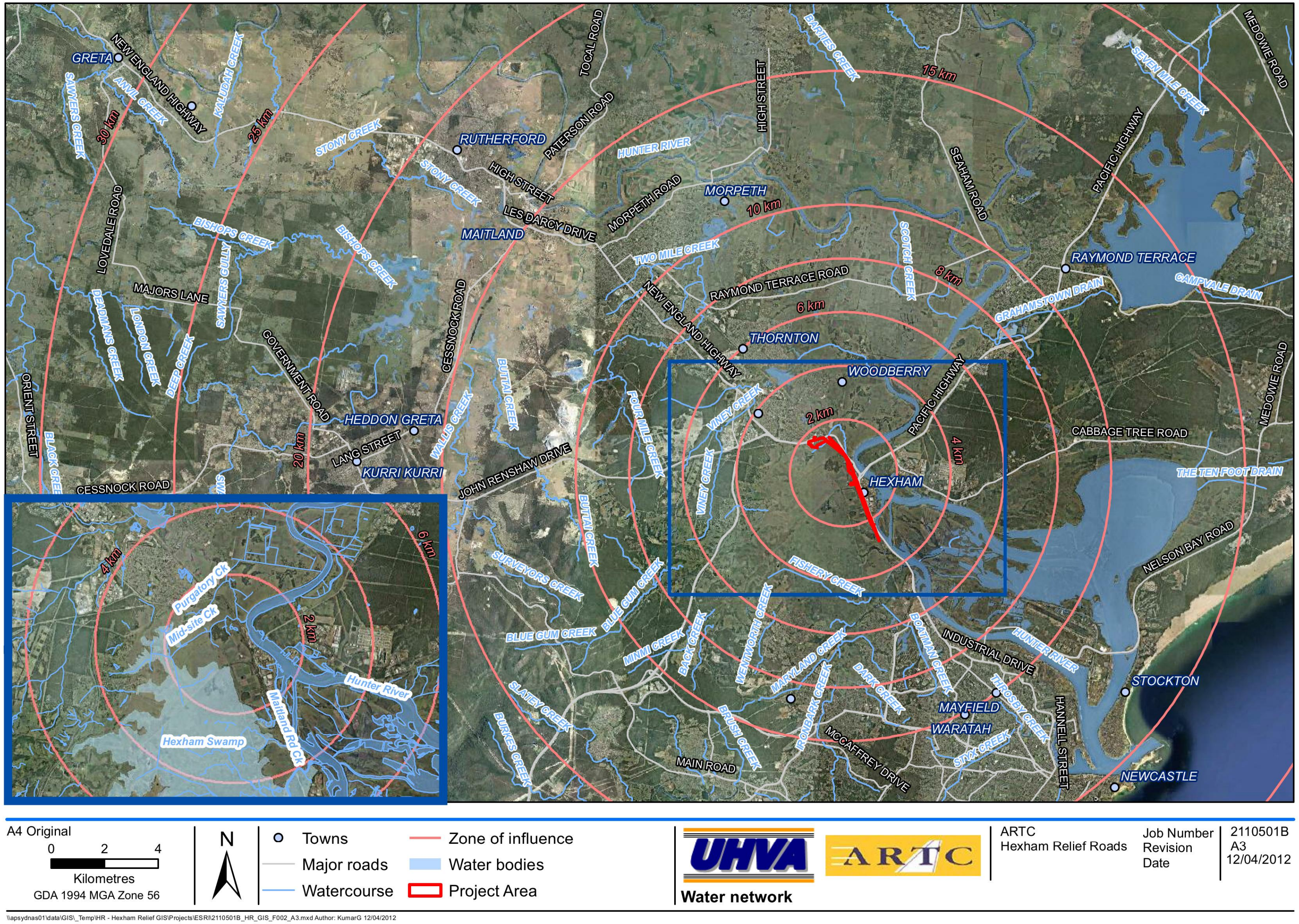
2.2 Potential receptors

For the purposes of this report, receptors are defined as drainage channels that originate within the proposed Project Boundary or are within 2km downstream, measured as a distance from the centroid of the proposed Project Area (**Figure 2-5**). The only fluvial waterbody outside this boundary and downstream from the works is the Hunter Estuary and it was felt unlikely that impacts would be observed past this point. This assessment therefore presents a worst case in terms of watercourses close to the site that have the potential to be impacted by the proposed Project.

This limits the in-depth fluvial assessment to Mid-Site Creek (site codes S1 and S2), Maitland Road Creek (site code S4), the Southern Arm of the Hunter River (site code S5), Purgatory Creek (site code S7), and the Plateau Drainage Channel (site code S8). A control site approximately 27.5km distance from the Project area was also selected to understand the upstream influence on geomorphology in the Hunter River (site code S6). Representative stretches of creek of approximately 200m were selected to conduct more detailed geomorphology assessments.

Figure 2-5 Potential receptors within the Study Area



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2.3 Channel geomorphology in the Study Area

The potential receptor watercourses for fluvial geomorphology have been defined (Section 2.2). In this section, two types of river classification have been completed for these channels within the Study Area. Following this, findings from a rapid geomorphological walkover survey are reported. The major processes affecting sediment sources and transport in these watercourses are then reviewed and a bank stability index is then produced.

2.3.1 River classification

The Strahler stream classification system is a method of classifying waterways according to the number of upstream tributaries. Numbering begins at the top of a catchment with the headwater tributary assigned the number 'one', i.e. it is a first order stream. Where two first order streams join, the waterway downstream of the junction is referred to as a second order stream. Where two second order streams meet the waterway downstream of the junction is referred to as a third order stream and so it continues (DPI, 2012). For the 2km radius around the project area it is clear that most of the streams are first and second order (Figure 2-6). The Hunter River was nominally allocated as a fifth order stream because it is a medium-sized river and it is common practice for rivers of this size to be between fourth and sixth order (Briney, 2012).

The seven stretches have also been categorised according to the RiverStyles^{TM} Classification Scheme (Thompson *et al.*, 2011).

- The Mid-Site Creek (site codes S1 and S2), Maitland Road Creek (site code S4), Purgatory Creek (site code S7) and the Plateau Drainage Channel (site code S8) are all classified as 'Channelised Fill'. They are in an alluvial valley setting, with one channel of low-moderate sinuosity and are laterally stable. They have a bed channel composed of sand and silt / clay and are a swampy low flow channel.
- The Southern Arm of the Hunter River (site code S5) is classified as a 'Meandering Fine-Grained' Channel. It is in an alluvial valley setting but unlike the sites described above has higher sinuosity, moderate lateral instability (controlled to a certain extent due to urban development) and a bed channel composed of silt and clay.
- The upstream Hunter River control stretch (site code S6) is classified as a 'Meandering Sand Bed' channel. As for the Hunter Estuary stretch (site code S5) it has high sinuosity but is active by virtue of its sandy bed composition which is more mobile than the clay bed further downstream.

These classifications are shown in Figure 2-7.

Figure 2-6 Strahler River Order Classification

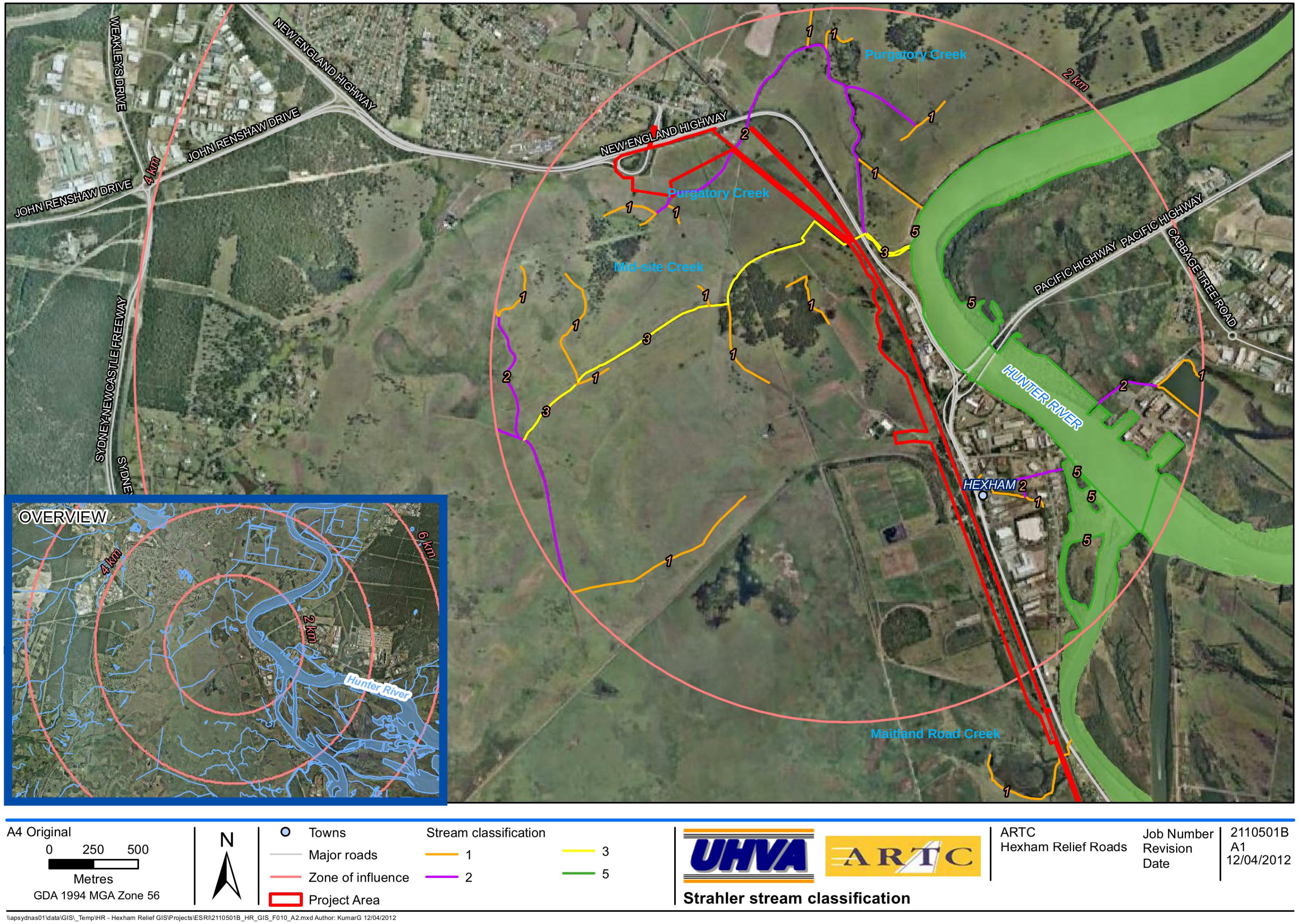
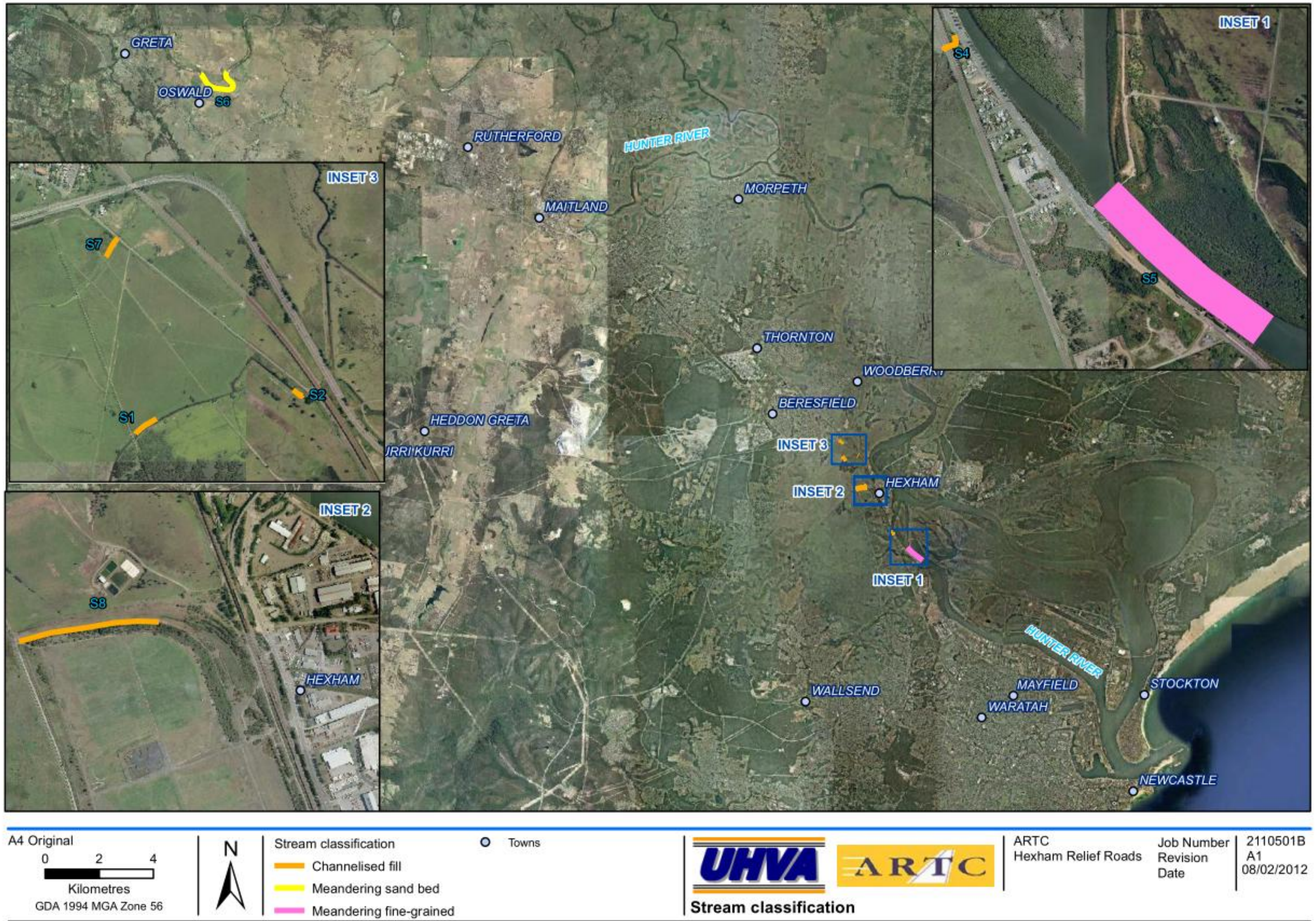


Figure 2-7 RiverStyles™ Classification Scheme



2.3.2 Rapid fluvial geomorphology walkover assessment

A rapid geomorphological walkover assessment was conducted on the Study Area following the RiverStyles™ procedures outlined originally in Thompson *et al.* (2001). The template summarises hydraulic unit attribute data for the Study Area stretch and ensures reporting in a consistent fashion. The completed templates can be seen in Appendix A.

2.3.3 Sediment sources and transport mechanisms

The major sources of sediment to the Study Area are naturally derived erosion occurring along the foot slopes of the surrounding residual soil hillside areas, urban runoff from settlements and the transport network and internal storages from the Swamp and drainage channel banks (as described in Section 2.1.2 and 2.1.5).

An estimated 8,500 tonnes of sediment is delivered into the Swamp annually from the catchment, although the load is variable, depending on climatic variation and development activities (ICTCMC, 1996). The output from all creeks draining the Swamp to the Hunter River is estimated in the same study to be only 400 tonnes annually, indicating that substantial amounts of sediment are trapped in the Swamp. Modelling conducted as part of this proposed Project estimates much smaller exports of sediment from the two sub-catchments draining the proposed Project Area (UHVA, 2012[e]). In baseline conditions, the northern catchment (including Purgatory Creek and the Mid-Site Creek) were estimated to export 34,100 kg/year and the Southern Catchment (including Maitland Road Creek) was estimated to export 10,200 kg/year. This is a factor of 100 times lower than the total export of sediment from the Hexham Swamp area into the Hunter River. More information on this modelling is provided in the Water Quality Technical Note (UHVA, 2012[e]).

Transport of this reduced sediment load will mostly be as bedload saltation (stochastic bumping along the channel bed) / pulses of material due to the low energy flow regime in the creeks. However, re-suspension of fine sediments in the creek channels and bank erosion caused by high magnitude / low frequency storm events will probably account for a significant portion of the reported load. Despite this storage, it is also reported that sedimentation has impacted mangrove habitat in the Hunter Estuary by increasing the amount of substrate required, leading to an imbalanced spread of mangrove that threatens other ecologically sensitive habitats and systems (HCRCMA, 2007). Indeed, the Hunter River is known to carry large suspended and bed sediment loads. This probably does not alter the sediment load or storage figures mentioned above on a long term basis, because the tidal cycle in the Hunter probably produces a ‘sloshing’ of sediment, up into tidal tributary creeks and then back out, with no net gain or loss over an annual cycle.

2.3.4 Bank stability

The stability of channel banks in the Study Area was assessed using a combination of literature review and site observations. The site observations are summarised in a semi-quantitative ranking developed by Rosgen (1996) and Henshaw and Booth (2000).

There are 1.8 million hectares of highly erodible soils in the Hunter-Central region and of this area, 93,700 hectares have moderate or greater active erosion (HCRCMA, 2007). The susceptibility to erosion of the surface soils in the Study Area, however, is considered to be low on the basis of vegetative cover, very low surface gradients (Section 2.1.1) and soil properties (Section 2.1.2). The Swamp is periodically inundated with significant runoff occurring to the drainage path and under these general sheet flow conditions the erosion hazard appears to be slight (NPWS, 1998). However, under concentrated flows the erosion risk is probably significantly higher. ICTCMC (1996) reviewed the extent of creek bank erosion around the Swamp and found that it was associated with areas where native vegetation had been cleared to grass pasture, cattle had access to creeks, fill has been placed along the banks to form bunds and finally where concentration of runoff has occurred through low fill embankments associated with tracks and easements or drains. Indeed, a sub-set of Hunter-Central River region streams were assessed for stability in a previous study and 44% were classed as being 'unstable' (HCRCMA, 2007).

Bank stability was assessed on site at 10 characteristic sub-points (every 10m) within each of the following watercourse reaches:

- Mid-site drainage ditch west
- Mid-site drainage ditch east
- Drainage ditch next to Maitland Road
- Hunter Estuary at Aash Island Bridge
- Purgatory Creek
- Spoil Plateau drain

Table 2-1 shows the integrated bank erosion hazard scores for these reaches within the Study Area. In general, the erosion scores for individual sub-points were either 'very low' or 'low' (Figure 2-8) but isolated sub-points had high bank instability risk which pushed the reach-length risks to 'moderate' or 'high'.

Figure 2-8 Stable vegetated channel with 'very low' bank erosion risk (Purgatory Creek)

However, some localised sheet and rill erosion was observed along the margins of the Swamp where urbanisation has resulted in increased and concentrated runoff, leading to elevated risk at sub-points within the watercourse reach. For example, the drainage ditch banks next to Maitland Road exhibited rotational slump failures (i.e. material moving downward and outward along a curved slip surface) on the downstream side of the culvert which diverts water under the railway line (Figure 2-9).

Figure 2-9 Maitland Road Creek bank erosion and retaining wall

This type of failure is common in cohesive material banks such as the ones in the Study Area with slopes less than sixty degrees (Watson and Basher, 2006). They are commonly caused by scour at the base of the bank and in this case are a result of re-directed flow through the culvert at an artificial angle to the bank, lack of new sediment material from the upstream reach due to deposition above the culvert and tidal inundation which has resulted in minor scour associated with increased ebb velocities. In the Maitland Road stretch an attempt has been made to reduce this bank erosion by deployment of a basic retaining wall structure in the bank. However, these walls were also being undermined at their upstream face and under the intersection between the wall and the channel bed.

The spatial variation in these bank erosion risks are shown in Figure 2-10.

Table 2-1 Bank erosion hazard index

Site	Bank height : bankfull height ratio	Sub-score	Bank angle (degrees)	Sub-score	Surface protection (%)	Sub-score	Bank material	Sub-score	Bank erosion observations	Sub-score	Total score	Risk rating category
Mid-Site drainage ditch west	1.2	4	30	2	85	1	Silt / clay	0	Minor erosion and / or bank undercutting	4	11	**Moderate**
Mid-Site drainage ditch east	1.5	4	65	4	80	1	Silt / clay	0	Minor erosion and / or bank undercutting	4	13	**Moderate**
Drainage ditch next to Maitland Road	1.5	4	90	6	30	4	Silt / clay	0	Extensive erosion & undercutting	6	20	**High**
Hunter Estuary at Aash Island Bridge	1	1	20	1	60	2	Silt / clay	0	No raw or undercut banks	1	5	**Very low**
Purgatory Creek	1	1	15	1	100	1	Silt / clay	0	No raw or undercut banks	1	4	**Very low**
Spoil plateau drain	1	1	50	2	100	1	Silt / clay	0	No raw or undercut banks	1	5	**Very low**

Bank erosion hazard scoring system

Factor	Very Low (1)	Low (2)	Moderate (4)	High (6)	Very High (10)
Bank height : bankfull height ratio	1.0 – 1.1	1.11 – 1.19	1.2 – 1.5	1.6 – 2.0	<2.0
Bank angle	0 – 20	21 - 60	61 - 80	81 - 90	<90
Surface protection	100 - 80	79 - 55	54 – 30	29 - 15	<15
Bank material*	Bedrock	Boulders	Gravel	No value	Sand
Bank erosion observations	No raw or undercut banks	Minor erosion and or bank undercutting	No value	Extensive erosion and bank undercutting	Severe erosion of banks on outside bends and both banks on straight stretches / banks held by placed structures (e.g. rip rap, retaining walls)

*Silt & clay = No adjustment

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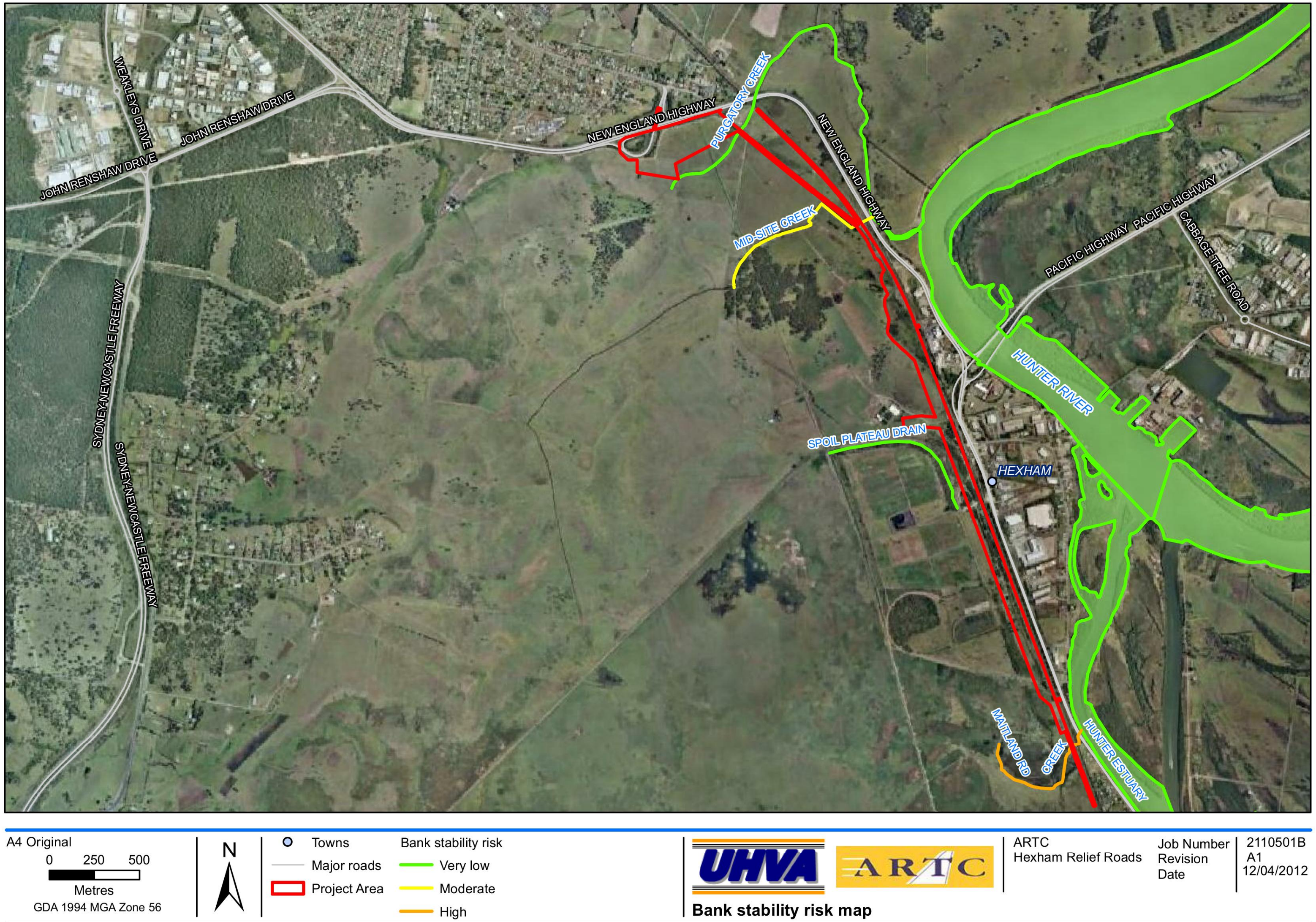
Figure 2-10 Bank stability risk map for channels in the Study Area



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3. Potential impacts of development

This report considers the potential impacts of the proposed Project to fluvial geomorphology. The drainage strategy for the proposed Project is reported in UHVA (2012[c]).

3.1 Project summary

The construction phase involves site establishment, construction of the relief roads, testing and commissioning and demobilisation sub-phases. Activities during site establishment will include installing environmental controls, clearing vegetation and construction of access roads.

A pervious formation with open channels is the preferred drainage solution (UHVA, 2012[c]). This would maintain the preconstruction drainage behaviour and would involve deployment of 150-200mm graded igneous rock providing a large volume of intercedes. Drainage from the formation will be divided into three regions, southern, central and northern. The northern region would flow into SEPP14 Wetland that subsequently drains into the Mid-Site creek and the southern region into the existing drainage channel system leading to Maitland Road Creek, while the central portion would be divided by the ridgeline with water to the west flowing north and water to the east flowing south.

3.2 Construction

This scheme will have no significant impact during the construction phase on Purgatory Creek or Hexham Swamps. Flow from the Project Area will be directed at its most northerly location into the swampland draining to Mid-Site creek (UHVA, 2012[c]). Although there may be a minor impact from removal of backing-up-flows due to more efficient west-east drainage under the proposed Relief Roads, this is not expected to result in any significant draw-down of water in the Hexham Swamps. In addition to this, there is no surface water connectivity between the HRR Project and Hexham Swamps during baseflow and intermediate flow conditions. During high flow conditions, there might be limited connectivity from the northern end of the site down into the Hexham Swamps but given that no increase in flow volumes are predicted as part of this Project and channels in the area are non-confined, there will be no significant alternation to runoff, erosion and hence geomorphology in the Swamps.

There are however, potential impacts to the other creeks in the area.

Maintenance of the existing drainage structure will generally lead to less geomorphological disruption. However, the conveyance capacity of the existing channels will need to be assessed with care, not only for design rainfall events but also for tidal surges. If capacity is exceeded, this could lead to bank overtopping and in-turn to deposition of fine sediment on the Project Area and damage to the channel structure. At present, it is proposed that drainage channels be sized for a 20 year rainfall event (UHVA, 2012[c]). The flooding extent plan for the 5% AEP (1 in 20 year ARI) indicates that the Project Area is 90% free of catchment wide flooding. Anything above this would inundate the Project Area rendering any local drainage ineffective.

The dimensions / performance of existing culverts and newly installed culverts / bridge buttresses on the Project Area and current bank erosion in particular will need to be evaluated. There is scope for significant bank and instream erosion impacts due to work close to the waterbodies. Re-suspension of material during the disturbance, direct physical damage to banks and change in flow character following re-culverting may occur. Wetting and drying related to dewatering / draining of ground adjacent to river banks could cause damage to the structural integrity of the banks. In addition, a change in sediment particle size being transported down these new channels could lead to further siltation.

There is potential for disruption to the soil surface across the entire Project Area due to increased traffic on Project Area, movement of construction machinery / materials, excavation and demolition activities, temporary stockpiling of material and wheel washing. The Study Area soils are highly susceptible to sheet and rill erosion particularly where the vegetation cover / topsoil has been removed or disturbed. Sediment derived from this erosion eventually impacts both the Swamp and the Hunter River (NPWS, 1998). This could result in additional sediment load in the Swamp and Hunter River and siltation of drainage channels. Modelling conducted as part of the Water Quality Technical Note (UHVA, 2012[e]) predict sediment loads of 113,000 and 18,200 kg/yr, respectively, for the Mid-Site Creek and Maitland Road Creek with no mitigation measures applied. This is an increase compared to estimated baseline loads reported in Section 2.3.3 of 331 and 178%, respectively. However, this increase in load is small compared to the total sediment export to the Hunter from all creeks in the Swamp of 400,000 kg/yr (Section 2.3.3). The construction phase could also result in a change to sediment type present in the system, with larger amounts of coal residue from the excavated stockpile. Poor management of excavated soil would exacerbate these issues.

Where channel diversions (southern and central regions), excavation of impermeable material and replacement with engineered fill (northern region) and creek crossings are required, liberation of large amounts of fine material following disruption to the soil surface might occur. There is a risk that the new channels will be less stable than the previous ones, both laterally and horizontally, leading to increased sediment loads. Sizing of these new channels and crossings / culverts should maintain a ‘baseline’ flow regime in terms of channel velocities and flushing rates / residence times.

There will be no geomorphology impact in the Northern region SEPP 14 Wetland from the new drainage channel as the flow gradient is from the channel to the wetland and not vice versa.

3.3 Operation

This scheme will have no significant impact during the operation phase on Purgatory Creek or Hexham Swamps. Flow from the Project Area will be directed at its most northerly location at point 104 into the Mid-Site creek. Although there may be a minor impact from removal of backing-up-flows due to more efficient west-east drainage, this is not expected to result in any significant draw-down of water in the Hexham Swamps.

There are potential impacts to creeks in the Central and Southern regions.

Increased runoff due to the increase in impermeable ground and focussed drainage system will increase the volume and velocity (flashiness) of runoff from the Project Area. This could lead to increased bank erosion, increased scour around culverts, re-suspension of channel sediments resulting in lateral movement of channel and ultimately higher export of sediment into the Hunter River (as detailed in UHVA, 2012[e]). The increase in sediment load without mitigation is expected to be lower than during construction, but still significant compared to baseline conditions.

During operation there will also be an additional increase of sediment input from the development arising from runoff from train tracks and associated infrastructure. Modelling conducted as part of the Water Quality Technical Note (UHVA, 2012[e]) predict sediment loads of 62,900 and 18,000 kg/yr, respectively, for the Mid-Site Creek and Maitland Road Creek with no mitigation measures applied. This is lower than the loads for the construction phase (Section 3.2) but an increase compared to estimated baseline loads reported in Section 2.3.3 of 184 and 176%, respectively. However, there are opportunities for reductions in the sediment load as a result of the new drainage infrastructure, because of deposition / filtering as part of pervious formation drainage scheme proposed in UHVA, 2012[C].

4. Mitigation Measures

A number of measures could be implemented to mitigate potential impacts from construction and operation of the Project Area. A preliminary outline of such measures is provided below, based on guidelines for controlled activities (Office of Water, 2011), Hunter-Central Rivers Catchment Management Authority Catchment Action Plan guidelines and general good site practice detailed in the Construction Industry Research and Information Association (CIRIA, 2006). These will be investigated further in the CEMP for the Project Area (UVHA, 2012[b]).

4.1 Construction

Potential mitigation measures during **construction** may include, but are not limited to, the following:

- Where practicable, stockpiled material would be placed away from water on stable, level ground above the 10% AEP flood level. Appropriate controls would be used to reduce runoff from the stockpiles. Storage of any loose material in particular, and especially during wet weather, would be carefully controlled at a distance of more than 40m from watercourses.
- Erosion would be minimised as per Blue Book Guidelines.
- Site access would be stabilised. Rumble grates or other vehicle wash facility to remove soil from vehicles leaving the Project Area would be installed.
- Sediment controls would be used in accordance with the Blue Book Guidelines to minimise the risk of sedimentation of natural watercourses.
- Watercourses impacted by the proposed project would be stabilised in accordance with the Blue Book Guidelines.
- Once works have been completed where required banks impacted by the proposed Project would be stabilised. The most appropriate technique for bank stabilisation is site-specific depending on the scale/type of erosion and will be detailed in the CEMP.
- Diversion channels and new crossings / culverts would be designed according to standard codes of practice. Excavation areas for the diversion channels would have suitable controls which may include water cut-off systems if appropriate.

4.2 Operation

Many of the above potential mitigation measures will also apply during the operation phase. Additional potential mitigation measures during **operation** may include, but are not limited to the following:

- The existing and newly diverted channels that will be utilised post-construction will be sized appropriately and designed to ARTC standards.
- During the operational phase of the project, the new drainage channels adjacent to the relief roads will be maintained by ARTC or QR National, in accordance with ARTC drainage maintenance programs.

5. Residual Impacts

Impacts following application of the mitigation measures suggested in Section 4 are reviewed in this section. In addition, cumulative impacts from other developments are assessed.

5.1 Construction

A short-term increase in sediment load into the Hunter River is anticipated during channel diversion works and improvements to the infrastructure of existing channels. All other identified potential impacts should be insignificant, based on adoption of the mitigation measures proposed.

5.2 Operation

No significant impacts are envisaged in terms of fluvial geomorphology for this proposed Project during the operation phase, if mitigation measures detailed in Section 4 are implemented.

5.3 Cumulative impacts

Cumulative impacts arise due to the influence or impacts of other construction and development activities in the local area. Any such activities have the potential to compound or exacerbate the specific impacts of the proposed Project, thereby forming a cumulative impact. The following developments were considered in case they produce cumulative impact to the Study Area:

- The upgrade of the Hunter Water DN900 CTGM trunk main between Tarro and Shortland (GHD, 2008). The new main has been laid in the existing Hunter Water easements south of Tarro and the Pacific Highway and the majority of the construction work was completed by February 2012 (*pers comm.* Hunter Water Project Team). This pipeline crosses all the watercourses reported in this study which drain Hexham Swamp from West to East.
- Hexham Train Support Facility and Industrial Subdivision (WorleyParsons, 2011a and b). This will be located in the eastern and central portions of the Project Area and occupy approximately 29 hectares of land.

The trunk main upgrade phase has been completed for the Tarro to Shortland section, other than some fencing at the Tarro interchange (*pers comm.* Hunter Water Project Team). Mitigation strategies suggested will mean cumulative impact on the Project Area during operation will be insignificant (GHD, 2008).

There could be a minor net increase in runoff associated with the train support facility if there is an increase in the impervious area but provided erosion issues are addressed by each project the impact of this increase in combination with the Proposed Scheme will be minimal. This is because the Study Area is relatively waterlogged and is situated in a large, open area where depth changes are negligible. The stormwater management recommended for the Project Area (WorleyParsons, 2011[b]) will offset any potential impacts by the restoration of favourable conditions in other areas of the Swamp.

6. Additional monitoring

A construction environmental management plan (CEMP) will be established for the construction phase of the project. The CEMP will provide the framework for the management of all potential environmental impacts resulting from the construction activity, including a soil and erosion management plan. The CEMP will outline the environmental mitigation measures to be implemented during the construction phase and will document mechanisms for demonstrating compliance with the Minister for Planning's Conditions of Approval, other relevant Project approvals and the Statement of Commitments. The CEMP will also set out the auditing and inspection frameworks for the Project Area which will cover water and soil management issues related to fluvial geomorphology. In particular, there will be a need to monitor bank integrity on the Project Area and provide additional protection where necessary.

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Appendix A

Fluvial Geomorphology Rapid Walkover Assessments

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	UVHA HEXHAM RELIEF ROADS	Date	02/09/2011
Surveyor	DE Reach code: S1	Time	11:30 hrs

Drainage channel	Creek	River	Estuary	Pond	Wetland	Lake
☒	☐	☐	☐	☐	☐	☐

Weather conditions	Sunny with periods of overcast cloud. Breezy with rain the previous night.	U-S Grid ref	-32.818215, 151.671356	D-S grid ref	-32.817305, 151.673276
Upstream elevation (m)	4	Downstream elevation (m)	4	Slope (m)	0

Watercourse attributes

Dimensions Width (m)	5.0	Max. depth (m)	1.2	Velocity (ms^{-1})	0.14
Shape description	Trapezoidal	Roughness Height (m)	n/a	Bank erosion	Mostly stable but some evidence of undercutting (root vegetation exposed)
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	5% emergent 5% submerged 80% free algae	Bank vegetation (% cover)	85% tree plus fallow land (daises and grass / shrub)	Bench vegetation (% cover)	n/a
Organic matter (%)	Logs = 0 Twigs / Leaves = 2 Detritus = 5				

Flow type

Smooth surface flow	Broken standing waves	Unbroken standing waves	Chute	Rippled	Scarcely perceptible flow	Upwelling	Free fall	Standing water
☒ [H1]	☐ [H2]	☐ [H3]	☐ [H4]	☐ [H5]	☐ [H6]	☐ [H7]	☐ [H8]	☐ [H9]

Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	*Form*	Single	Forked	Braided	Open
			☒	☐	☐	☐

Sand bars	Gravel bars	Rock outcrops	Riparian strip	Floodplain connectivity
☐	☐	☐	☐	Partial connectivity through bank cut but high banks limit overtopping in other areas

Floodplain land use	Improved pasture / grazing and waterlogged land	Bank structure (concave, convex, straight, undercut) & slope	Straight 20° right Straight 40° left

Bed character

% composition	Boulder	Cobble	Gravel	Sand	Fine sand	Silt / clay
	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 10 D-S = 10	U-S = 90 D-S = 90

Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)	Supply	Deposition	Erosion	Conveying
Low packing	☐	☒	☐	☐

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, 11, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	UVHA HEXHAM RELIEF ROADS			Date	02/09/2011
Surveyor	DE	Reach code: S2		Time	12:20 hrs

Drainage channel	Creek	River	Estuary	Pond	Wetland	Lake
☒	☐	☐	☐	☐	☐	☐

Weather conditions	Sunny with periods of overcast cloud. Breezy with rain the previous night.	U-S Grid ref	-32.815880, 151.675476	D-S grid ref	-32.817151, 151.677439
Upstream elevation (m)	3	Downstream elevation (m)	3	Slope (m)	0

Watercourse attributes

Dimensions Width (m)	7.0	Max. depth (m)	1.2	Velocity (ms^{-1})	0.05
Shape description	Trapezoidal	Roughness Height (m)	n/a	Bank erosion	Mostly stable but some evidence of undercutting (root vegetation exposed)
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	30% emergent 0% submerged 5% free algae	Bank vegetation (% cover)	80% grass / shrub	Bench vegetation (% cover)	n/a
Organic matter (%)	Logs = 0 Twigs / Leaves = 1 Detritus = 10				

Flow type

Smooth surface flow	Broken standing waves	Unbroken standing waves	Chute	Rippled	Scarcely perceptible flow	Upwelling	Free fall	Standing water
☐ [H1]	☐ [H2]	☐ [H3]	☐ [H4]	☐ [H5]	☒ [H6]	☐ [H7]	☐ [H8]	☐ [H9]

Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	*Form*	Single ☒	Forked ☐	Braided ☐	Open ☐

Sand bars	Gravel bars	Rock outcrops	Riparian strip	Floodplain connectivity	High banks limit overtopping
☐	☐	☐	☐		

Floodplain land use	Improved pasture / grazing and waterlogged land. Dirt track leading from Woodlands Close crosses just downstream from the stretch.	Bank structure (concave, convex, straight, undercut) & slope	Straight 85° right Straight 45° left

Bed character

% composition	Boulder	Cobble	Gravel	Sand	Fine sand	Silt / clay
	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 100 D-S = 100

Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)	Low packing	Supply ☐	Deposition ☒	Erosion ☐	Conveying ☐

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

<table>
<tr><td>Project</td><td colspan="4">UVHA HEXHAM RELIEF ROADS</td><td>Date</td><td>02/09/2011</td></tr>
<tr><td>Surveyor</td><td>DE</td><td colspan="3">Reach code: S4</td><td>Time</td><td>14:50 hrs</td></tr>
<tr><td>Drainage channel ☐</td><td>Creek ☒</td><td>River ☐</td><td>Estuary ☐</td><td>Pond ☐</td><td>Wetland ☐</td><td>Lake ☐</td></tr>
<tr><td>Weather conditions</td><td colspan="2">Sunny with periods of overcast cloud. Breezy with rain the previous night.</td><td>U-S Grid ref</td><td>-32.844382, 151.689536</td><td>D-S grid ref</td><td>-32.842958, 151.690453</td></tr>
<tr><td>Upstream elevation (m)</td><td colspan="2">1</td><td>Downstream elevation (m)</td><td>1</td><td colspan="2">Slope (m)
0</td></tr>
<tr><td colspan="7">Watercourse attributes</td></tr>
<tr><td>Dimensions</td><td>Width (m)</td><td>4.0</td><td>Max. depth (m)</td><td>0.9</td><td>Velocity (ms^{-1})</td><td>0.4</td></tr>
<tr><td>Shape description</td><td colspan="2">Trapezoidal</td><td>Roughness Height (m)</td><td>n/a</td><td>Bank erosion</td><td>Right bank near property fence line is undercut</td></tr>
<tr><td>Instream vegetation
(% cover [emergent, floating, submerged, algae, moss])</td><td>30% emergent
0% submerged
5% free algae</td><td>Bank vegetation
(% cover)</td><td>80% grassed
20% mangrove mud flats</td><td>Bench vegetation
(% cover)</td><td>80% grassed / shrubs
60% mangrove trees</td><td>Organic matter (%)
Logs = 0 Twigs / Leaves = 5 Detritus = 20</td></tr>
</table>

<table>
<tr><td colspan="9">Flow type</td></tr>
<tr><td>Smooth surface flow
☒ [H1]</td><td>Broken standing waves
☐ [H2]</td><td>Unbroken standing waves
☐ [H3]</td><td>Chute
☒ [H4]</td><td>Rippled
☒ [H5]</td><td>Scarcely perceptible flow
☐ [H6]</td><td>Upwelling
☒ [H7]</td><td>Free fall
☐ [H8]</td><td>Standing water
☐ [H9]</td></tr>
</table>

<table>
<tr><td colspan="7">Channel Planform</td></tr>
<tr><td>Sinuosity
(straight, low, intermediate, high)</td><td>Intermediate</td><td>Form</td><td>Single ☒</td><td>Forked ☐</td><td>Braided ☐</td><td>Open ☐</td></tr>
<tr><td>Sand bars ☐</td><td>Gravel bars ☐</td><td colspan="2">Rock outcrops ☐</td><td>Riparian strip ☒</td><td>Floodplain connectivity</td><td>Disconnected from surrounding floodplain</td></tr>
<tr><td>Floodplain land use</td><td colspan="4">Wetland in upstream stretch
Road and rail corridors in downstream stretch</td><td>Bank structure
(concave, convex, straight, undercut) & slope</td><td>Convex 10° left
Straight 90° right</td></tr>
</table>

<table>
<tr><td colspan="8">Bed character</td></tr>
<tr><td>% composition</td><td>Boulder
U-S = 0 D-S = 0</td><td>Cobble
U-S = 0 D-S = 0</td><td>Gravel
U-S = 0 D-S = 0</td><td>Sand
U-S = 0 D-S = 0</td><td colspan="2">Fine sand
U-S = 0 D-S = 0</td><td>Silt / clay
U-S = 100 D-S = 100</td></tr>
<tr><td>Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)</td><td colspan="3">Low packing</td><td>Supply ☐</td><td>Deposition ☒</td><td>Erosion ☒</td><td>Conveying ☒</td></tr>
</table>

Created 04/08/2011 Dan Evans (after Thompson et al, 2011, *Aq Conserve*, 11, 373 – 389)

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	UVHA HEXHAM RELIEF ROADS				Date	02/09/2011
Surveyor	DE	Reach code: S5			Time	13:40 hrs
Drainage channel ☐	Creek ☐	River ☐	Estuary ☒	Pond ☐	Wetland ☐	Lake ☐
Weather conditions	Sunny with periods of overcast cloud. Breezy with rain the previous night.		U-S Grid ref	-32.817656, 151.682063	D-S grid ref	-32.822805, 151.685432
Upstream elevation (m)	0		Downstream elevation (m)	0		Slope (m) 0

Watercourse attributes						
Dimensions	Width (m)	200	Max. depth (m)	4.2	Velocity (ms^{-1})	0.25
Shape description	U-shaped		Roughness Height (m)	n/a	Bank erosion	Mostly stable with mangrove swamp to sides
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	None	Bank vegetation (% cover)	60% mangrove	Bench vegetation (% cover)	n/a	Organic matter (%) Logs = 2 Twigs / Leaves = 2 Detritus = 10

Flow type								
Smooth surface flow ☒ [H1]	Broken standing waves ☐ [H2]	Unbroken standing waves ☐ [H3]	Chute ☐ [H4]	Rippled ☐ [H5]	Scarcely perceptible flow ☐ [H6]	Upwelling ☐ [H7]	Free fall ☐ [H8]	Standing water ☐ [H9]

Channel Planform						
Sinuosity (straight, low, intermediate, high)	High	*Form*	Single ☐	Forked ☐	Braided ☒	Open ☐
Sand bars ☐	Gravel bars ☐	Rock outcrops ☐		Riparian strip ☐	Floodplain connectivity	No connectivity
Floodplain land use	Maitland road, urban and wooded				Bank structure (concave, convex, straight, undercut) & slope	Straight 10° left Straight 30° right

Bed character						
% composition	Boulder U-S = 0 D-S = 0	Cobble U-S = 0 D-S = 0	Gravel U-S = 0 D-S = 0	Sand U-S = 0 D-S = 0	Fine sand U-S = 25 D-S = 30	Silt / clay U-S = 75 D-S = 65
Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)	Low packing		Supply ☐	Deposition ☒	Erosion ☐	Conveying ☒

FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	UVHA HEXHAM RELIEF ROADS		Date	02/09/2011
Surveyor	DE	Reach code: S7	Time	12:55 hrs

Drainage channel	Creek	River	Estuary	Pond	Wetland	Lake
☒	☐	☐	☐	☐	☐	☐

Weather conditions	Sunny with periods of overcast cloud. Breezy with rain the previous night.	U-S Grid ref	-32.813464, 151.669843	D-S grid ref	-32.811525, 151.671281
Upstream elevation (m)	2	Downstream elevation (m)	2	Slope (m)	0

Watercourse attributes

Dimensions	Width (m)	3	Max. depth (m)	0.1	Velocity (ms^{-1})	0.0
Shape description		U-shaped	Roughness Height (m)	0.2	Bank erosion	No observed erosion

Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	90% emergents	Bank vegetation (% cover)	100% reeds / grass	Bench vegetation (% cover)	100% grass	Organic matter (%) Logs = 0 Twigs / Leaves = 10 Detritus = 10

Flow type

Smooth surface flow	Broken standing waves	Unbroken standing waves	Chute	Rippled	Scarcely perceptible flow	Upwelling	Free fall	Standing water
☐ [H1]	☐ [H2]	☐ [H3]	☐ [H4]	☐ [H5]	☒ [H6]	☐ [H7]	☐ [H8]	☐ [H9]

Channel Planform

Sinuosity (straight, low, intermediate, high)	Straight	*Form*	Single ☒	Forked ☐	Braided ☒	Open ☐

Sand bars	Gravel bars	Rock outcrops	Riparian strip	Floodplain connectivity	Low banks and channel geometry mean banks easily overtopped in high flows
☐	☐	☐	☒		

Floodplain land use	Grazing + waterlogged land	Bank structure (concave, convex, straight, undercut) & slope	Straight 15° left Straight 15° right

Bed character

% composition	Boulder	Cobble	Gravel	Sand	Fine sand	Silt / clay
	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 0 D-S = 0	U-S = 100 D-S = 100

Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)	Low packing	Supply ☐	Deposition ☐	Erosion ☐	Conveying ☒

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FLUVIAL GEOMORPHOLOGY SITE DESCRIPTION TEMPLATE

Project	UVHA HEXHAM RELIEF ROADS					Date		02/09/2011
Surveyor	DE	Reach code: S8				Time		12:00 hrs
Drainage channel ☒	Creek ☐	River ☐	Estuary ☐	Pond ☐		Wetland ☐		Lake ☐
Weather conditions	Sunny with periods of overcast cloud. Breezy with rain the previous night.			U-S Grid ref		-32.828223, 151.675916	D-S grid ref	-32.827759, 151.679665
Upstream elevation (m)	5			Downstream elevation (m)		4		Slope (m) 1

Watercourse attributes							
Dimensions	Width (m)	3	Max. depth (m)	0.5		Velocity (ms^{-1})	0.0
Shape description		Deep u-shaped	Roughness Height (m)	0.1		Bank erosion	No observed erosion
Instream vegetation (% cover [emergent, floating, submerged, algae, moss])	100% emergents	Bank vegetation (% cover)	100% reeds / grass	Bench vegetation (% cover)	40% trees / scrub	Organic matter (%) Logs = 0 Twigs / Leaves = 25 Detritus = 10	

Flow type								
Smooth surface flow ☐ [H1]	Broken standing waves ☐ [H2]	Unbroken standing waves ☐ [H3]	Chute ☐ [H4]	Rippled ☐ [H5]	Scarcely perceptible flow ☐ [H6]	Upwelling ☐ [H7]	Free fall ☐ [H8]	Standing water ☒ [H9]

Channel Planform						
Sinuosity (straight, low, intermediate, high)	Straight	*Form*	Single ☒	Forked ☐	Braided ☒	Open ☐
Sand bars ☐	Gravel bars ☐	Rock outcrops ☐		Riparian strip ☒	Floodplain connectivity	No overtopping
Floodplain land use	Waterlogged land and old spoil heap plateau				Bank structure (concave, convex, straight, undercut) & slope	Convex 50° left Straight 50° right

Bed character							
% composition	Boulder U-S = 0 D-S = 0	Cobble U-S = 0 D-S = 0	Gravel U-S = 0 D-S = 0	Sand U-S = 0 D-S = 0	Fine sand U-S = 0 D-S = 0		Silt / clay U-S = 100 D-S = 100
Bed stability (packed & armoured, packed not armoured, mod compaction, low compaction, no packing)	Low packing			Supply ☐	Deposition ☒	Erosion ☐	Conveying ☐