

# EDEN ESTATE GEOMORPHOLOGY ASSESSMENT

BRISBANE | PERTH | SINGAPORE | BRAZIL

RESPONSE TO RFIS



B25311

—  
17/11/2025

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# EXECUTIVE SUMMARY

Hydrobiology was engaged by QM Properties to undertake a geomorphology and bank stability assessment in support of the Eden Estate development at 176 Baileys Mountain Road, Upper Coomera. The work responds to the City of Gold Coast Request for Information (RfI), which required an appropriately qualified geomorphologist to confirm that proposed waterway setbacks of less than 30 metres are appropriate given local geomorphic and soil conditions. The assessment focused on Reaches 1 and 2 of Yaun Creek, the sections most influenced by the development footprint. These reaches occur within the mid-catchment zone of Yuan Creek where channels are incised into highly erodible Neranleigh–Fernvale metasediments, contrasting with the more stable basaltic headwaters. The combination of steep gradients, shallow soils and reduced riparian cover creates a landscape prone to scour, bank retreat and sediment delivery during high-intensity rainfall events.

Hydrobiology completed a desktop geomorphic review and hydraulic stability analysis, integrating post-development model outputs for velocity and bed-shear stress under multiple Annual Exceedance Probability (AEP) scenarios. Results indicated that sections of both reaches remained erosion hotspots, with modelled velocities exceeding stability thresholds during the 1% AEP event. Subsequent scour and Bank Stability and Toe Erosion Model (BSTEM) analyses demonstrated that targeted riprap armouring, with a median rock size ( $D_{50}$ ) of 0.256 m, would reduce maximum lateral retreat by at least 60%, achieving stable conditions (Factor of Safety > 1).

The proposed mitigation design includes toe protection, graded filter layers, and tie-ins to stable channel sections, among other recommendations. Collectively, these measures will stabilise high-risk reaches, reduce sediment loss, and maintain hydraulic balance while supporting ecological outcomes. The findings provide a defensible technical response to the City of Gold Coast's RfI, confirming that the proposed mitigation will ensure long-term channel stability and sustainable environmental performance for the Yaun Creek system.

For efficient location of information for the assessor, Table 1-1 below outlines each RfI submitted by the City of Gold Coast and reference register to sections where these RfI's are addressed. While this table provides a register of relevant sections, it is recommended that the assessor read the report in its entirety.

Table 1-1: RfI's Reference Table

| City of Gold Coast RfI                                                                                                                                                                                                                                                                                                                                                                    | Information Reference                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Map (conceptually) the sections of Reach 1 and Reach 2 that are required for armouring (rip rap).</b>                                                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>See Section 3.4 for hydraulic/geomorphic risk areas and Section 3.6 for conceptual map / conceptual designs</li> </ul>                                                                                                                                                                                                                                                                                                                                 |
| <b>Where Reach 1 or Reach 2 requires extensive sections of armouring, review and assess the plan of development design for a potential balance of ecological outcomes (setbacks) and armouring.</b>                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>See Section 2.4 for BSTEM assessment which suggests minimal retreat with 256mm riprap.</li> <li>No setbacks have been allowed which requires primarily riprap implementation. See Section 3.2 for proposed ecological outcomes.</li> </ul>                                                                                                                                                                                                             |
| <b>Where changes are made to the existing development – provide an amended (conceptual) map of required armouring for site waterways</b>                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>No changes to existing development by the developer were noted.</li> <li>See Section 3.6 for conceptual map and conceptual designs.</li> </ul>                                                                                                                                                                                                                                                                                                         |
| <b>Ensure that the geomorphic/bank stability assessment uses the pre- and post-development velocities obtained from the hydraulic impact assessment for different AEP events for the analysis. Additionally, the hydraulic impact assessment should incorporate suitable roughness coefficient (Manning's n) values for Reaches 1 to 4, in accordance with the geomorphic assessment.</b> | <ul style="list-style-type: none"> <li>See previous Hydrobiology assessment for smaller events (0.5EY and 2% AEP). This report and Section 2.3 covers the 1% AEP design event which naturally ensures stability during the 0.5EY and 2% AEP events.</li> <li>Section 2.4 uses 1% AEP post development BSS hydraulics for assessment.</li> <li>See Section 3.3 for review of Mannings n. Roughness values are to be implemented into the hydraulic model following this assessment.</li> </ul> |
| <b>Where significant areas of rock armouring are proposed, ecological outcomes are requested to be considered in the design. This can include mimicking natural features such as the use of different rock sizes and appropriately sized and placed logs to provide a greater range of micro habitats for instream organisms and riparian fauna.</b>                                      | <ul style="list-style-type: none"> <li>See Section 3.2 for proposed ecological outcomes.</li> <li>See Section 3.6 for conceptual designs.</li> </ul>                                                                                                                                                                                                                                                                                                                                          |

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# 1. INTRODUCTION

## 1.1 BACKGROUND

QM Properties is currently progressing design approvals for the Eden Estate development located at 176 Baileys Mountain Road, Upper Coomera (Figure 1-1). As part of the assessment process, the City of Gold Coast issued a Request for Information (Rfi 11694) requiring assistance from a suitably qualified specialist (e.g. riparian engineer or fluvial geomorphologist) to demonstrate that proposed waterway setbacks of less than 30 metres from the high bank are appropriate given the site's geomorphic and soil characteristics.

In response, Hydrobiology previously undertook a geomorphology and bank stability assessment for the site, which identified that mitigation measures would be required to ensure long-term stability of the streambanks due to potential increases in channel velocity associated with the proposed development footprint. The assessment recommended a range of measures including:

- Increasing setbacks and limiting streambank infilling to reduce encroachment and constriction.
- Installing rip rap ( $D_{50} \Rightarrow 0.256\text{m}$ ) along channel bed, toe and bank sections where setbacks cannot be achieved.
- Implementing a combination of both approaches where appropriate.

Following submission of these recommendations, further Rfis were received from the City of Gold Coast (21 August 2025) requesting additional detail to confirm appropriate site-specific bank stability measures, including mapping of armouring extents, consideration of ecological outcomes, integration of hydraulic modelling results, and design refinements to ensure balanced environmental and engineering outcomes for Yaun Creek.

The specific Rfi language received from City of Gold Coast was as follows:

*In accordance with Strategic Framework 3.7.3.1(2), 3.7.3.1(5), 3.7.4.1(1), 3.7.4.1(5) and Performance outcome PO5 of the Environmental significance overlay code, the applicant is requested to provide the following further detail to determine appropriate site bank stability measures:*

- Map (conceptually) the sections of Reach 1 and Reach 2 that are required for armouring (rip rap).
- Where Reach 1 or Reach 2 requires extensive sections of armouring, review and assess the plan of development design for a potential balance of ecological outcomes (setbacks) and armouring.
- Where changes are made to the existing development – provide an amended (conceptual) map of required armouring for site waterways
- Ensure that the geomorphic/bank stability assessment uses the pre- and post-development velocities obtained from the hydraulic impact assessment for different AEP events for the analysis. Additionally, the hydraulic impact assessment should incorporate suitable roughness coefficient (Manning's *n*) values for Reaches 1 to 4, in accordance with the geomorphic assessment.
- Where significant areas of rock armouring are proposed, ecological outcomes are requested to be considered in the design. This can include mimicking natural features such as the use of different rock sizes and appropriately sized and placed logs to provide a greater range of micro habitats for instream organisms and riparian fauna.

## 1.2 SCOPE

QM Properties requested Hydrobiology to undertake further works to address the outstanding geomorphology RfIs. These RfIs formed the scope of the current works and included:

- Review existing assessments and changes to development plans:
  - Review previous geomorphic and hydraulic assessments and integrate updated pre- and post-development velocity data for a range of AEP events.
- Conceptual mapping of required armouring:
  - Review the development layout and identify / map (conceptually) the sections of Reach 1 and Reach 2 which requiring rip rap armouring.
- Revised conceptual design:
  - Prepare an amended conceptual plan showing proposed armouring and setback adjustments, where applicable.
  - Incorporate recommendations for enhanced ecological outcomes, including the use of variable rock sizes and void-filled rock to encourage rapid vegetation recruitment.
- Reporting:
  - Document the analysis, mapping and recommendations in a concise technical memorandum or report suitable for submission to the City of Gold Coast.
  - Provide recommendations from a qualified geomorphologist confirming the appropriateness of the proposed mitigation measures.

The outputs will directly address the City's RfI requirements and provide QM Properties with a clear, defensible basis for approval of the development application.

## 1.3 STUDY AREA

Following confirmation of the area of interest (Figure 1-1) between Hydrobiology and the Client, this assessment focused on the geomorphic assessment of Reach 1 and Reach 2. The extent of areas requiring armouring are illustrated in **Error! Reference source not found.** Reach 3 and 4 were not included in this assessment as they were previously deemed to be in a stable condition (Hydrobiology, 2025).

- Reach 1 – Unnamed tributary of Yaun Creek traversing the middle section of the project area from the northern boundary down to the confluence with the Yaun Creek main channel. This reach is

characterised by an alternating sequence of marsh and a defined low-flow channel, dense riparian vegetation, accumulations of large wood, and partial bedrock confinement.

- Reach 2 – Section of Yaun Creek traversing the south-western boundary of the project area down to the confluence where an unnamed tributary of Yaun Creek joins from the south at Courtney Park. This reach comprised a bedrock-dominated upstream section, a cobble-boulder mid-reach, localised meander-bend erosion, and a well-defined flood channel active during high-flow events.

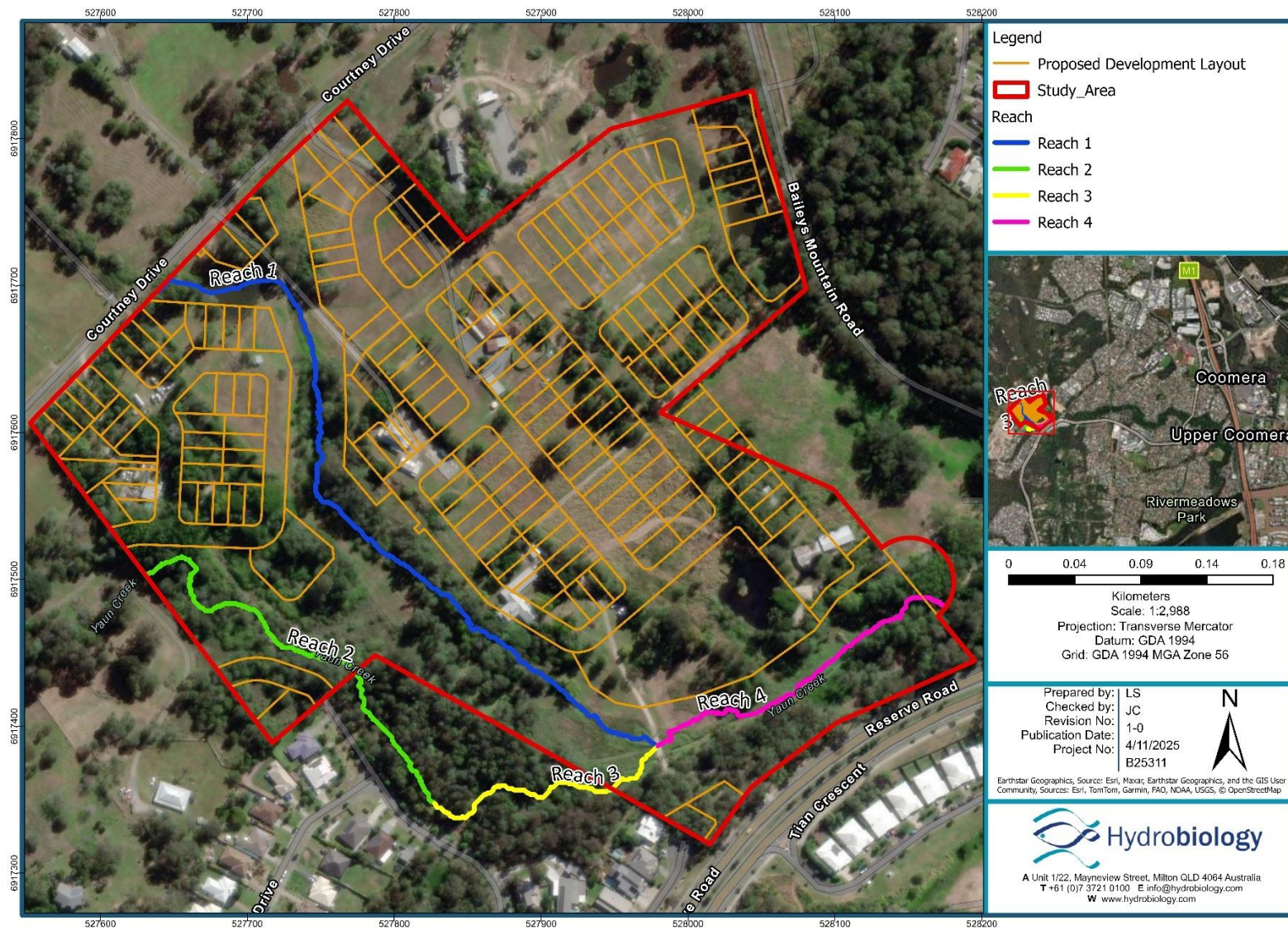


Figure 1-1 Site layout and waterways defined within and adjacent to the proposed development footprint.

# 2. APPROACH

## 2.1 BACKGROUND

A targeted desktop-based assessment was conducted to directly address each item raised in the Rfl. Given that setbacks were not feasible within the approved development footprint, this assessment focused on evaluating rock armouring requirements for integration into engineered solutions. The methodology was structured into two key phases: a comprehensive desktop assessment and a detailed hydraulic assessment of the area.

## 2.2 LITERATURE AND DOCUMENT REVIEW

A detailed review of all existing project information was undertaken to establish baseline conditions and fully integrate the Rfl requirements. This involved:

- Reviewing the original geomorphic assessment and all updated development layouts and channel designs.
- Collating the available hydraulic model outputs for pre- and post- development conditions, including velocities, Bed Shear Stress (BSS), stream power, and depth-velocity product ( $Z_0$ ) for the 1% Annual Exceedance Probability (AEP) scenarios. Smaller events were not re-assessed as mitigation scenarios were to be designed for the 1% AEP.
- Conducting a review of scientific and industry literature to identify appropriate mitigation measures for the specific context of Eden Estate and Yaun Creek (See Appendix A for selected reviewed literature and documents).
- Assessing the Manning's (n) values applied within the existing hydraulic model to verify their suitability for the reaches of concern, ensuring consistency with the described geomorphic conditions.
  - Hydrobiology will work with the hydraulic modeller to adopt appropriate manning's n values to be implemented into the hydraulic model following this investigation.

- Assembling all necessary spatial datasets, including LiDAR, aerial imagery, soils, and geology, to support the spatial analysis and mapping.

## 2.3 HYDRAULIC ASSESSMENTS

An assessment of updated hydraulics and channel stability thresholds was performed to determine the appropriate riprap sizing required to ensure waterway stability post-development. The following tasks were completed:

- Empirically defined channel stability thresholds were applied to post development hydraulic output (velocity and BSS) to indicate the appropriate  $D_{50}$  required at varying locations within the study area.
- An updated post-development scour risk analysis was conducted, estimating potential maximum scour depths at channel toe and bank positions using the newly defined and validated roughness values.
- An incipient motion analysis was performed to identify the minimum material sizes that would remain stable and not be subject to transport during the 1% AEP event, informing armouring specifications for high-risk locations as an option for the design engineer to incorporate.
- An updated Bank Stability and Toe Erosion Model (BSTEM) assessment was conducted to measure stream bank and stream toe stability. This used the post-development inputs and modelled the stabilising effect of the proposed riprap mitigations.
- Liaison with the hydraulic modeller to ensure that the newly defined Manning's roughness ( $n$ ) values for all proposed reaches were adequately incorporated into the updated hydraulic model following this assessment.

The following sub-headings provides a detailed explanation of the hydraulic stability assessment conducted:

### 2.3.1 CHANNEL STABILITY THRESHOLD

Hydraulic model outputs, namely velocity and Bed Shear Stress (BSS), were compared against empirically derived permissible thresholds from Fischenich (2001) to assess erosion potential across the study area. These thresholds were developed for a range of substrate types, with those relevant to this assessment presented in Table 2-1.

Table 2-1 Permissible velocity values for various boundary materials (Fischenich, 2001).

| Boundary Material         | Permissible Velocity (m/s) |
|---------------------------|----------------------------|
| Sandy loam (noncolloidal) | 0.53                       |
| Silty loam (noncolloidal) | 0.53-0.69                  |
| Alluvial silt (colloidal) | 1.14                       |
| Stiff clay                | 0.91 - 1.37                |

### 2.3.2 SCOUR ASSESSMENT

The velocity and depth-velocity product ( $Z_o$ ) outputs from the hydraulic model were used to assess probable maximum scour depths for the 0.5%, 1%, and 2% AEP event. The NRCS version of Blench and Lacey's equation based on regime relationships was used to calculate the general scour (Natural Conservation Resources Service, 2007).

provides the values for the different coefficients used for the Lacey and Blench equations, respectively. As recommended by Natural Conservation Resources Service (2007), scour depths were calculated using both versions of the formula and the largest value was considered as the maximum scour depth.

The regime relationship is expressed as follows:

$$y_s = KQd^a Wf^b D50^c$$

where:

- $y_s$  is maximum scour depth,
- $a, b, c$  are constant exponents (Table 2-2),
- $Qd$  is design discharge,
- $Wf$  is flow width at design discharge, and
- $D50$  is median size of bed material.

Table 2-2 Constants for Lacey equation (Natural Conservation Resources Service, 2007).

| Stream Condition   | K     | a   | b | c    |
|--------------------|-------|-----|---|------|
| Straight reach     | 0.030 | 1/3 | 0 | -1/6 |
| Moderate bend      | 0.059 | 1/3 | 0 | -1/6 |
| Severe bend        | 0.089 | 1/3 | 0 | -1/6 |
| Right angle bends  | 0.119 | 1/3 | 0 | -1/6 |
| Vertical rock wall | 0.148 | 1/3 | 0 | -1/6 |

Table 2-3 Constants for Blench equation (Natural Conservation Resources Service, 2007).

| Stream Condition  | K     | a   | b    | c       |
|-------------------|-------|-----|------|---------|
| Straight reach    | 0.162 | 2/3 | -2/3 | -0.1092 |
| Moderate bend     | 0.162 | 2/3 | -2/3 | -0.1092 |
| Severe bend       | 0.162 | 2/3 | -2/3 | -0.1092 |
| Right angle bends | 0.337 | 2/3 | -2/3 | -0.1092 |

## 2.4 BSTEM ASSESSMENT

The bank stability assessment was conducted using the Bank Stability and Toe Erosion Model (BSTEM), developed by National Sediment Laboratory, U.S. Department of Agriculture (Simon et al., 2000), to quantitatively determine the stability of cross-sections. BSTEM uses three limit equilibrium-method models to determine the Factor of Safety (Fs) for multi-layered streambanks. Any Factor of Safety produced below 1.0 is considered unstable and likely to fail, while values between 1.0 and 1.3 are conditionally stable, and values over 1.3 are considered stable.

Model inputs included:

- Bank cross-sections (six) extracted from the proposed development surface within the study area (Reach 1 and 2) provided by QM Properties.

- Bank shear stress for the 1% AEP extracted from the hydraulic model provided by QM Properties.

The shear stresses were analysed in BSTEM at each of the six cross-sections within the study area, assuming rip rap protection ( $D_{50} = 256$  mm). Model outputs included estimates of probable maximum lateral retreat and volume of eroded sediment.

# 3. FINDINGS

## 3.1 BACKGROUND GEOMORPHOLOGY

The Yaun Creek catchment lies within the Gold Coast hinterland and forms part of the Upper Coomera sub-catchment. The underlying geology is diverse and exerts a strong control over the terrain, soil development, and stream morphology. In the headwater areas, the landscape is dominated by Miocene Lamington Volcanics, particularly basalt flows from the Mount Warning shield volcano. These basalt units have weathered over time to produce deep, clay-rich ferrosols and dermosols, which are moderately stable and support dense vegetation. In contrast, the mid-reaches of the catchment are underlain by older, more resistant Neranleigh–Fernvale metasediments, including greywacke, shale, and chert. These rocks weather to shallow, less fertile Kurosols and Tenosols, which are highly erodible when vegetation is removed (Isbell, 2002; Queensland Globe, 2025).

The geomorphology of the study area, located within these mid-reaches, is defined by broad colluvial slopes. Alluvial deposits composed of gravel, sand, and silt form discontinuous terraces and narrow floodplains along the creek margins (Department of Environment and Resource Management, 2011). While erosion processes are typically low across the study area, they are significantly accelerated where land has been cleared for grazing and housing development. On these exposed metasediment-derived soils, the landscape becomes prone to sheetwash, gullying, and slope instability. Sediment delivery to the stream system is episodic and driven by high-intensity rainfall events common in subtropical regions, with sediment transport largely dominated by mixed load transport (Department of Environment and Resource Management, 2011; Sinclair Knight Merz, 2004).

Stream morphology directly reflects this underlying physical template of the study area. As the creek flows downstream, it adopts a more sinuous form, with increased sediment deposition, riffle-pool sequencing, and signs of geomorphic adjustment such as bank erosion, headcuts, and sediment bar formation. Observations from the field assessment confirm these processes, providing evidence of construction-related sediment input and culvert-induced flow disruptions.

The contrast between relatively stable, basalt-dominated headwaters and erodible metasediment mid-reaches (i.e. study area) governs the channel's sensitivity to disturbance and informs the need for targeted stability measures, particularly along Reaches 1 and 2, to manage scour, bank retreat, and sediment connectivity.

### 3.2 MITIGATION MEASURES

To address the high risk of scour and bank instability along Reach 1 and 2 (Figure 3-1) the following based rip-rap mitigation measures within the literature are proposed to ensure medium to long-term channel stability (refer to Appendix A for the comprehensive measures):

- Design specifications, toe protection, and filter layer:
  - The riprap must be composed of angular, well-graded rock with a median diameter ( $D_{50}$ ) to provide adequate resistance against the modelled hydraulic forces (i.e., velocity, bed shear stress. (refer to Section 3.4.1 and 3.4.3 for sediment sizes of each area of interest).
  - A geotextile filter or graded granular filter must be installed beneath the riprap to prevent the piping of the underlying fine-grained, cohesive soils, which can be a critical failure mechanism.
- Longitudinal extent, bends, and transitions:
  - The armouring must extend approximately one full channel width upstream one full channel width downstream of recommended locations for intervention. This prevents the initiation of erosion at the upstream end and depositional issues downstream.
- Bed and bank stabilisation (tie-in points):
  - The design must prioritise stabilising the channel bed to prevent vertical incision, which is a primary failure mechanism for bank protection. Only after the bed is stabilised should bank armouring be installed.
  - The bank riprap must be structurally tied into the bed armouring or grade-control structure to form an armoured bed layer.
  - The upstream end of the riprap must be securely keyed into stable soils. The downstream end must be tied into the stable, densely vegetated channel or the existing bedrock control to prevent flow from outflanking the structure.
- Sizing criteria and layer thickness:
  - The median rock diameter ( $D_{50}$ ) must be sized at, or slightly above, permissible sediment threshold of motion for the selected design event. In high risk areas the incipient motion threshold as detailed in Figure 3-2 can be adopted at the discretion of the design engineer. The below assessments provide grading options up to the 1% AEP to be selected by the design engineer.
  - Riprap must comprise a well-graded mix of angular, fractured rock. This ensures interlocking to resist "plucking" and rolling, providing a stable matrix superior to rounded stone.
  - The minimum blanket thickness must be at minimum of  $1.5 \times D_{50}$  or  $D_{100}$ . Also, increase the blanket thickness when placing underwater to safely convey interstitial flows through the rock matrix without dislodging stones.
- Overtopping flows (embankments):
  - The riprap design must be engineered to withstand overtopping flows. The hydraulic behaviour is critically dependent on embankment slope – gentler slopes promote surface skimming, while steeper slopes drive high-velocity flow through the rock layer's interstitial spaces, generating internal destabilising forces.

- To ensure integrity, the riprap system must be structurally continuous. A robust toe anchor and a competent filter layer are therefore mandatory to prevent unravelling and subsurface erosion during an overtopping event.
- Nature-based integration & alternatives:
  - To enhance ecological value, soil-filled riprap or well-graded, void-filled rock (i.e., rock mulch) can be used to support native vegetation establishment. This design must be sized conservatively and graded to prevent flow concentration, allowing natural sediment deposition to further stabilise the structure and promote riparian growth over time.

### 3.3 MANNINGS N REVIEW

- Manning's roughness (n) values assessed within the literature and compared against on site conditions are summarised in **Error! Reference source not found..** Hydrobiology was advised a constant value of 0.1 was adopted for the model domain which differed to those recommended by the literature. The analysis showed:
  - Reach 1 exhibited the highest main channel roughness (base n = 0.12), influenced by its complex morphology including large wood (LW), dense riparian vegetation, and partial bedrock confinement (Table 3-2).
  - Reach 4 also demonstrated high roughness (base n = 0.15) due to its marshy wetland conditions and dense ground cover.
  - Reaches 2 and 3, characterised by more stable and eroded substrates respectively, have lower base values of 0.08 and 0.065, indicating more hydraulically efficient conditions.
  - While stabilising erosion-prone areas with riprap, mitigation measures should focus on maintaining existing channel roughness to ensure its long-term functionality.
- Sections recommended for remediation (riprap  $D_{50} = 256$  mm) should receive a manning's n value of between 0.04-0.05 per Chow (1959).

Table 3-1: Summary of manning's values recommended based on literature and document review

| Reaches | Key geomorphic features informing n                                                                       | Main channel range n (range and base) | Overbank/ marsh/ floodplain n (range and base) | Sources                                                                      |
|---------|-----------------------------------------------------------------------------------------------------------|---------------------------------------|------------------------------------------------|------------------------------------------------------------------------------|
| Reach 1 | Alternating marsh & defined low-flow channel, dense riparian vegetation, LWD, partial bedrock confinement | 0.08 – 0.15 (0.12)                    | 0.045 – 0.060 (0.050)                          | (Arcement & Schneider, 1989; Barnes, 1967; US Army Corps of Engineers, 1994) |
| Reach 2 | Bedrock upstream, cobble-boulder mid-reach, localized meander erosion, flood channel at high flow         | 0.06 – 0.10 (0.08)                    | 0.040 – 0.055 (0.048; 0.055 in bends)          | (Chow, 1959; Kilgore & Cotton, 2005; US Army Corps of Engineers, 1994)       |
| Reach 3 | Deep pool & head cut; incised reach near culvert; vertical instability                                    | 0.05 – 0.08 (0.065)                   | 0.035 – 0.050 (0.042)                          | (Barnes, 1967; US Army Corps of Engineers, 1994)                             |

| Reaches | Key geomorphic features informing n                                        | Main channel range n (range and base) | Overbank/ marsh/ floodplain n (range and base) | Sources                                                                     |
|---------|----------------------------------------------------------------------------|---------------------------------------|------------------------------------------------|-----------------------------------------------------------------------------|
| Reach 4 | Marshy wetland, dense ground cover, narrow low-flow channel below culverts | 0.10 – 0.20 (0.15)                    | 0.045 – 0.060 (0.050)                          | (Arcement & Schneider, 1989; Kilgore & Cotton, 2005; Melbourne Water, 2025) |

Table 3-2: Selected site photos indicative of Mannings N values.

## Reach 1



Tree root acting as natural weirs



Large wood in the channel

## Reach 2



Wide channel more erosion



Deposition in channel

## Reach 3

|                                                                                    |                                                                                     |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|   |   |
| Deep pool                                                                          | Wide deep channel                                                                   |
| <b>Reach 4</b>                                                                     |                                                                                     |
|  |  |
| Marshy wetland area; dense ground cover                                            | Marshy wetland area                                                                 |

## 3.4 HYDRAULIC ASSESSMENTS

### 3.4.1 CHANNEL STABILITY THRESHOLD

Post-development hydraulic modelling (velocity) indicated that the upstream sections of Reaches 1 and 2 remained erosion hotspots, with additional hotspot zones downstream (Figure 3-1). During the 1% AEP event, modelled flow velocities exceed permissible stability thresholds at these locations. Accordingly, these sections are expected to experience ongoing hydraulic forcing under both low- and high-flow conditions, sustaining a heightened risk of bank retreat and bed instability. These sections are to be addressed through riprap mitigation (Figure 3-6).

### 3.4.2 INCIPIENT MOTION

Incipient motion analysis showed that bed shear stress (BSS) along the reaches was sufficient to mobilise sediment up to boulder size (305 mm). This indicated channel reworking during the 1% AEP event. The focus area (Reaches 1 and 2) had the highest erosive potential, with significant boulder movement. Such erosive power can trigger bank and bed erosion in Reaches 1 and 2. Material implemented within the designs should adopt the channel stability threshold  $D_{50}$  unless the design engineer deems there to be an unacceptably high level of risk to adjacent infrastructure.

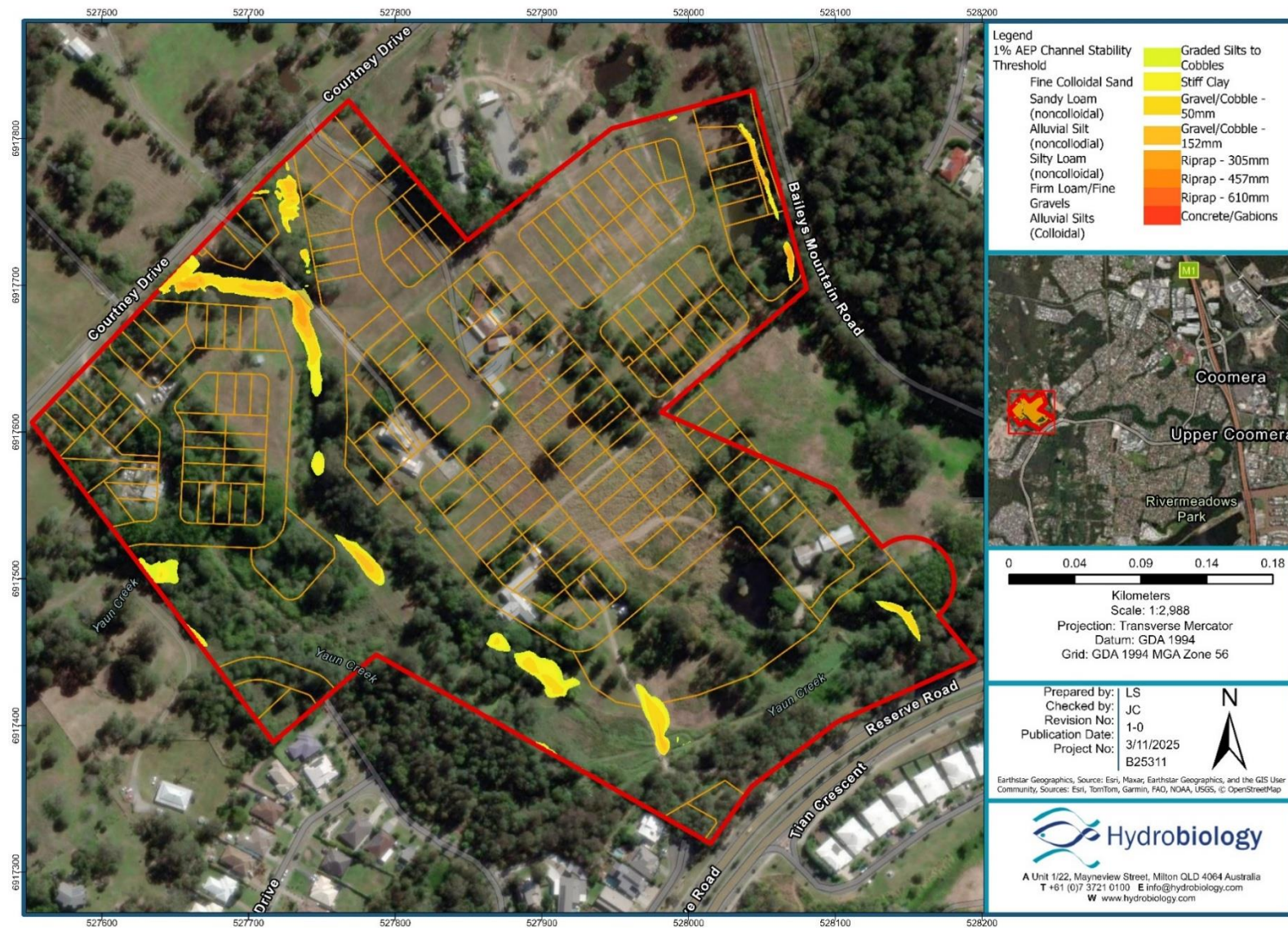


Figure 3-1 Channel stability thresholds for velocity at 1% AEP event (post development).

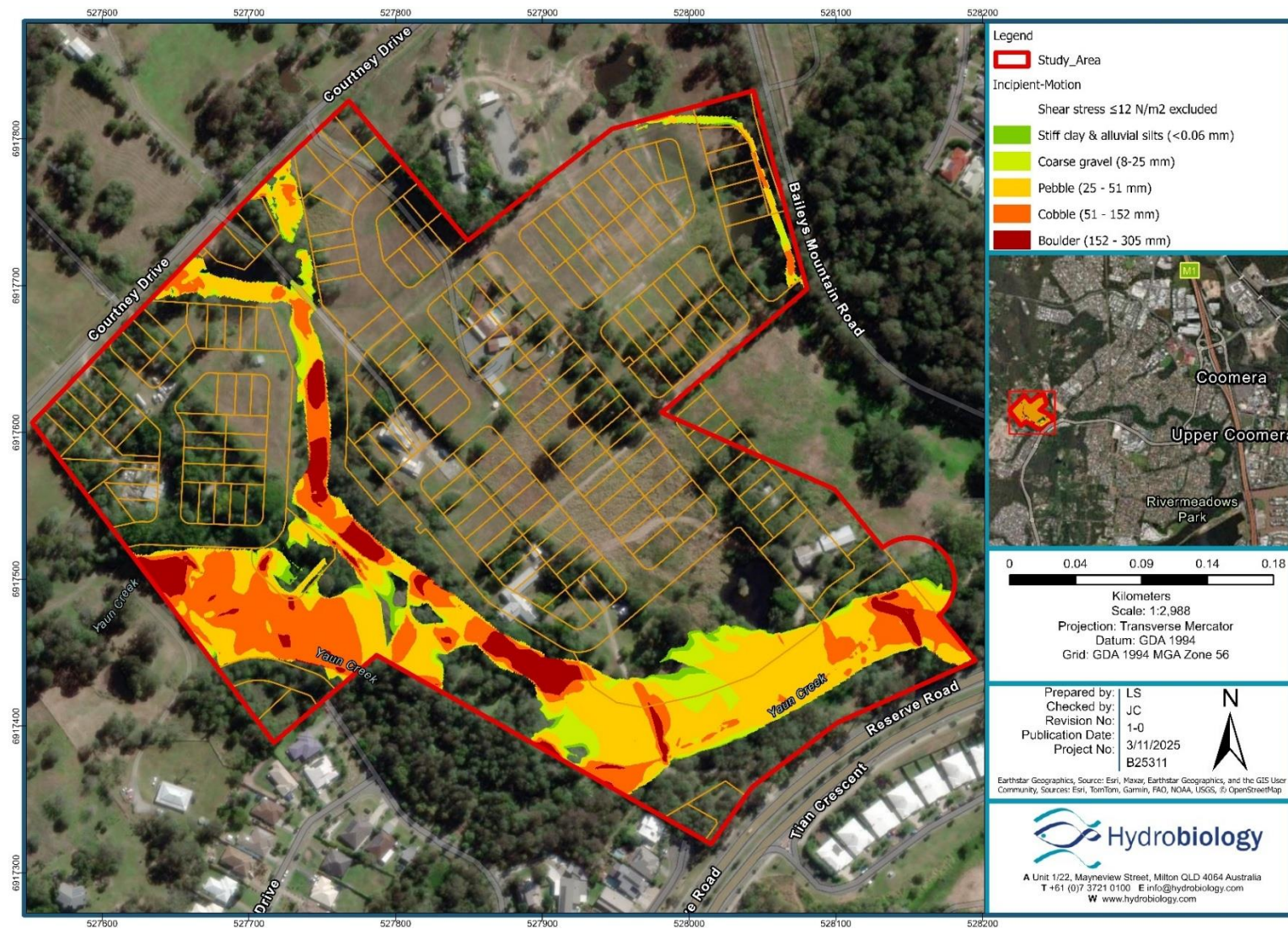


Figure 3-2 Incipient motion at 1% Annual Exceedance Probability (AEP) threshold (post development).

### 3.4.3 SCOUR ASSESSMENT

The assessment of scour depths showed a significant reduction in erosion potential (Figure 3-3 and Figure 3-4). In Reach 1, predicted maximum scour depth under the 1% AEP event decreases to about 0.2m, down from the preliminary maximum estimate of about 0.8 m. In Reach 2, the maximum predicted scour depth is also about 0.2 m for the 1% AEP event. These results confirm that riprap designed at the sediment-transport threshold is effective in mitigating scour at the identified high-risk locations.

## 3.5 BSTEM ASSESSMENT

Table 3-3 shows how far the banks are expected to erode sideways (maximum lateral retreat) during the 1% AEP post development event, comparing an unprotected condition with a condition where the bank toe is armoured with riprap ( $D_{50} = 256\text{mm}$ ).

Across selected reaches (Figure 3-5), the preliminary unprotected case indicated substantial instability, with predicted retreat ranging from 1.3cm to 5.8cm during the 1% AEP event, consistent with an active erosion hotspot where toe scour and slumping can propagate bank failure. When riprap was installed, the modelled retreat across reaches dropped by at least 60% for each bank. This indicates that resisting forces (bank strength and confining effects with toe protection) exceed driving forces (e.g., hydraulic shear or forces). At the same time, the factor of safety exceeded 1, and therefore, failure is not expected under the riprap design. While lateral erosion at the toe is predicted within the BSTEM model, adoption of appropriate design methods such as interlocking, implementation of geotextile, and keying in of toe protection will ameliorate these risks even further.

Table 3-3 Modelled rates of maximum lateral retreat during the 1% AEP event for the condition with no bank or toe protection, and that including the installation of rip rap with a median diameter of 0.256 m.

| S/N | Cross-sections analysed along Reach 1 | Reference condition (Preliminary analysis) | Lateral erosion at toe Riprap present | Percentage change (before and after Riprap) |
|-----|---------------------------------------|--------------------------------------------|---------------------------------------|---------------------------------------------|
| 1   | XS1                                   | 4.4cm                                      | 1.8cm                                 | 59%                                         |
| 2   | XS2                                   | 1.8cm                                      | 0.5cm                                 | 72%                                         |
| 3   | XS3                                   | 4.4cm                                      | 1.8cm                                 | 59%                                         |
| 4   | XS4                                   | 1.3cm                                      | 0.3cm                                 | 77%                                         |
| 5   | XS5                                   | 2.0cm                                      | 0.6cm                                 | 70%                                         |
| 6   | XS6                                   | 5.8cm                                      | 2.5cm                                 | 57%                                         |



Figure 3-3 Maximum Scour (m) at 1% AEP event (baseline condition).

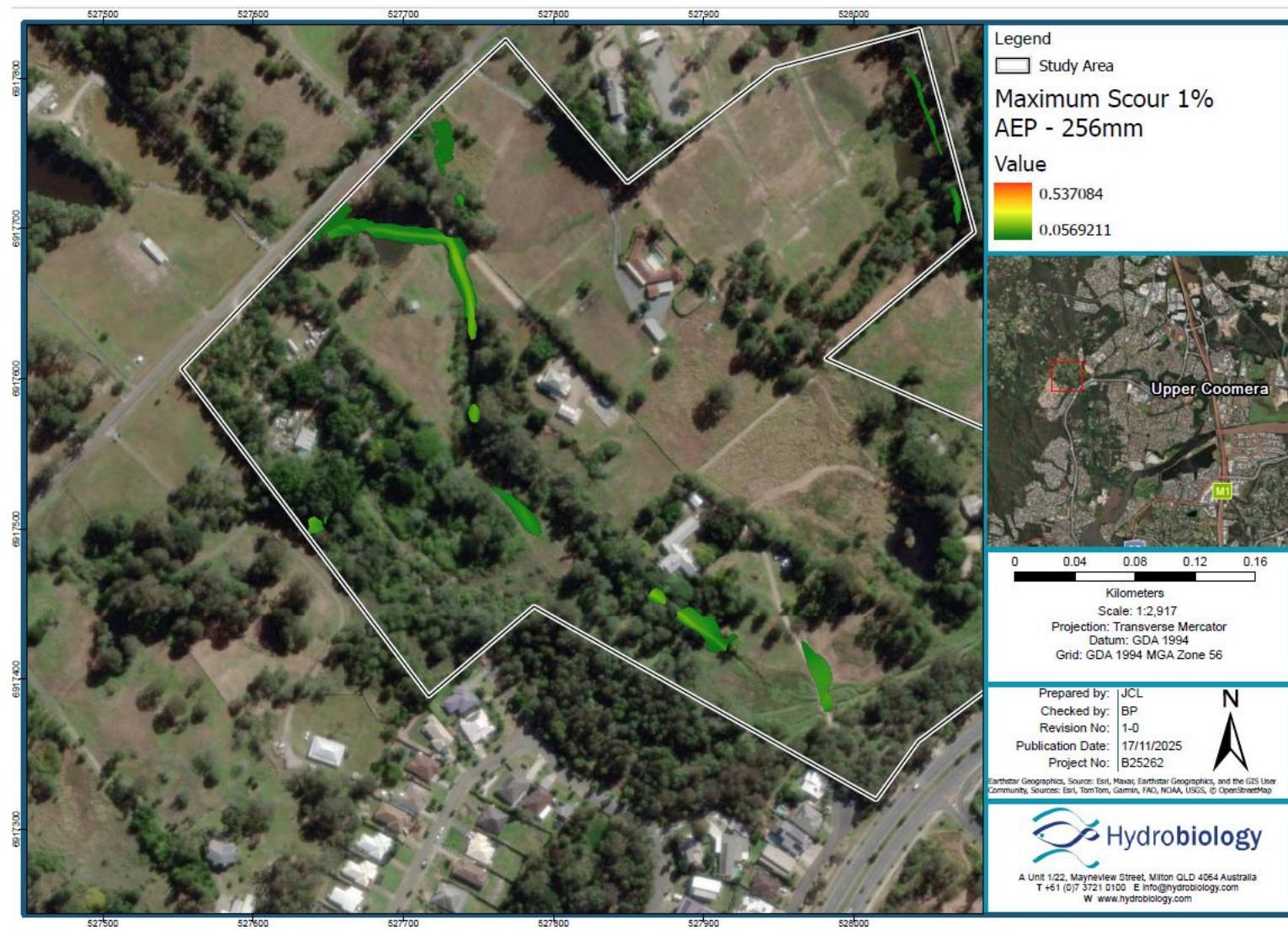


Figure 3-4 Maximum Scour (m) 1% AEP event with 256mm riprap applied in at risk areas (waterway condition following interventions).

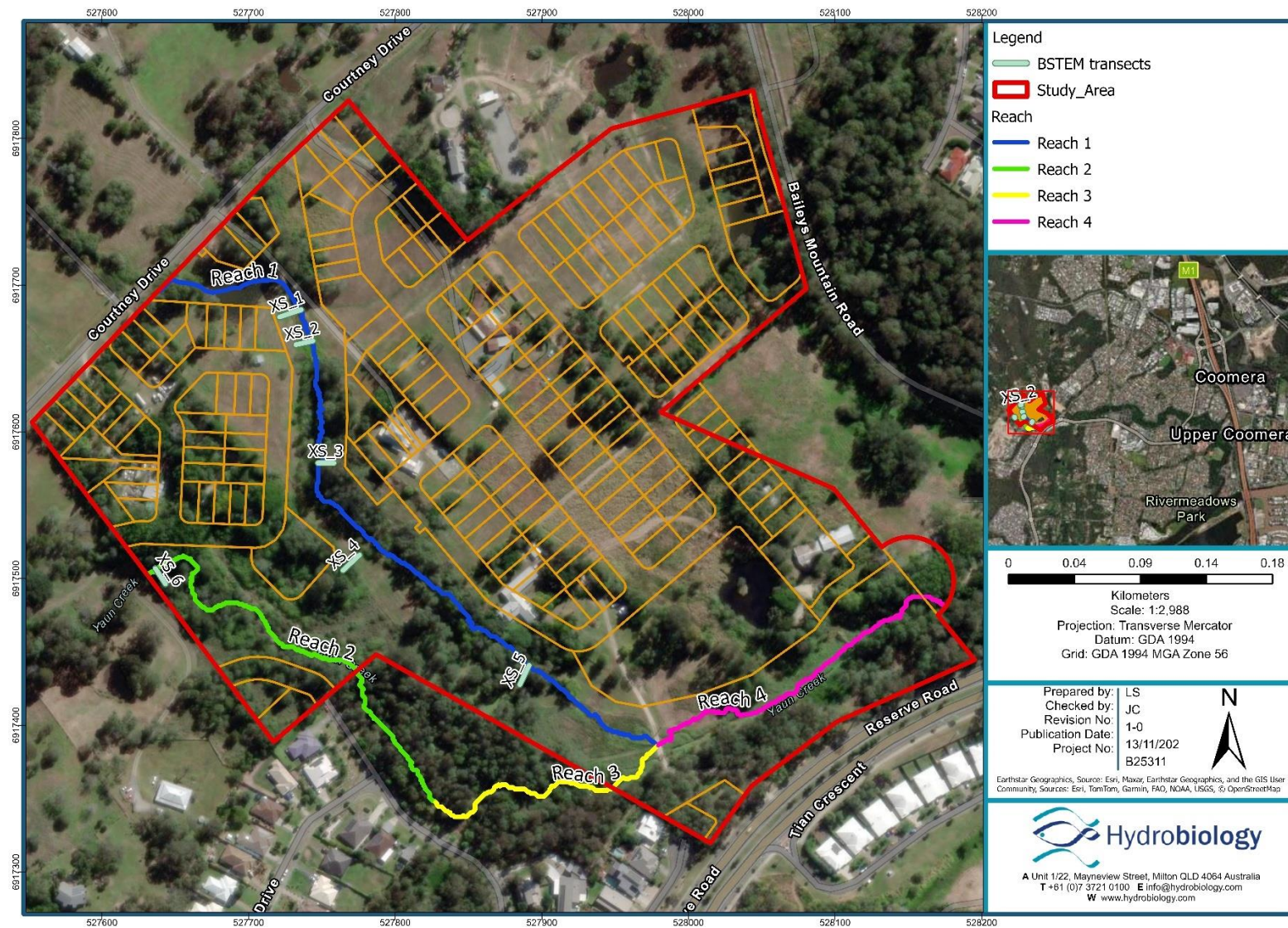


Figure 3-5 Locations of cross-section input into BSTEM.

### 3.6 CONCEPTUAL DRAWINGS

As per the additional RfI's submitted by City of Gold Coast, Figure 3-6 shows conceptual areas required to be protected due to the level of risk defined by the geomorphic assessment. The location at the interface of Reach 1, 3, and 4 which is not circled is assumed to be addressed through separate creek crossing design. If this is not part of the intentions of the developer to address through separate design this should also be protected to prevent erosion downstream of the existing crossing.

Figure 3-7 and Figure 3-8 presents a general, not for construction conceptual approach to waterway design which implements recommendations set out in Section 3.2 as a guide for the design engineer to use during subsequent detailed design phases. These conceptual designs are intended to be implemented at locations circled in Figure 3-6. Location specific detailed designs should be produced utilising these conceptual designs at later stages.

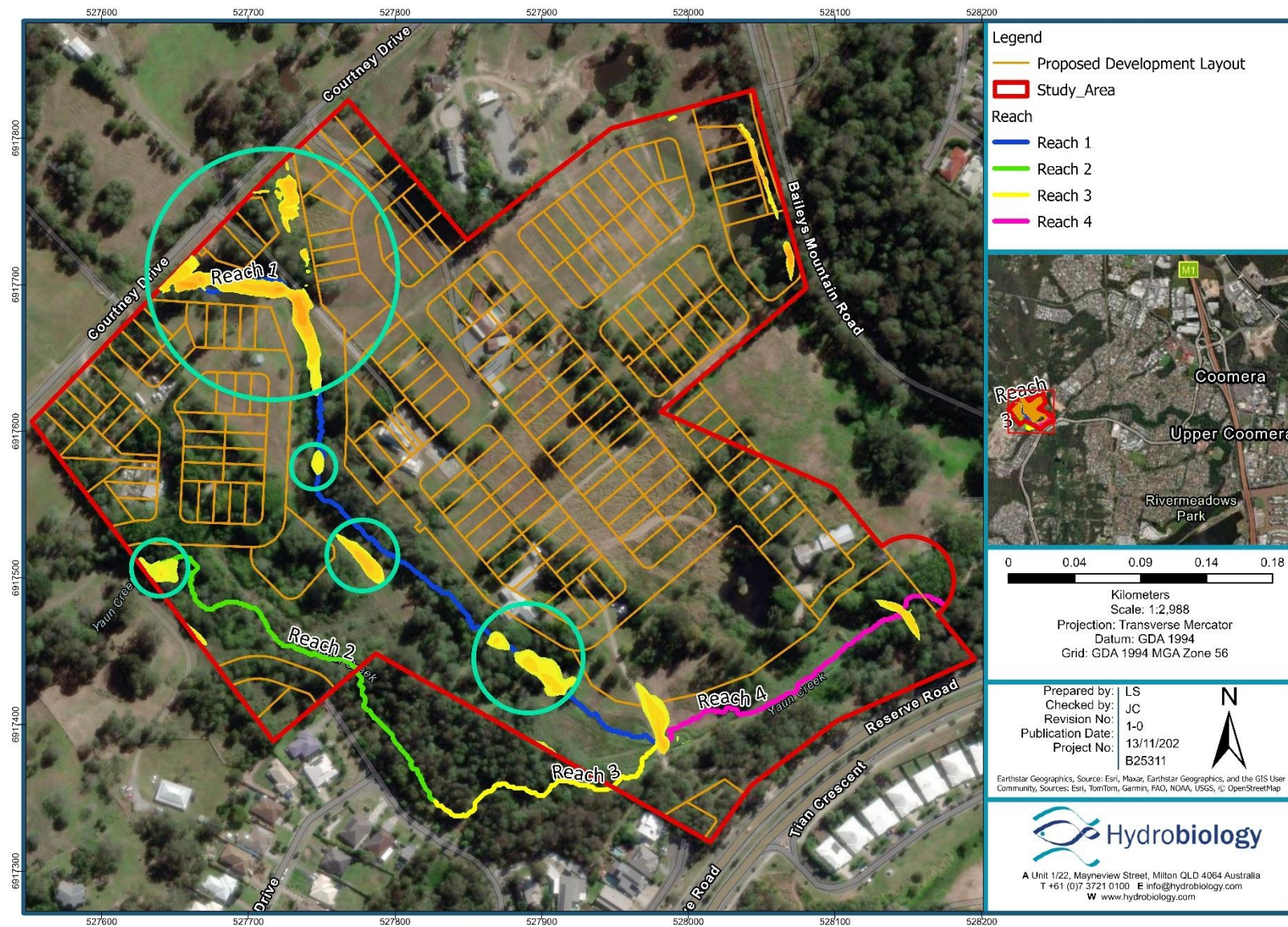


Figure 3-6 Proposed armouring locations are shown with turquoise circle (conceptual)

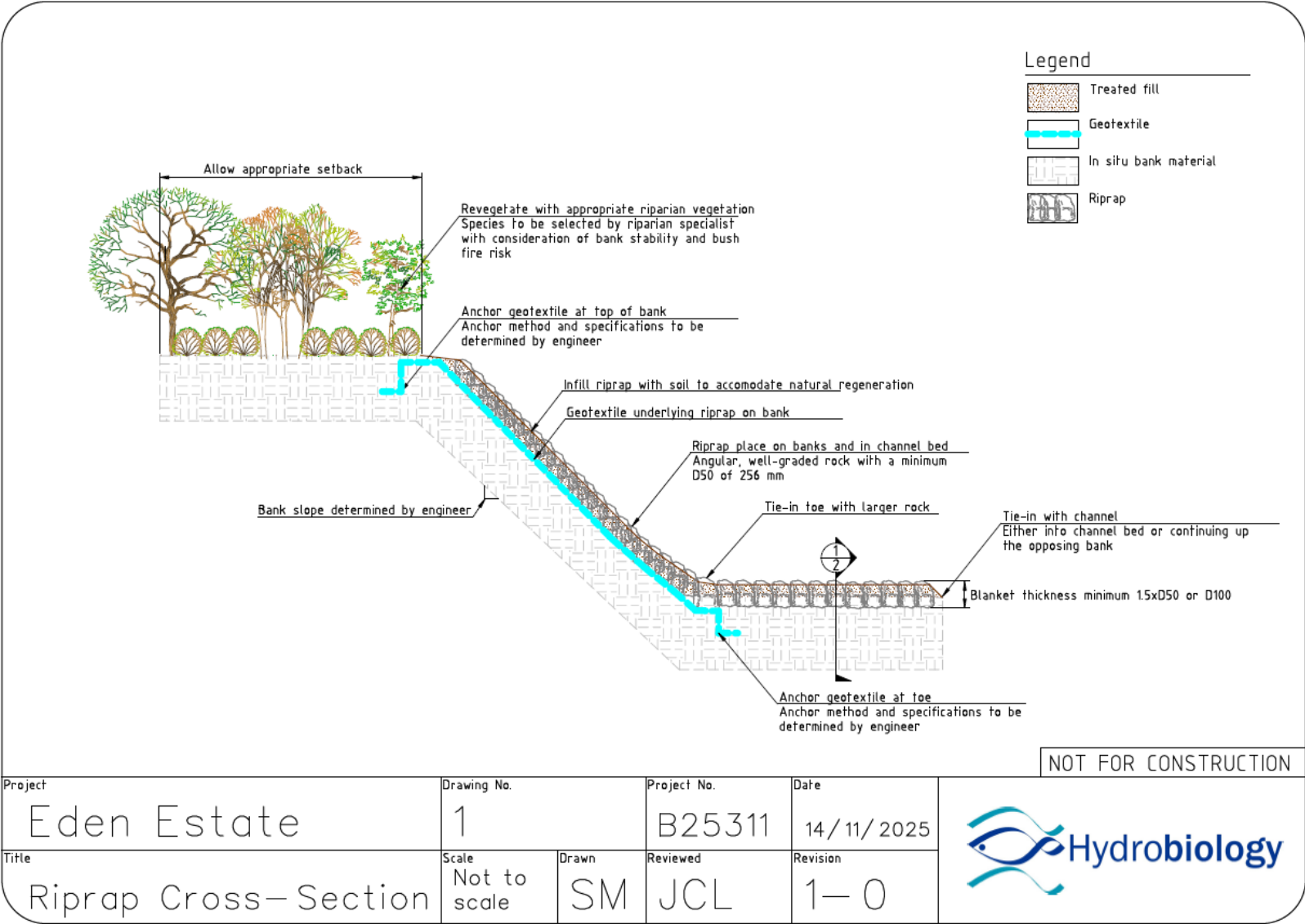


Figure 3-7: Cross Sectional General Design Principals

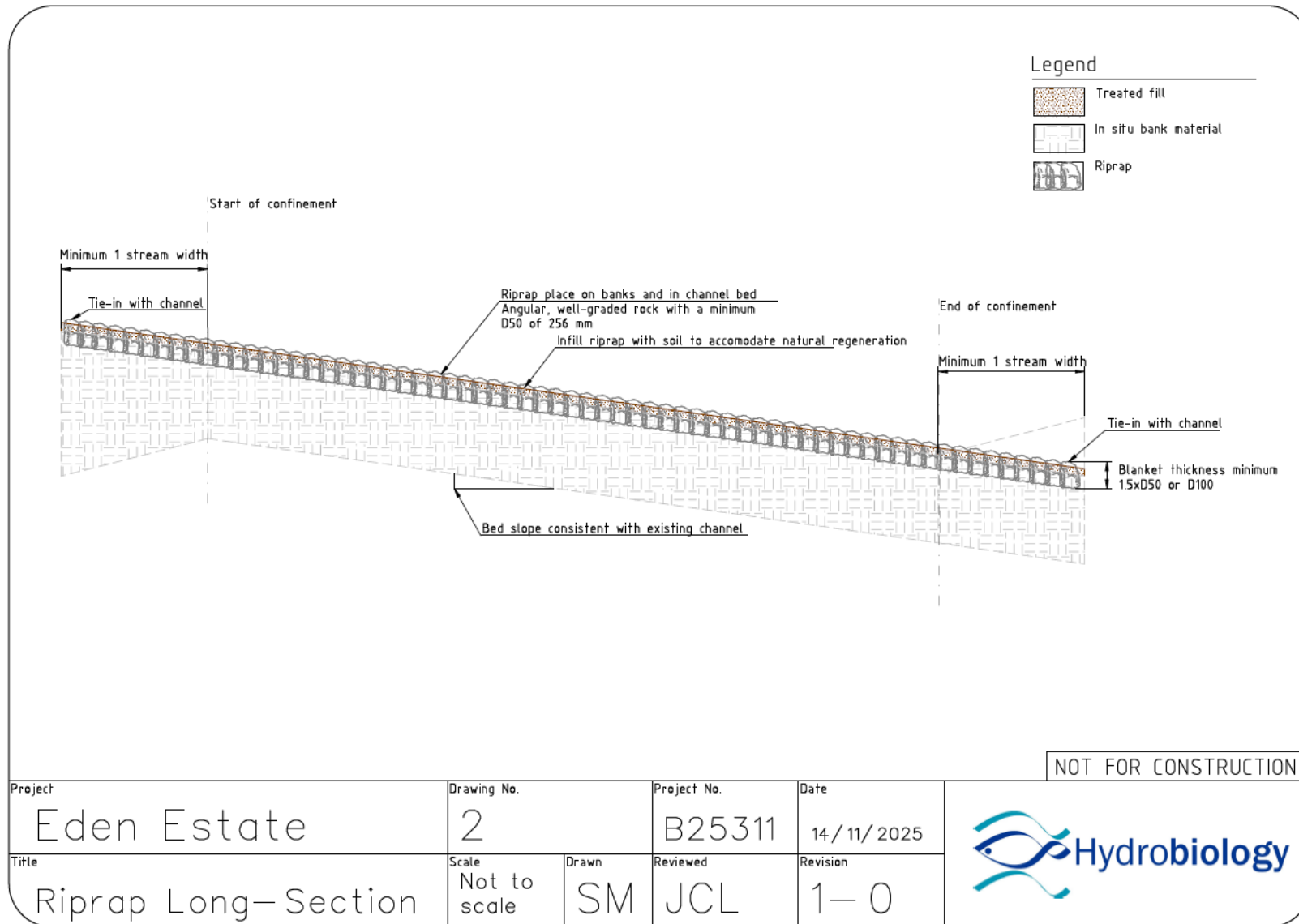


Figure 3-8: Longitudinal General Design Principles

# 4. DISCUSSION AND CONCLUSION

The geomorphic and hydraulic analyses undertaken for Reaches 1 and 2 of Yaun Creek demonstrate that the current condition of these waterways and setting make it inherently sensitive to hydrological changes associated with the proposed Eden Estate development. The combination of steep gradients, erodible metasediment-derived soils, and reduced vegetative buffering along these reaches creates conditions conducive to bank retreat, toe scour, and lateral migration. Modelling outputs confirm that even under the 1% AEP event, flow velocity and Bed Shear Stress exceed empirically derived stability thresholds for in-situ fine-grained and mixed alluvial materials, validating the need for targeted protection measures.

The scour and BSTEM analyses clearly demonstrate the stabilising effect of riprap armouring. Without protection, Reach 1, particularly cross-section XS1 (at bend), showed the greatest susceptibility to toe erosion, with predicted lateral retreat up to 41.7 cm during the 1% AEP event. In contrast, the application of angular riprap ( $D_{50} = 0.256$  m) substantially reduced predicted retreat to less than 2 cm per event, resulting in stable conditions (Factor of Safety > 1). This will be further ameliorated by implementation of appropriate mitigations as set out in Section 3.2. Similar improvements were observed across all other assessed cross-sections, indicating that the proposed armouring design is both geomorphically and hydraulically effective in resisting erosive forces.

From a geomorphic perspective, the proposed mitigation measures, comprising appropriately sized riprap, graded filter layers, and structural tie-ins to stable channel features, are expected to interrupt toe scour, reduce near-bank shear, and limit the progression of lateral erosion. These engineered stabilisation works will also reduce sediment supply to the waterway, maintaining channel form and improving downstream sediment balance. Where possible, the design should continue to integrate

nature-based elements such as soil-filled riprap to rapidly restore riparian function, promote habitat diversity, and support longer-term channel adjustment under reduced maintenance conditions.

Overall, this assessment confirms that targeted rock armouring, designed in accordance with site-specific hydraulic conditions, will effectively mitigate the risk of scour and bank instability within the development area. The outcomes provide a defensible and practical response to the City of Gold Coast's RfI, ensuring that the proposed development maintains waterway stability, protects downstream assets, and supports sustainable geomorphic function in the Yaun Creek system.

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# APPENDIX A. MITIGATION MEASURES



## A.1 ACADEMIC AND GREY LITERATURE FINDINGS

Table 5-1 Literature and document review on the mitigation measures of riprap on stream channels.

| S/N | Tittles                                                                                                                       | Author                 | Mitigation of negative effects – some consideration description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----|-------------------------------------------------------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Bridge Scour and Stream Instability<br><br>Countermeasures: Experience, Selection, and Design Guidance-Third Edition Volume 2 | (Lagasse et al., 2001) | <ul style="list-style-type: none"> <li>○ Riprap is placed to armour eroding banks, embankments, and the vicinity of hydraulic structures without unduly constricting flow. It works best where the channel planform is relatively stable; in reaches that are actively degrading or migrating, use extra care and pair the rock with measures that address the underlying geomorphic drivers.</li> <li>○ Extend the riprap vertically from the toe of the bank up the slope to at least about 0.6 m (about 2 ft) above the design high water. At the toe, key it down to at least the combined long-term degradation and local toe-scour depth; where excavation is not practical, build a mounded or trenched toe so the rock can “launch” as scour occurs. Keep bank slopes reasonably flat (about 1V:1.5H or flatter). Make the layer thick enough—at minimum the larger of 1.5×D50 or D100—and increase thickness when placing underwater.</li> <li>○ Always separate the riprap from native soils with a filter to prevent piping: use a properly graded granular filter and/or geotextile, with adequate thickness and overlaps. Choose durable, angular, blocky stone with a well-graded mix so the matrix interlocks and resists segregation; avoid rounded or platy rocks that can slide or shingle under load.</li> <li>○ Tie the riprap smoothly into the existing ground at the upstream and downstream ends using key trenches sized to the stone. Place from the toe upward to prevent rolling and gradation segregation, minimise drop heights over geotextiles, and avoid excessive trafficking of equipment on the finished surface.</li> <li>○ Around structures, wrap abutments, guide banks, and piers with riprap aprons sized to local velocities and expected scour. Around piers, use a full-planform apron with a radius on the order of a few pier widths, and allow for launching as scour develops. Extend revetment below the bed per toe-down guidance and up the face to a safe freeboard above design flow so the armour remains continuous during floods.</li> </ul> |
| 2   | Hydraulic Design of Flood Control Channels                                                                                    | (USACE, 1994)          | <ul style="list-style-type: none"> <li>• Choose angular, well-graded rock so pieces interlock and “nest.” Avoid uniform stone that segregates and leaves big voids; a broad gradation improves stability, drainage, and self-adjustment as the bank reshapes.</li> <li>• Make the blanket thick enough to resist displacement—typically at least the characteristic diameter of the design stone (and never less than a foot), with extra thickness for underwater work to cover placement uncertainty and future settling.</li> <li>• Design the toe first. Key it below anticipated scour or use a launchable (sacrificial) toe that can roll down and maintain cover as the channel erodes. Most riprap failures start at an unprotected or under-built toe.</li> <li>• Carry protection far enough through bends and transitions. Extend past the bend exit where secondary currents stay erosive and tie the ends into stable ground. Use filters (granular or fabric) beneath the rock whenever bank soils are erodible to prevent piping and loss of fines.</li> <li>• Place stone carefully to avoid segregation and breakage—minimize drop heights, shape and choke voids, and verify thickness with spot checks. In debris- or wave-prone reaches, upsize stone and add thickness to absorb impacts and runoff.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

| S/N | Tittles                                                               | Author                                            | Mitigation of negative effects – some consideration description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----|-----------------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3   | Simplified design guidelines for riprap subjected to overtopping flow | (Frizell et al., 1998)                            | <ul style="list-style-type: none"> <li>• Know the slope of the embankment and the amount of water expected to flow over it. Flow behaviour changes with slope—on gentler slopes, water tends to skim across the surface, while on steeper slopes, it moves mainly through the rock layer. Designs should recognise and plan for both conditions.</li> <li>• Choose the rock size so that stones are stable but still efficient in resisting movement. Base the selection on the relationship between slope, flow, and rock gradation. Add a reasonable safety margin depending on the level of risk and the importance of the structure. Keep the rock mix well graded so the smaller stones fill the gaps and lock the larger ones in place.</li> <li>• Set the layer thickness to allow water to move safely through the rock without dislodging it. If the flow inside the rock is too deep or too fast, increase the stone size or thickness until the movement is controlled. The aim is for water to pass mostly within the rock layer, not above it, for reliable protection.</li> <li>• For gentler slopes, some shallow surface flow can be acceptable if the shear stress is low enough to avoid stone movement. On steeper slopes, most or all the water should be carried through the rock to prevent erosion or sliding. Balancing surface and internal flow keep both the slope and the protection layer stable.</li> <li>• Provide a properly graded bedding or a suitable filter beneath the rock. Build a strong, continuous toe tied into stable ground, as this is often the key to preventing overall failure. Use consistent placement, maintain good contact between stones, and apply practical safety factors based on expected conditions and maintenance capacity.</li> </ul> |
| 4   | Stone Sizing Criteria                                                 | (USDA NRCS, 2007)                                 | <ul style="list-style-type: none"> <li>• Define the embankment slope, expected unit discharge, tailwater conditions, and whether the reach is straight, curved, confined, or wide. Classify the setting as gentler or steeper so you know if flow will skim the surface or move mainly within the rock.</li> <li>• Size the rock at the threshold of movement for the design flows, then add a reasonable safety margin. Use a well-graded, angular mix so stones interlock, resist plucking, and limit void migration. Avoid overly uniform stone that rolls or rattles loose.</li> <li>• Set the armour thickness to safely carry most flow within the layer without lifting stones. If checks show interstitial velocities or depths are too high, step up the stone size or the thickness and re-evaluate until movement is unlikely.</li> <li>• Use a graded bedding or a compatible filter (or geotextile, where appropriate) to prevent piping and loss of fines. Build a continuous, well-keyed toe tied into stable ground, and make clean, robust tie-ins at crests, ends, and structures to prevent flanking.</li> <li>• Account for curvature, transitions, outlets, and local accelerations; avoid hard points that create jets unless intentionally designed.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 5   | Stream stabilisation / prepared by Antonietta Torre                   | (Western Australia. Water River Commission, 2001) | <ul style="list-style-type: none"> <li>• The protected area should extend upstream and downstream of the eroding section by at least one channel width, ensuring stability at the structure's ends. The thickness of riprap should be a minimum of twice the median rock diameter (<math>2 \times D_{50}</math>) or at least equal to the maximum stone size.</li> <li>• Riprap must be constructed of well-graded, angular rock. The tractive forces of high flows determine stone sizing, which depends on bank slope, flow depth, rock density and shape, bed slope, and the channel's width and curvature.</li> <li>• The technique should not be used where the bed is actively deepening—bed levels must be stabilised first. Sediment tends to accumulate along riprap over time, encouraging vegetation establishment and improving stability.</li> <li>• The bank is usually rock paved to above high-water mark, although sometimes only the toe needs reinforcement. Banks may need battering before placement, and a filter cloth can be installed beneath the rock to prevent undermining from flows washing out sediment. A trench should be excavated at the toe so the riprap extends below bed level, or a rock ledge may be constructed on hard beds.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

| S/N | Tittles               | Author                                                                  | Mitigation of negative effects – some consideration description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----|-----------------------|-------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6   | Rockwork construction | (Melbourne Water, 2025)                                                 | <ul style="list-style-type: none"> <li>A rock layer placed on streambanks to protect from erosion; suitable for most bank-erosion types and provides long-term protection. Not to be used where the bed is actively deepening—stabilise bed level first. Sediment can accumulate in voids, allowing vegetation to establish over time.</li> <li>Banks may need battering. Place filter cloth beneath the rock to stop undermining from flows. Excavate a toe trench and lay riprap below bed level; on hard beds, a rock ledge along the toe is an alternative. Paving typically extends to above high-water mark; typical height <math>\sim 2/3</math> of bank.</li> <li>Use well-graded, angular rock. Design stone size based on tractive forces during high flows, considering bank slope, flow depth, rock density/shape, bed slope, and channel width/radius of curvature at the site.</li> <li>Extend protection upstream and downstream <math>\sim</math>one channel width beyond the unstable zone to prevent outflanking. Armor thickness <math>\geq 2 \times D_{50}</math> (or at least <math>D_{max}</math>).</li> <li>In highly erosive/dispersive soils, a geotextile may be required beneath riprap for support and anti-piping, typically used with a granular filter/embedment layer.</li> </ul>                                                                                                                                                                                                                          |
| 7   | Rock armouring        | (Department of the Environment, Tourism, Science, and Innovation, 2025) | <ul style="list-style-type: none"> <li>Use angular, well-graded rock placed to a design thickness to form an interlocking mass and put the emphasis on toe protection to resist fluvial entrainment.</li> <li>Pair the hard works with vegetation establishment so the bank progressively self-stabilises and, ideally, the structure's role diminishes within the required design life for the structural component.</li> <li>Before armouring, diagnose the erosion type: if mass failure/slumping is active, use other interventions first or alongside armouring; also test whether threatened infrastructure could be moved more efficiently than protected.</li> <li>Apply armouring selectively: it can rapidly stabilise banks and cut sediment inputs with relatively low ongoing maintenance, but it may not address root causes, can shift erosion elsewhere, is incompatible with meander evolution, may reduce habitat and limit recreation—so use only where those trade-offs are acceptable.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 8   | Open Hydraulics       | (UDFCD, 2016)                                                           | <ul style="list-style-type: none"> <li>Prefer soil riprap or void-filled riprap (over bare rock) to control erosion while supporting vegetation and habitat; match the choice to site hydraulics (velocity, shear, slopes, bends).</li> <li><b>Soil riprap:</b> Fill all voids with suitable topsoil; add 4–6 in of topsoil on top (outside the low-flow channel), then seed and protect with straw/coir mats to lock in soil and reduce early washout.</li> <li><b>Void-filled riprap:</b> Use a well-graded mix (rock, cobble, gravel, sand, soil) that interlocks and acts as an internal filter; prevent segregation during hauling/placement, compact at optimum moisture, and verify quality with a test section and on-site oversight.</li> <li><b>Sizing &amp; safety:</b> Size rock for the governing velocity/slope (mild vs. steep methods) and apply a conservative safety factor (typically <math>\geq 1.5\times</math>); for steep slopes, increase largest rock size <math>\sim 30\%</math> to mitigate flow concentration effects.</li> <li><b>Bends &amp; details:</b> At channel bends, upsize based on adjusted bend velocity; keep finished elevations within <math>\pm 0.10</math> ft to avoid concentrating flow that can unravel the section.</li> <li><b>Bioengineering integration:</b> Where feasible, pair riprap with vegetation, soil lifts, coir/TRMs, and wetland sod to improve stability and habitat; reserve hard armour or boulders for locations where shear exceeds vegetative resistance.</li> </ul> |

| S/N | Tittles                                                                                                                             | Author                       | Mitigation of negative effects – some consideration description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9   | Rock riprap design for protection of stream channels near highway structures volume 1 -- hydraulic characteristics of open channels | (Blodgett, 1986)             | <ul style="list-style-type: none"> <li>Anticipate deeper scour than an average cross-section suggests. Size and extend the riprap both above the design stage and below the bed to account for a deeper thalweg. This prevents the revetment from simply redirecting lateral erosion into vertical scour. Side slopes must still be stable for the underlying soil.</li> <li>Replace fixed toe depths with an embedment depth based on empirical scour relationships linked to bed-material size (D50). The design should assume the thalweg can shift, requiring the armoured toe to remain effective across the channel section.</li> <li>Increase riprap extents (e.g., longer aprons) and embedment depths to handle localized high shear. Use realistic roughness values in calculations to avoid overstating channel capacity. Base designs on average conditions with allowances for short-term extremes, not on a single survey.</li> </ul>                                                                                                                     |
| 10  | Managing Infrastructure in the Stream Environment                                                                                   | (Sholtes et al., 2017, 2018) | <ul style="list-style-type: none"> <li>Use riprap primarily as a hardened toe where immediate protection is critical, but pair it with bioengineering or flow-deflection (e.g., bendway weirs, vanes, spurs) to shift shear off the bank and reduce downstream erosive side-effects of hard armouring. Expect that continuous bank armouring can increase bed scour and habitat simplification, so limit its areal extent and integrate living materials wherever feasible.</li> <li>If incision is ongoing/likely, riprap alone on banks is insufficient—use rock grade-control (low ramps/drops) or armoured beds and include flanking protection to avoid outflanking.</li> <li>Straightened or narrowed corridors steepen slope and promote incision; prefer selective toe armouring plus width/sinuosity or setback options rather than blanket riprap.</li> <li>Check whether the bed is supply-limited or mobile; designs that harden long banks can shift adjustment to the bed (armouring/scour), so limit armoured length and maintain conveyance.</li> </ul> |
| 11  | Countermeasure of river bend scour using a combination of submerged vanes and riprap                                                | (Biswas & Barbhuiya, 2018)   | <ul style="list-style-type: none"> <li>Stream bank erosion can be protected using a combination of riprap and vanes, depending on flow pattern and waterway curvature.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 12  | Streambank Protection with Riprap: An Evaluation of the Effects on Fish and Fish Habitat                                            | (Quigley & Harper, 2004)     | <ul style="list-style-type: none"> <li>Several features are thought to contribute to improving rip-rap revetments, including scalloping the low water shoreline; placing large rock at the toe; using rocks larger than required for hydraulic stability; adding spurs; incorporating planting baskets or eco-pockets; or building stepped benches for riparian vegetation</li> <li>Artificially supplementing a channel with spawning gravel could compensate for lowered gravel recruitment or gravel scouring caused by bank protection works. Careful design is required to ensure newly placed substrate will not be flushed out, and gravel may need to be regularly replaced.</li> <li>When a project eliminates off-channel or side channel habitat, or reduces the opportunity for such habitat to form, compensatory habitat should be created, restored, or enhanced.</li> </ul>                                                                                                                                                                             |

# APPENDIX B. BSTEM – RIPRAP MODEL OUTPUTS



## B.1 TOE EROSION MODEL OUTPUT

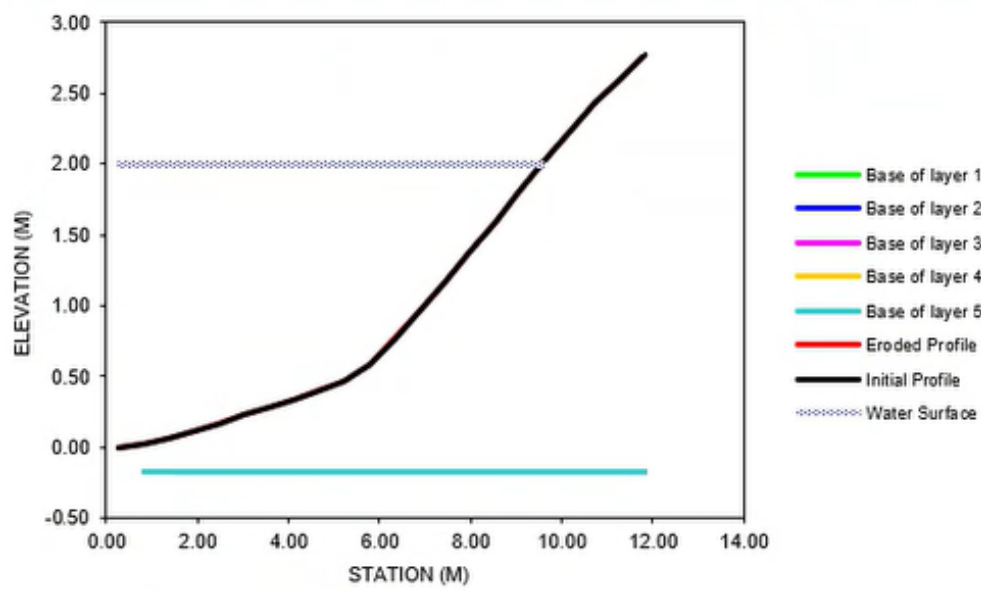


Figure 1-1 BSTEM toe-erosion results for cross-section 1 (XS1)

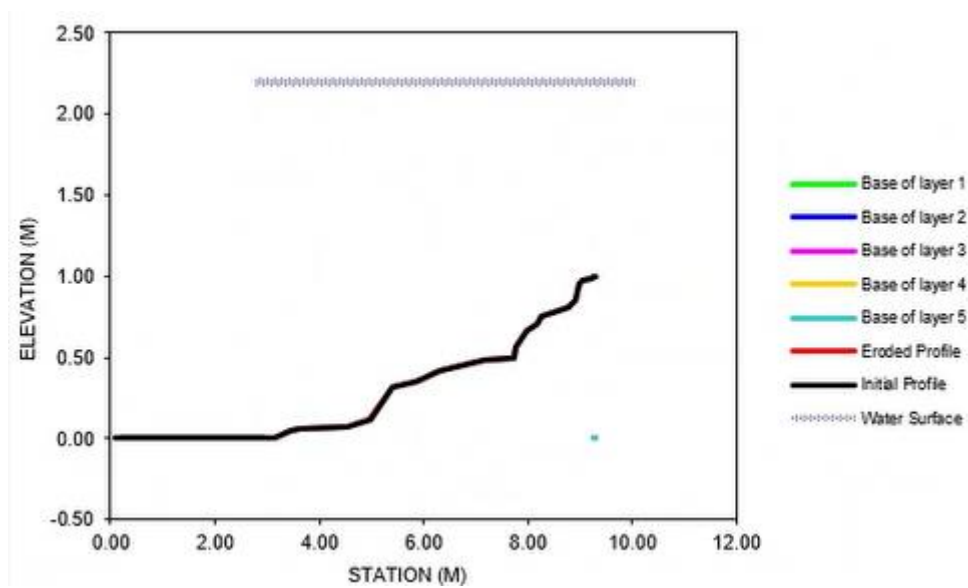


Figure 1-2 BSTEM toe-erosion results for cross-section 2 (XS2)

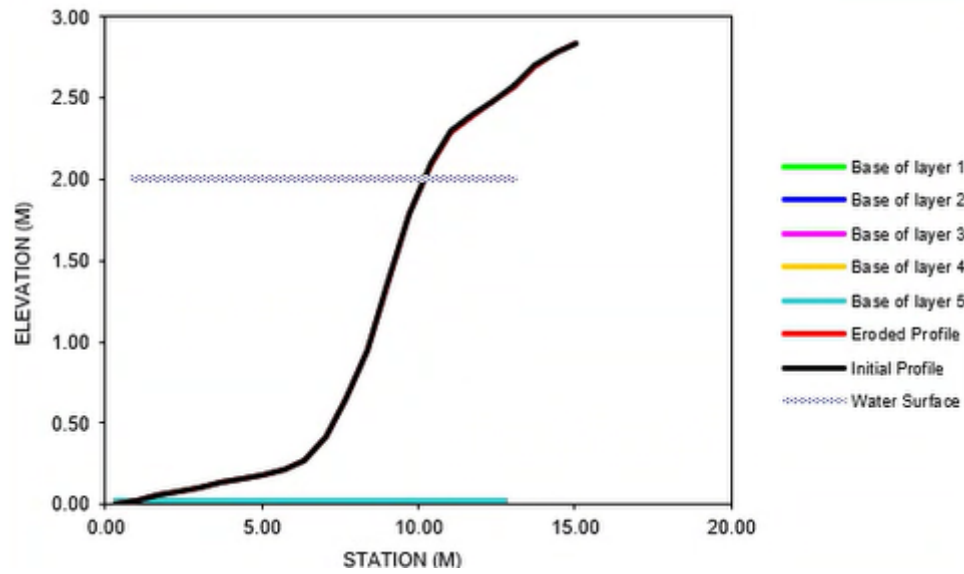


Figure 1-3 BSTEM toe-erosion results for cross-section 3 (XS3)

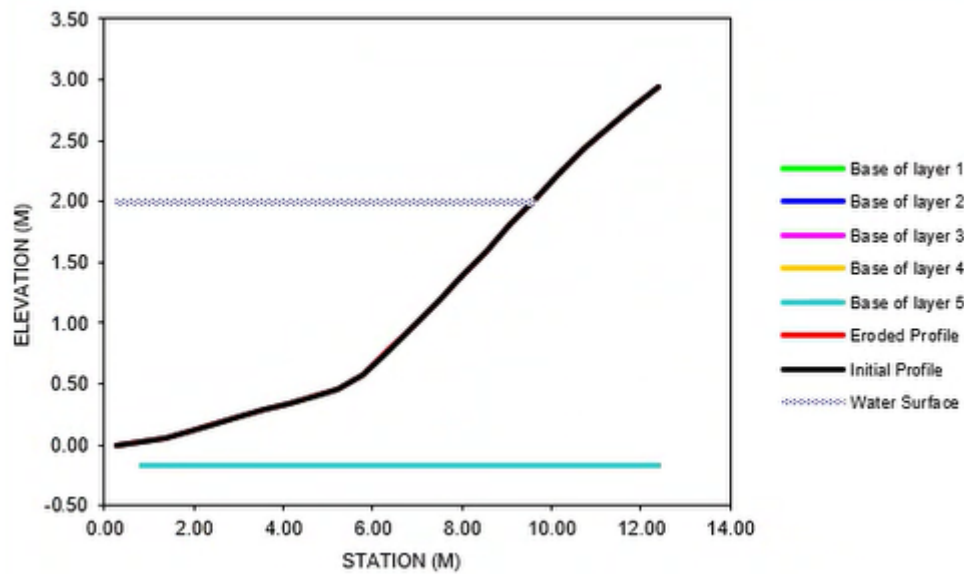


Figure 1-4 BSTEM toe-erosion results for cross-section 4 (XS4)

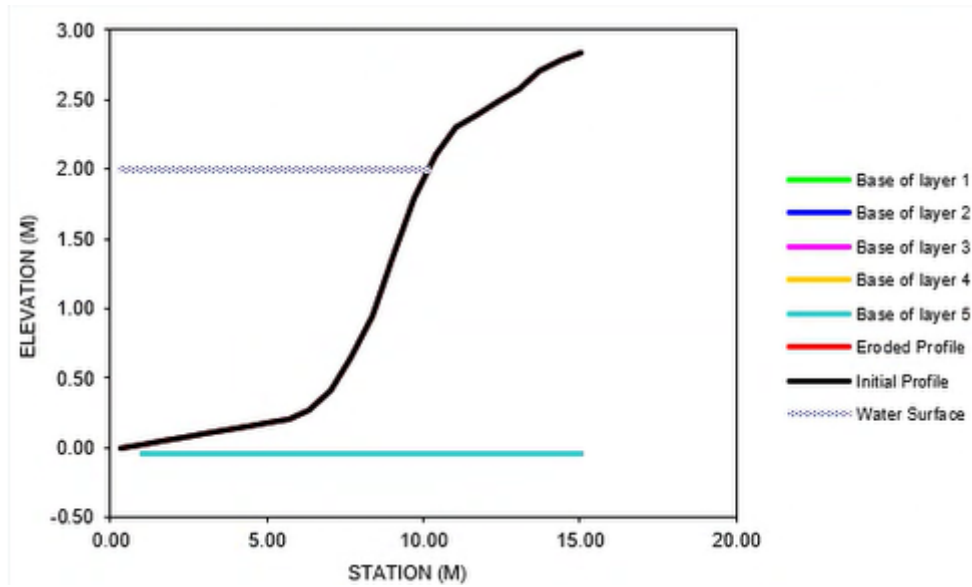


Figure 1-5 BSTEM toe-erosion results for cross-section 5 (XS5)

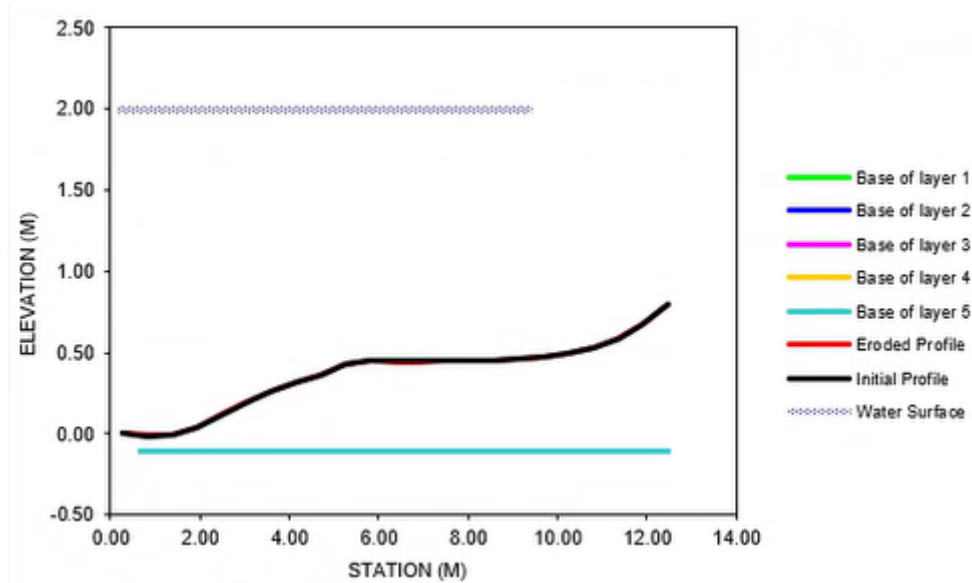


Figure 1-6 BSTEM toe-erosion results for cross-section 5 (XS6)

## B.2 BANK EROSION MODEL OUTPUT

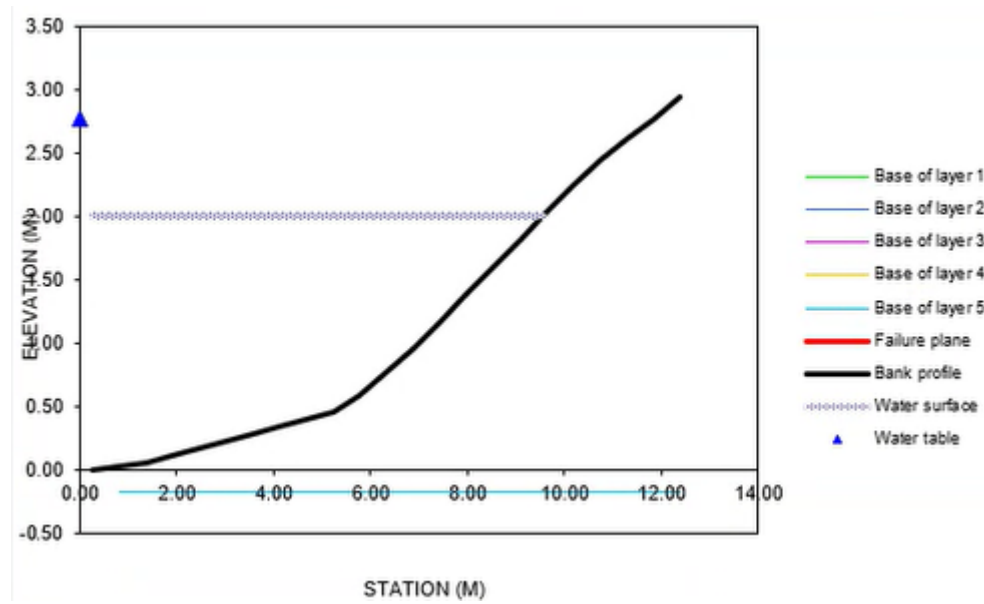


Figure 1-7 BSTEM bank-erosion results for cross-section 1 (XS1)

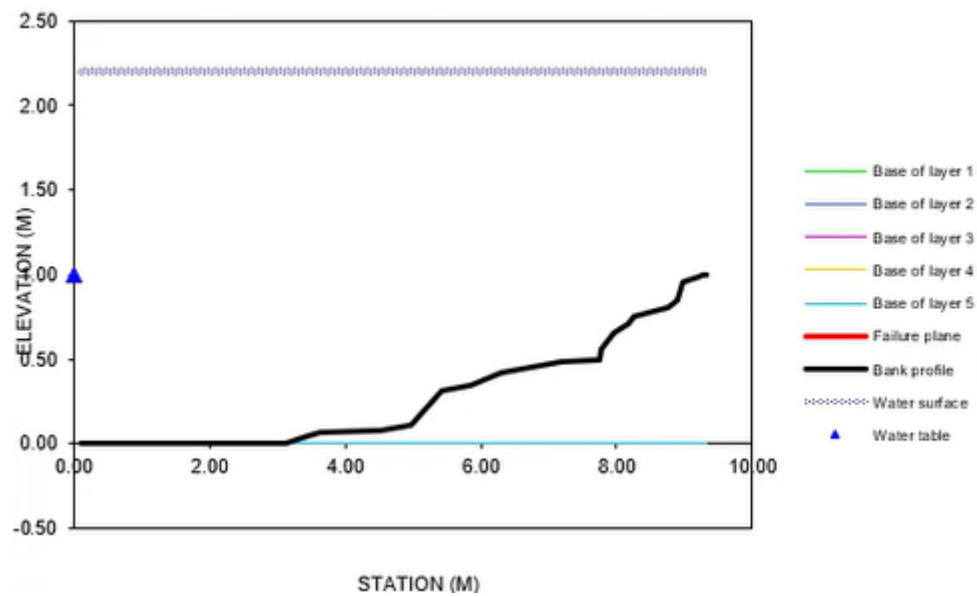


Figure 1-8 BSTEM bank-erosion results for cross-section 2 (XS2)

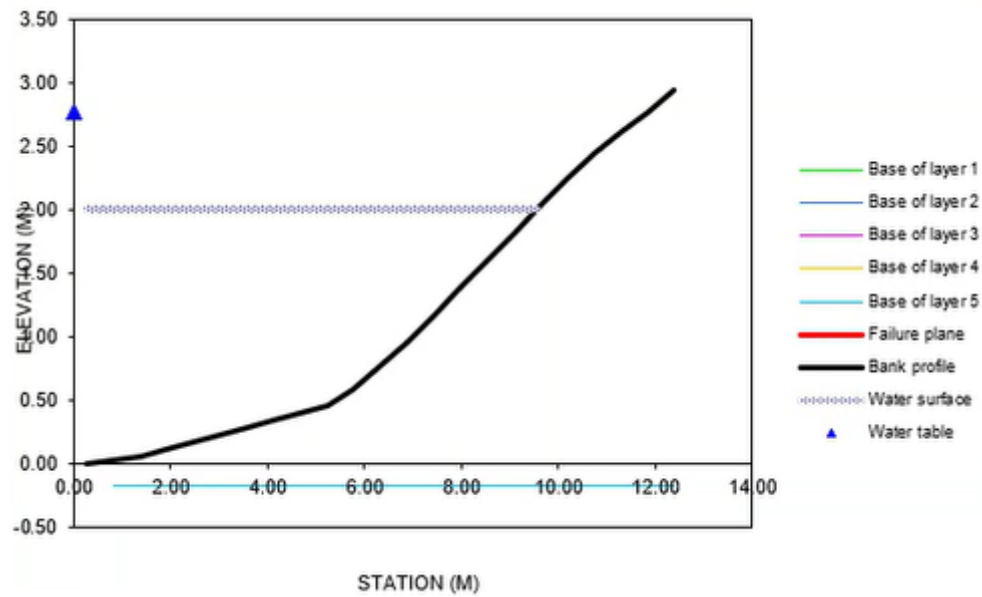


Figure 1-9 BSTEM bank-erosion results for cross-section 3 (XS3)

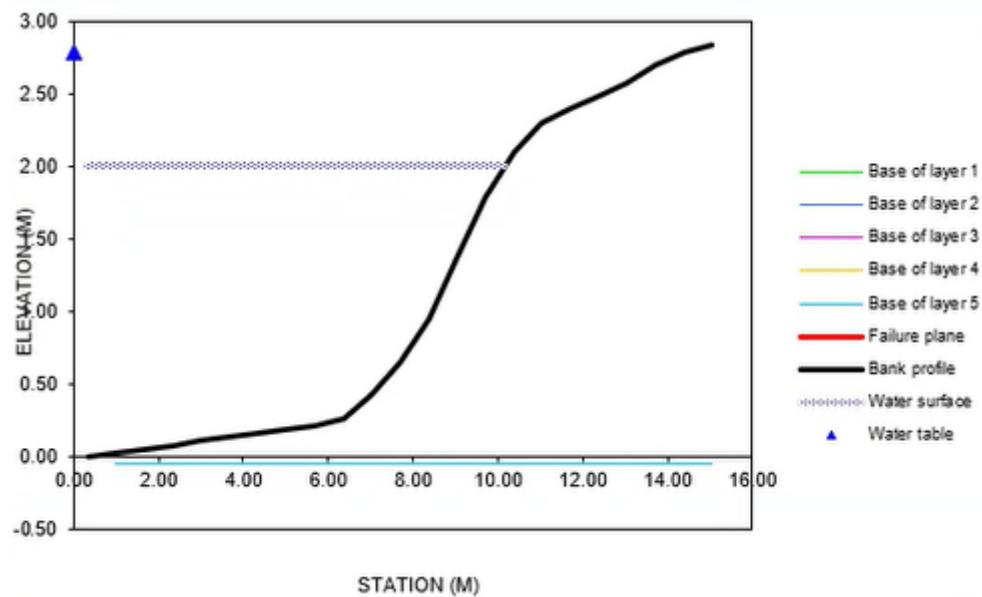


Figure 1-10 BSTEM bank-erosion results for cross-section 4 (XS4)

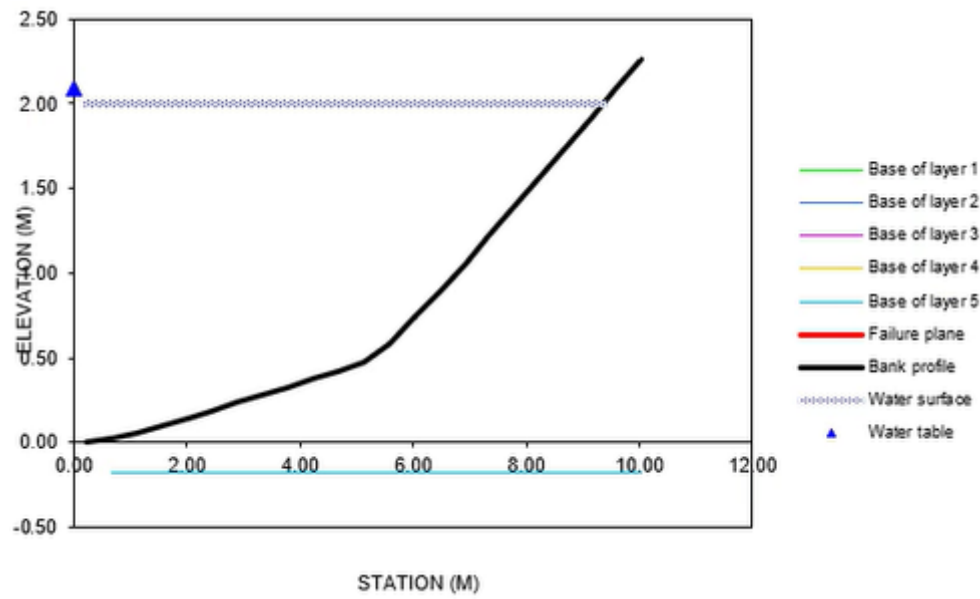


Figure 1-11 BSTEM bank-erosion results for cross-section 5 (XS6)

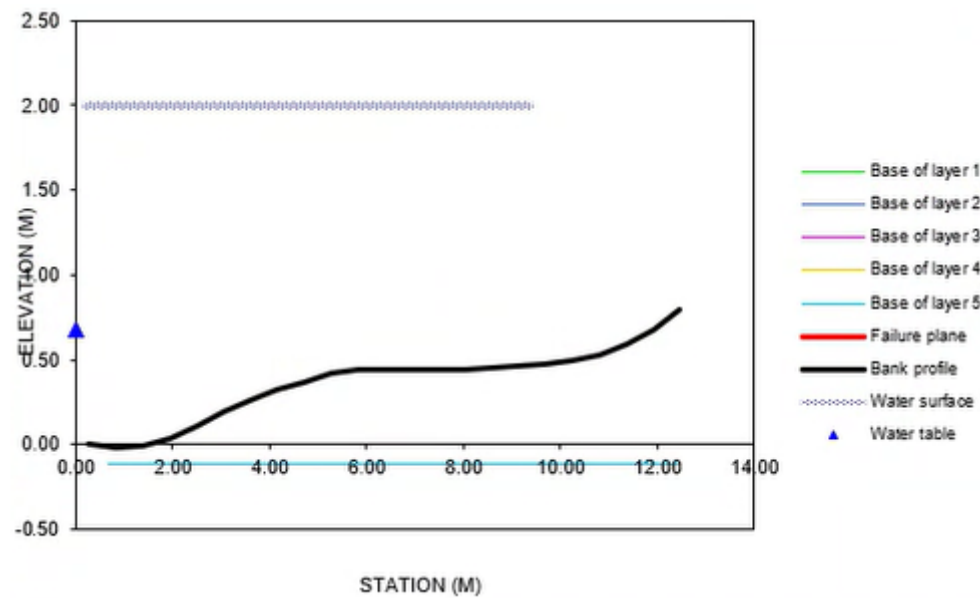


Figure 1-12 BSTEM toe-erosion results for cross-section 5 (XS6)



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