The value of Y' is computed by iteratively solving the semi-logarithmic velocity profile equation:

$$\frac{V}{V_*'} = 6.25 + 5.75 \log \frac{Y'}{K_S} \quad (3)$$

where V = mean velocity at the cross section,

K_s = characteristic roughness of the bed, and

V_*' = shear velocity due to grain resistance given by:

$$V_*' = \sqrt{gY'S} \quad (4)$$

The characteristic roughness height of the bed (K_s) was assumed to be 3.5 D_{84} (Hey, 1979). Normalized grain shear stress (ϕ') is the ratio of the grain shear stress (τ') to the critical shear stress for particle mobilization (τ_c). When ϕ' is equal to 1, the bed material begins to mobilize (point of incipient motion), and substantial sediment transport occurs when ϕ'>1.5 (Mussetter et al., 2001). The concept of equal-mobility, as advanced by Parker et al. (1982) and Andrews (1984), shows that, at ϕ'>1.5, all material up to about five times the median size can be transported by the flow, and measureable transport rates would be expected.

The incipient motion analysis was conducted to evaluate the flows required to mobilize the sampled surface bed material. The hydraulic input to the incipient motion calculations was based on the TUFLOW model results from the 50-, 20-, 10- 5- 2- and 1-percent Annual Exceedance Probability (AEP) simulations (Table 1). To extract this information, representative cross sections were identified for each of the channels where TUFLOW model results were available.

Table 1. Summary of AEP flows for each of the modeled reaches used in incipient motion and sediment continuity analyses.

Reach	Discharge (cms)					
	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP
P1	18.6	13.6	8.7	6.2	4.0	2.2
P2	44.0	35.2	12.7	13.2	7.0	3.1
P3	84.5	68.6	46.0	33.7	20.9	10.4
P4	127.5	81.6	64.0	47.5	28.2	13.3
P5	191.5	137.6	80.7	51.6	29.7	14.5
P6	199.0	142.2	80.8	51.4	29.7	14.4

Reach	Discharge (cms)					
	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP
W1	12.7	9.7	6.5	4.6	3.0	1.7
W2	32.4	24.1	13.3	10.8	5.6	2.8
W3	61.7	53.1	33.6	25.5	15.5	7.5
W4	107.9	85.4	53.7	37.1	22.9	11.4
W5	134.8	104.3	63.4	45.1	26.8	13.0
B1	10.4	7.7	4.8	3.4	1.8	1.0
B2	38.9	29.2	18.2	12.4	7.4	3.6
B3	70.3	51.6	31.1	20.7	11.9	4.8
B4	110.7	81.9	49.9	33.5	20.2	9.5
B5	115.4	86.6	51.8	34.3	19.6	8.5
B6	113.8	80.9	45.7	29.1	16.7	6.9
U1	15.8	12.6	6.1	6.5	4.6	3.1
U2	42.6	32.8	17.7	12.3	8.0	4.2
U3	61.9	46.6	28.5	20.1	12.8	6.7
U4	222.5	166.0	96.0	63.9	37.9	19.0

4.2. Incipient Motion Results

The results of the incipient motion analyses for the individual channels in the Western Hub are provided in the following sections.

4.2.1. Pinarra Creek

The results of the incipient motion analysis for the 6 subreaches of Pinarra Creek are shown in **Figure 23**. Based on the average surface gradation the bed material is not mobilized by flows up to and including the 1%AEP in SR P1, most likely the result of the poorly defined channels in the subreach (Figure 5a). In SR P2, the bed material is just mobilized by about the 5%AEP flow and significant sediment transport takes place at about the 1%AEP flow. In SR P3, the bed material is just mobilized between the 20%AEP and 10%AEP flows and significant sediment transport occurs at the 2%AEP flow. In SR P4, the bed material is just mobilized at about the 10%AEP flow and significant sediment transport occurs between the 2%AEP and 1% AEP flows. Where the channel is confined in the Broadway Gorge (SR P5), the bed material is just mobilized by less than the 50% AEP flow and significant sediment transport occurs at the 20% AEP flow. Less confinement in SR P6 means that the bed material is just mobilized at the 50% AEP flow and significant sediment transport occurs at the 10% AEP flow. Within the limitations imposed by the assumed bed material gradation, the results of the analysis indicate that bed material mobilization takes place roughly at the 10% AEP flows but significant sediment transport is infrequent in the alluvial subreaches (P1-P4) but relatively frequent in the bedrock confined subreaches (P5, P6) which is consistent with what occurs in other channels in the western Pilbara where sediment transport is driven by infrequent, short duration, flood events (Harvey et al., 2014; Tetra Tech 2016).

4.2.2. Western Channel

The results of the incipient motion analysis for the 5 subreaches of the Western Channel are shown in **Figure 24**. Based on the assumed bed material gradation, the bed material in SR W1 is just mobilized at the 5% AEP flow and significant sediment transport requires in excess of the 1% AEP flow. In SR W2, the bed material is just mobilized at the 10% AEP flow and significand sediment transport occurs at about the 1% AEP flow. In SR W3, the bed material is just mobilized at the 2% AEP flow and significant sediment transport requires in excess of the 1% AEP flow. Where the channel is more confined in SR W4, the bed material is just mobilized at the 10% AEP flow and significant sediment transport occurs at the 2% AEP flow. Within the better defined channel in SR W5, the bed material is just mobilized at the 20% AEP flow and significant sediment transport occurs at the 10% AEP flow. Again, within the limitations imposed by the assumed bed material gradation, the results of the analysis indicate that bed material mobilization takes place roughly at the 10% AEP flows but significant sediment transport is infrequent in the less confined subreaches (W1-W3) but more frequent in the more confined subreaches (W4, W5).

4.2.3. Boolgeeda Creek

The results of the incipient motion analysis for the 5 subreaches of Boolgeeda Creek are shown in **Figure 25.** Based on the assumed bed material gradation, it is apparent that very little sediment transport occurs in SR B1, B2 and B3, which is very consistent with the poorly defined cross sections in these subreaches (Figure 13a). However, it is more than likely that some transport of finer material does occur in the upper subreaches of Boolgeeda Creek. Where the channels are better defined in SR B4, B5 and B6 (Figure 13b) the bed material is just mobilized at about the 10 % AEP flows and significant sediment transport occurs at the 1% to 2% AEP flows which is consistent with the other channels in the Western Hub area.

4.2.4. Unnamed 1 Tributary

The results of the incipient motion analysis for the 4 subreaches of Unnamed 1 Tributary are shown in **Figure 26**. Based on the assumed bed material gradation, bed material is just mobilized at the 10% AEP flow and significand sediment transport occurs at the 2% AEP flow in SR U1-1. However, in SR U1-2 the bed material is very infrequently mobilized (>1%AEP flow) and this is probably due to the less confined channel configuration (Figure 15). Where the channel is confined in SR U1-3, the bed material is just mobilized at less than the 50% AEP event and significant sediment transport occurs at all flows in excess of the 50% AEP flow. Similarly, because of the very confined channel in SR U1-4, the bed material is very frequently mobilized and significant sediment transport occurs at all flows in excess of the 50% AEP flow. The results of the analysis tend to suggest that the bed material is more mobile in this tributary than in the other channels of the Western Hub, probably because the slope of the channel (0.0069) is steeper than the other channels that have slopes on the order of 0.0045.

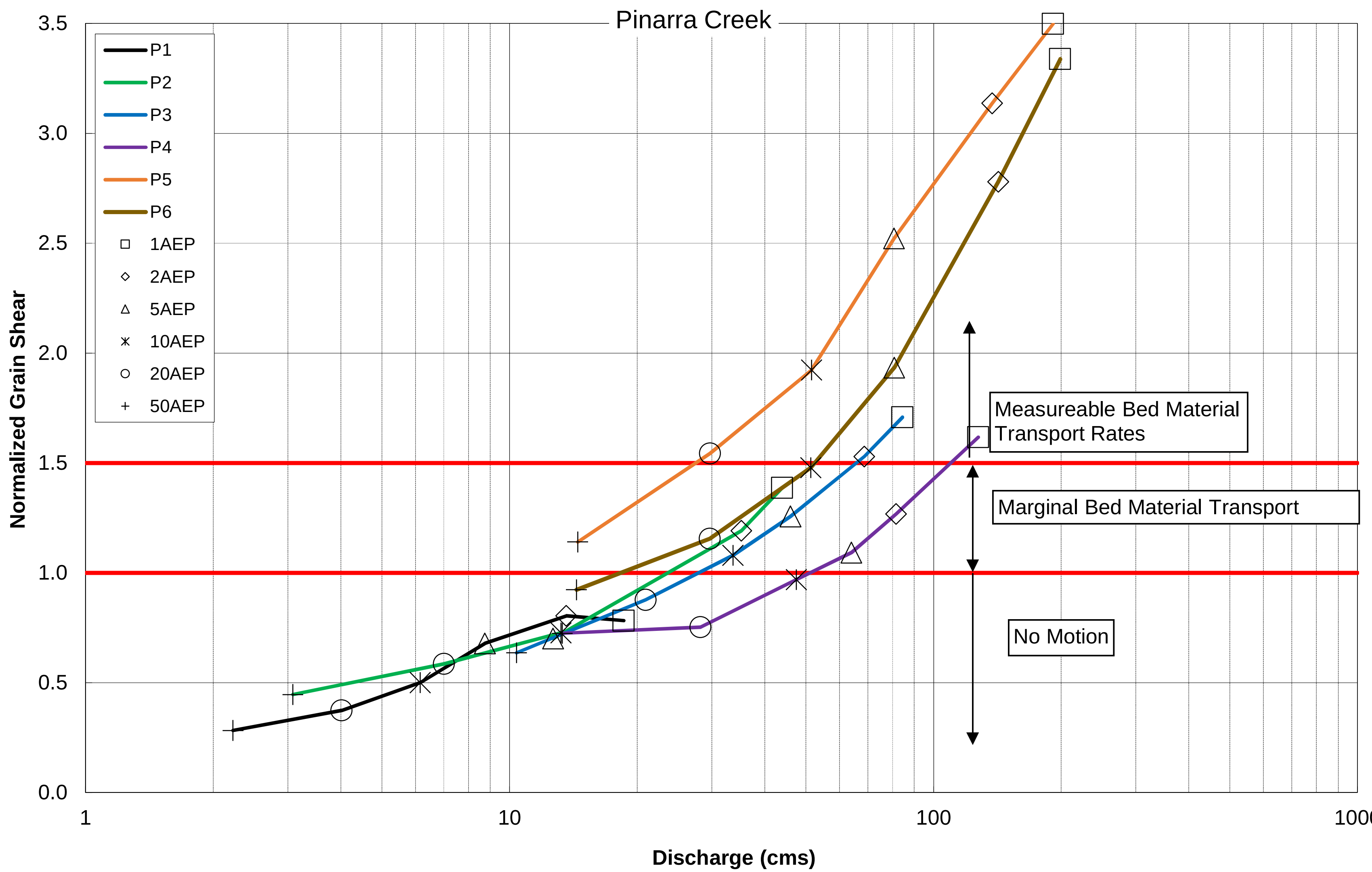

Figure 23. Results from the incipient motion (normalized grain shear) analysis based on TUFLOW model output at selected cross-sections along Pinarra Creek.

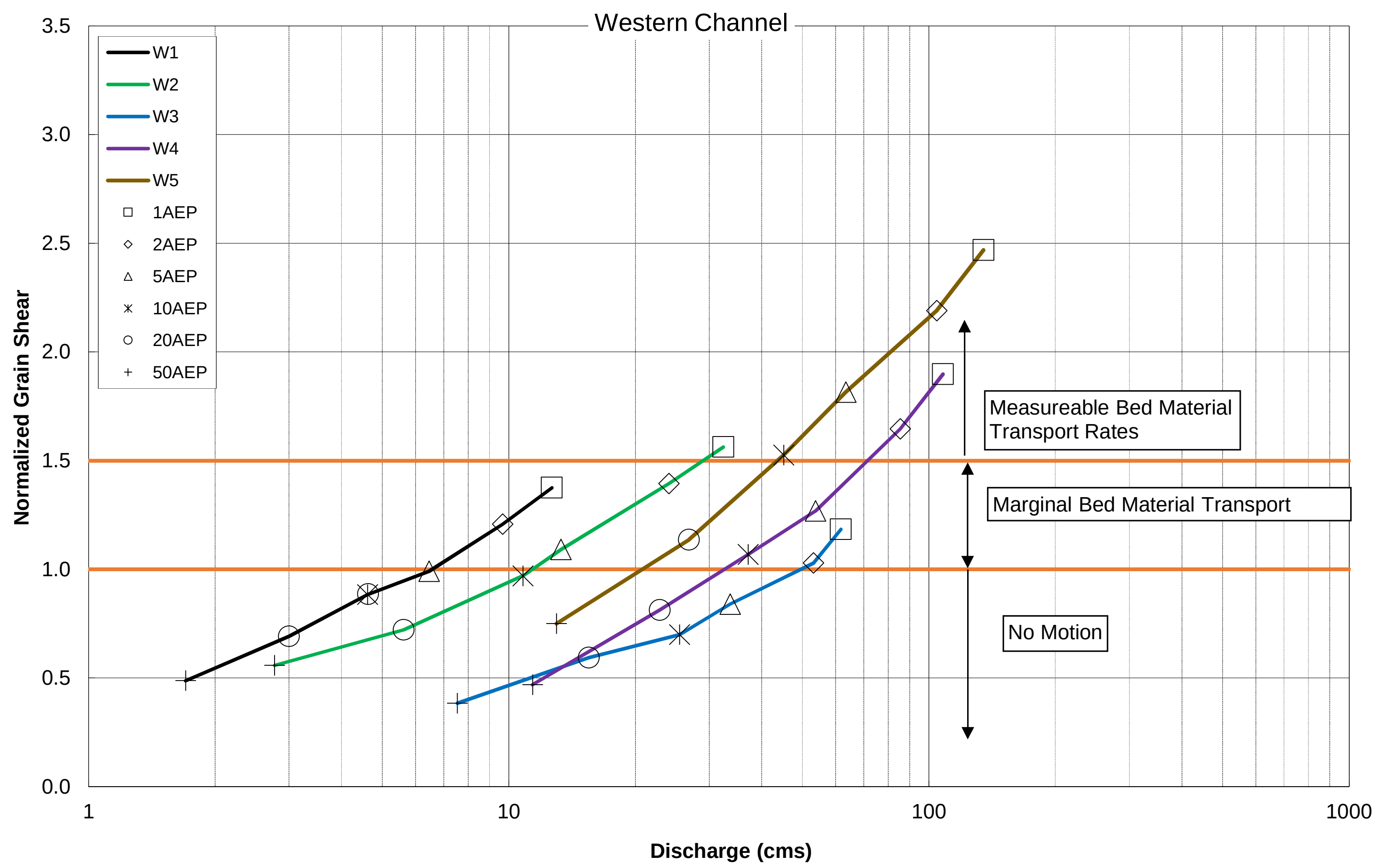

Figure 24. Results from the incipient motion (normalized grain shear) analysis based on TUFLOW model output at selected cross-sections along Western Channel.

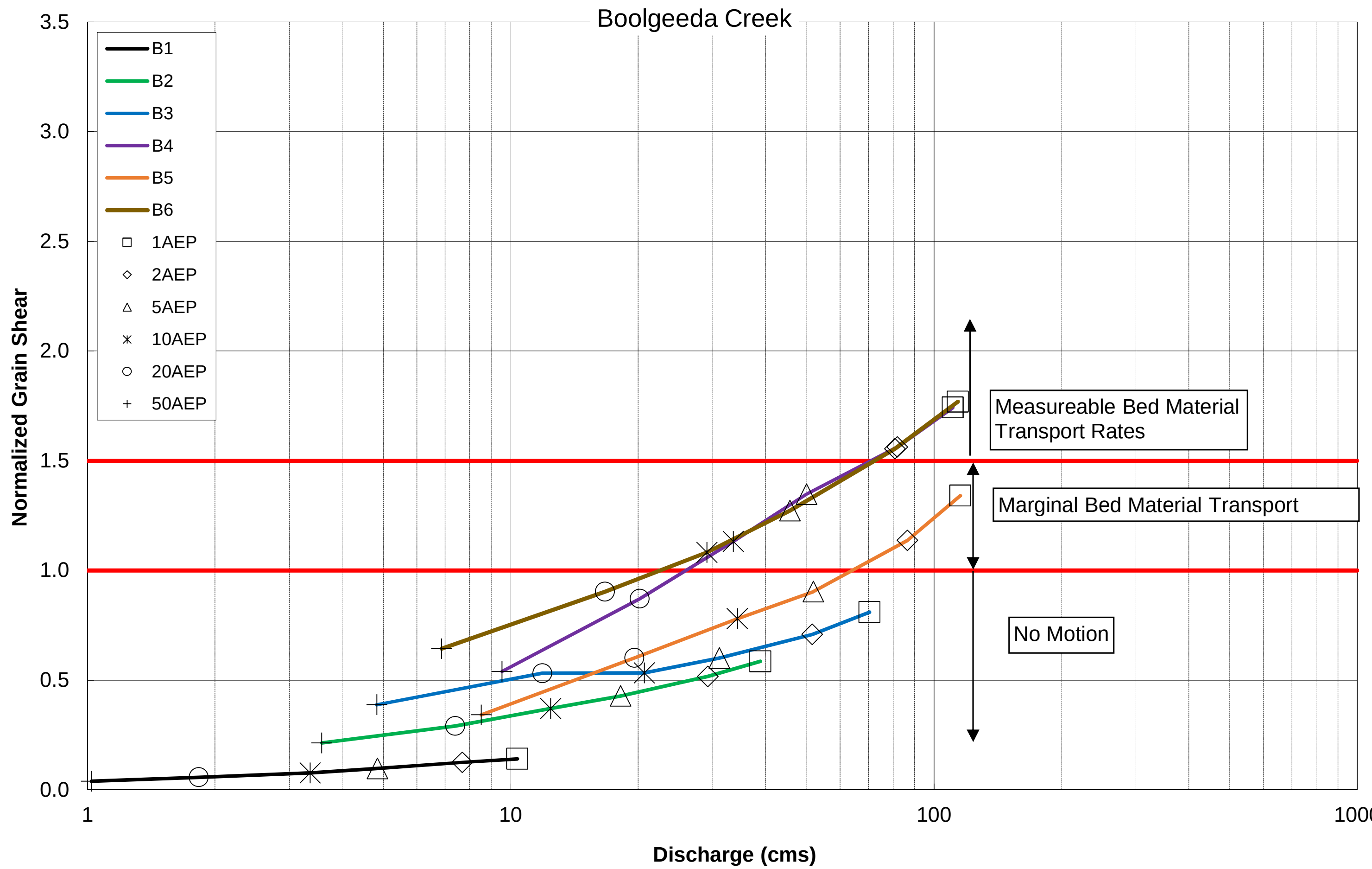

Figure 25. Results from the incipient motion (normalized grain shear) analysis based on TUFLOW model output at selected cross-sections along Boolgeeda Creek.

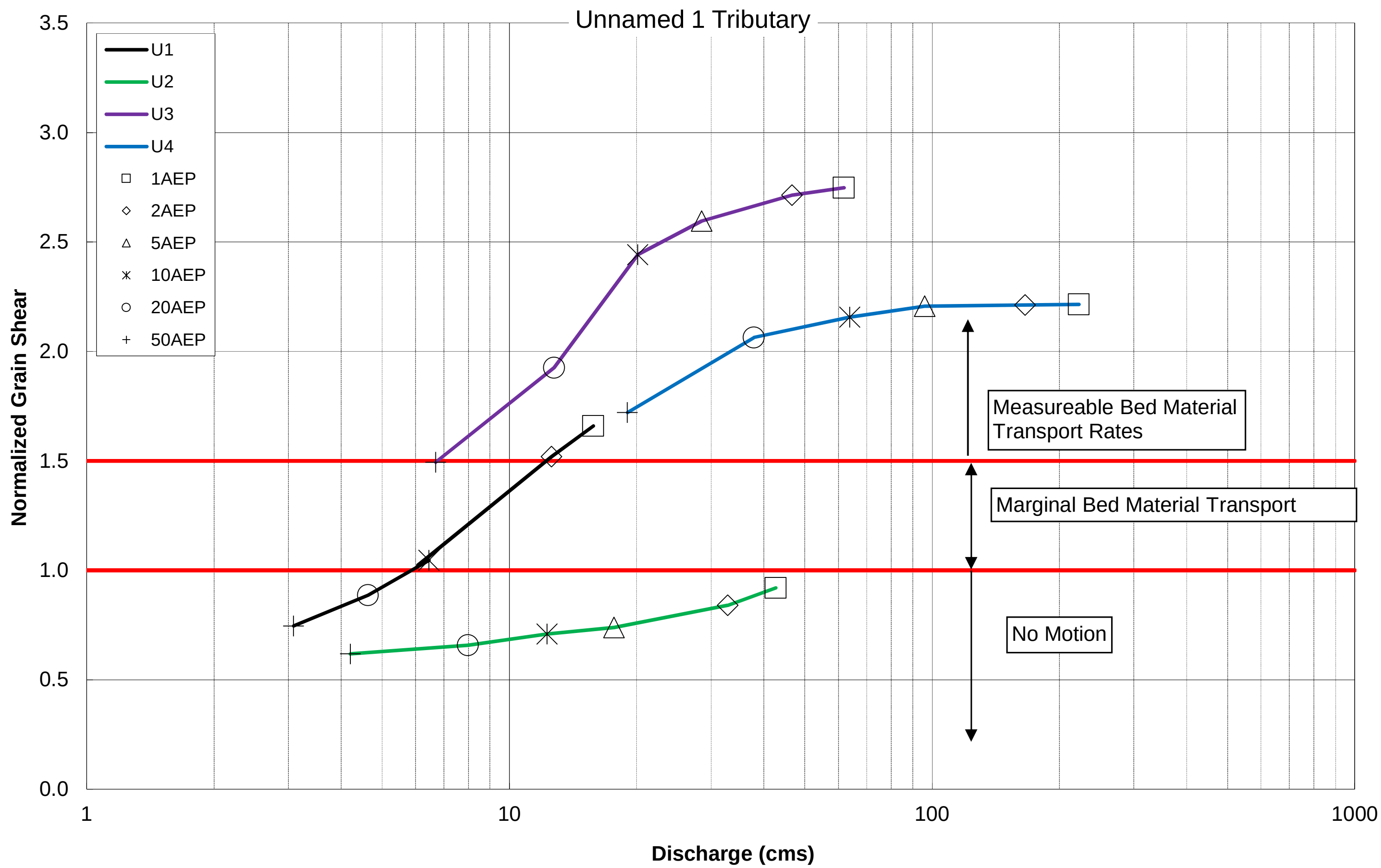

Figure 26. Results from the incipient motion (normalized grain shear) analysis based on TUFLOW model output at selected cross-sections along Unnamed 1 Tributary.

5. SEDIMENT CONTINUITY ANALYSIS

A sediment-continuity analysis was performed using the TUFLOW model output for the 10% AEP event, which is assumed to mobilize the bed material surface gradation, and the averaged subsurface bed material gradation (D_{50} 12mm:Figure 8) for each of the subreaches identified in Pinarra Creek, Western Channel, Boolgeeda Creek and Unnamed 1 Tributary. The sediment-continuity analysis involved selection of an appropriate sediment-transport formula, preparation of sediment-transport capacity rating curves, development of by-storm event (10% AEP) sediment-transport volumes for each of the cross sections to develop subreach-averaged values, and computing sediment continuity between subreaches in a stepwise fashion. The sediment continuity analysis does not incorporate specific erosional and depositional processes but assumes that sediment is available to be transported and the system is not supply-limited. The sediment supply to the upstream reach of each channel is assumed to be equal to the transport capacity of the reach unless field evidence indicates that the channel in the upstream reach is either strongly degradational or aggradational, which was not the case for the Western Hub channels.

5.1. Selection of Sediment-transport Formula

Selection of the formula used to compute the bed-material transport capacity rating curves for the cross sections was based on the range of bed-material sizes, hydraulic characteristics within the modeled reach, and previous experience with similar channels (Harvey et al., 2014; Tetra Tech, 2016). A number of functions are applicable to the bed-material and hydraulic conditions of the Western Hub channels, but most of the functions do not include a method for addressing the effects of hiding of the smaller-size classes by larger-size classes, an important consideration in mixed sand-and-gravel systems similar to those within the Western Hub site. The Wilcock and Crowe (2003) equation considers these hiding effects and was, therefore, selected for use in this analysis.

The Wilcock and Crowe (2003) equation was developed through a series of experiments designed specifically to study the hiding effects and resulting transport of sand/gravel mixtures. The equation computes the bed-material load per unit width by size fraction (q_{bi}) as:

$$q_{bi} = \frac{W_i^* F_i V_*^3}{(s-1)g} \qquad (5)$$

where s = ratio of sediment to water density

F_i = fraction of size i on the bed surface

g = acceleration due to gravity,

V_* = shear velocity given by:

$$V_* = \sqrt{gRS} \qquad (6)$$

where R = hydraulic depth of the main channel, and

$W_i^* = 0.002\,\phi^{7.5}$ for ϕ <1.35

$$W_i^* = 14\left(1 - \frac{0.894}{\phi^{0.5}}\right)^{4.5} \quad \text{for } \phi \geq 1.35 \qquad (7)$$

where ϕ is the ratio of the bed shear stress to the reference shear stress.

The reference shear stress is based on the fraction of sand that is present in the bed material and an experimentally derived hiding function.

Considering the amount of sand present (about 20%) in the sampled subsurface bed materials (Figure 8), it is reasonable to expect that this material is transported as both bed and suspended load. The Wilcock and Crowe bed-load function may exclude an important component of the transported sediment (i.e., the suspended bed-material load), so an evaluation of total bed-material load function is preferred. As a result, the suspended bed-material load was computed using Einstein's (1950) approximation of the vertical sediment concentration profile, which was then added to the bed load predicted by the Wilcock and Crowe function to estimate the total sediment load.

Main-channel averaged hydraulic data from the TUFLOW model and the subsurface bed-material gradation were used as input to the Wilcock and Crowe (2003) equation to develop sediment-transport capacity rating curves for each of the subreaches. The computed sediment-transport capacity rating curves represent the total bed-material sediment-transport capacity, including both the bed and suspended load. It should also be noted that the rating curves represent bulked (with-void) sediment volumes to facilitate the sediment-continuity analysis and prediction of aggradation/degradation volumes.

5.2. Sediment Continuity Results

The results of the sediment continuity analyses for each of the channels evaluated in the Western Hub are provided in the following sections.

5.2.1. Pinarra Creek

The by-subreach sediment rating curves for Pinarra Creek are shown in **Figure 27**. With the exception of the 2 confined subreaches (P5, P6), the transport rates for the range of modeled flows are quite low. In the upstream-most subreach (P1), at the 10% AEP flow the supply and transport capacity are assumed to be equal (**Figure 28**) and as a result the reach is neither aggradational nor degradational (**Figure 29**). However, since the outflow from SR P1 is significantly less than the transport capacity in SR P2 (Figure 28), the net result is that the subreach becomes degradational (Figure 29). In reality, it is more than likely that the bed material would coarsen to compensate for the increased transport capacity. Assuming that SR P2 did degrade, the resulting increased sediment supply to SR P3 (Figure 28) leads to aggradation in SR P3 but the supply and transport capacity become more balanced in the more downstream subreaches (P4, P5, P6) that are very mildly aggradational (Figure 29). The results of the continuity analysis indicate that the channel of Pinarra Creek is neither strongly aggradational nor degradational under existing conditions and this is consistent with the field observations.

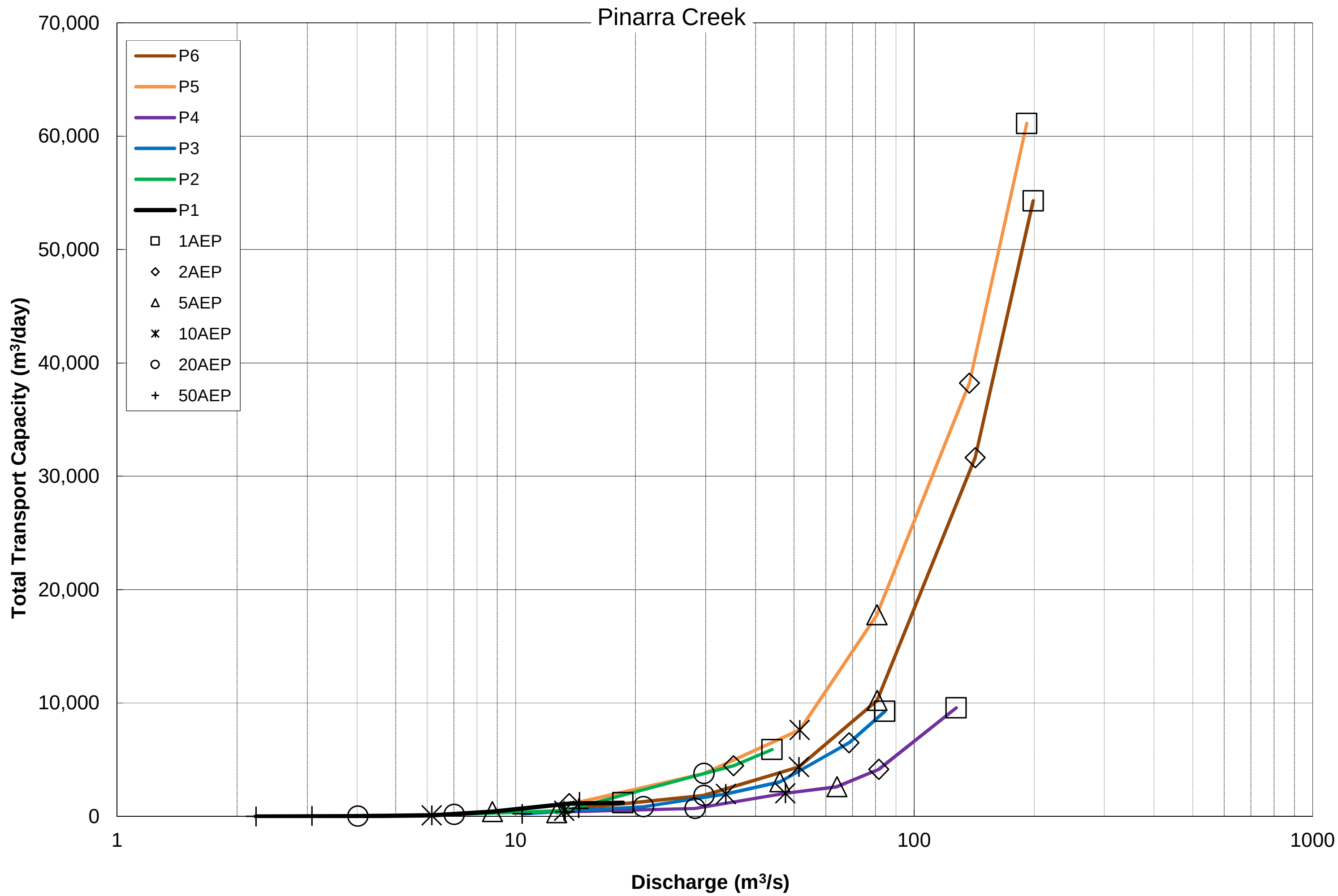

Figure 27. Total bed material sediment-transport capacity rating curves (sediment load as a function of discharge) for the 6 sub-reaches evaluated along Pinarra Creek.

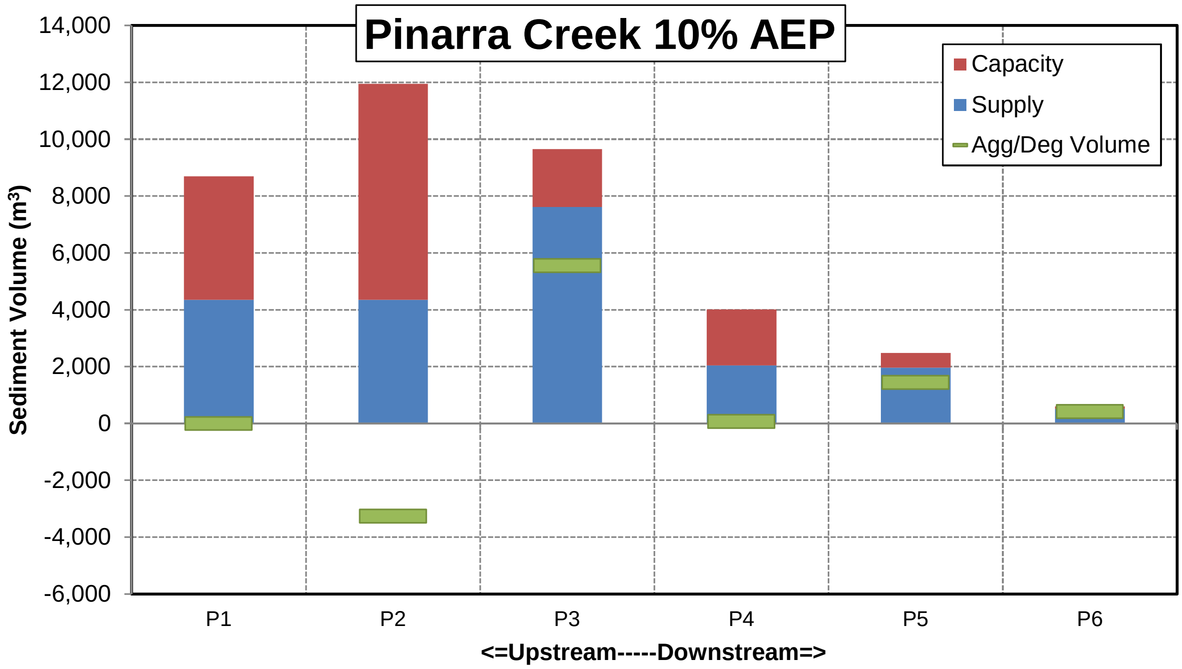

Figure 28. Total sediment supply, transport capacity and the resulting aggradation/degradation volume predicted by the Pinarra Creek sediment-continuity analysis at the 10-percent AEP flow.

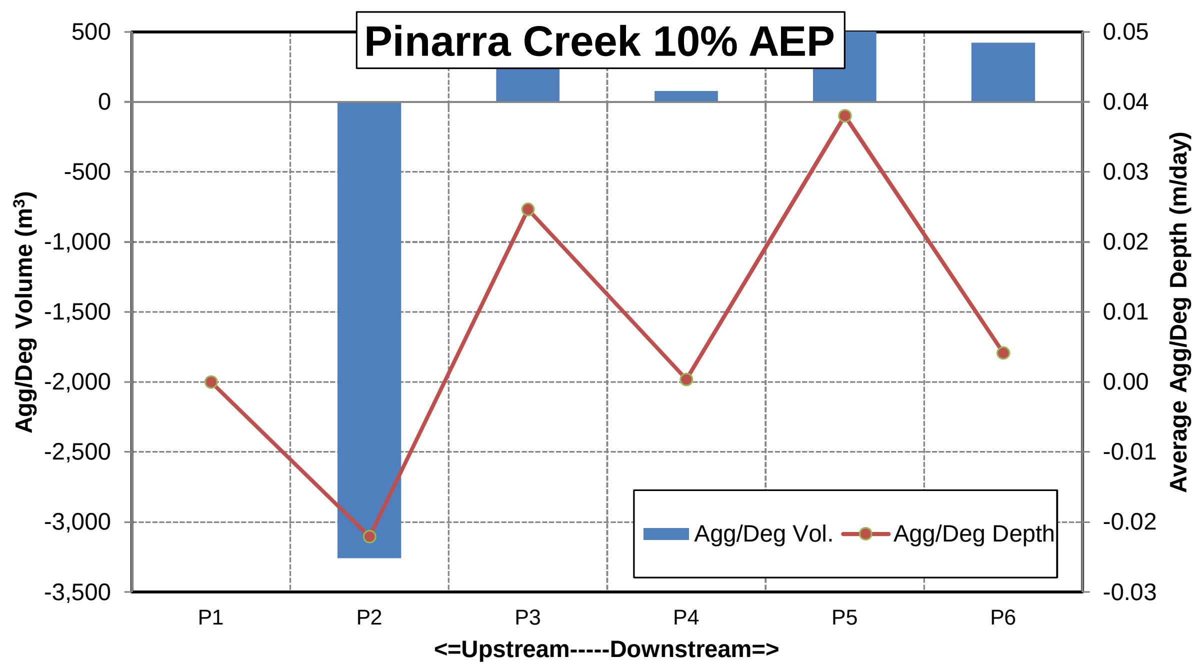

Figure 29. Total sediment supply, transport capacity and the resulting aggradation/degradation volume and depth predicted by the Pinarra Creek sediment-continuity analysis at the 10-percent AEP flow.

5.2.2. Western Channel

The by-subreach sediment rating curves for the Western Channel are shown in **Figure 30**. With the exception of the 2 more confined subreaches (W4, W5), the transport rates for the range of modeled flows are quite low. In the upstream-most subreach (W1), at the 10% AEP flow the supply and transport capacity are assumed to be equal (**Figure 31**) and as a result the reach is neither aggradational nor degradational (**Figure 32**). Subreaches W2 and W4 are mildly degradational while SR W3 is mildly aggradational (Figure 32). However, SR W5 is more strongly degradational because of the well-defined channel (Figure 32). If the channel was in fact strongly degradational the bankfull depth would be greater and there would probably be evidence of extensive channel bank erosion and widening as well. In reality, the channel spanning bedrock outcrops and associated coarser bed material in SR W5 (Figure A.28) would tend to counteract the predicted degradation. The results of the modeling suggest that the Western Channel is neither strongly aggradational not degradational under existing conditions which is consistent with the field observations.

5.2.3. Boolgeeda Creek

The by-subreach sediment rating curves for the Western Channel are shown in **Figure 33**. The transport rates for the 3 upstream-most subreaches (B1, B2, B3) that are very poorly defined (Figure 13a) are very low, but the rates for the well-defined channels in SR B4, B5 and B6 (Figure 13b) are quite a bit higher. Low transport rates at the 10% AEP flow in SR B1, B2 and B3 (**Figure 34**) result in the subreaches being neither aggradational nor degradational (**Figure 35**). However, the imbalance between the inflow from SR B3 and the transport capacity in SR B4 results in the subreach being degradational (Figure 35). In reality the bed material in the subreach would probably coarsen to counter the supply-transport imbalance. Predicted degradation in SR B4 results in aggradation in SR B5 (Figure 35) but in all likelihood the coarsening of the upstream bed material would regulate the downstream supply and supply and transport capacity in SR B5 would be very similar. This would likely have a flow-on effect to SR B6 which is predicted to be slightly degradational (Figure 35). The results of the modeling suggest that the Boolgeeda Creek is neither strongly aggradational not degradational under existing conditions.

5.2.4. Unnamed 1 Tributary

The by-subreach sediment rating curves for the Unnamed 1 Tributary are shown in **Figure 36**. The transport rates for the 2 upstream-most subreaches (U1-1, U1-2) that are poorly defined are quite low, but the rates for the well-defined channels in SR U1-3 and U1-4 (Figure 15) are quite a bit higher. At the 10% AEP flow, the upstream subreaches, U1-1 and U1-2 are neither aggradational nor degradational (**Figure 37**). However, SR U1-3 is somewhat degradational (**Figure 38**) because of the better defined channel (Figure 15). Subreach U1-4 is a deeply incised reach of Boolgeeda Creek Tributary and as the sediment rating curves show has a high potential sediment transport rate. Whether the channel will degrade or not depends on the caliber of the bed material and adjacent narrow sections of the channel indicate the potential for significant bed material coarsening in response to any sediment imbalance (Figure A.37). The results of the modeling suggest that the Unnamed 1 Tributary is neither strongly aggradational not degradational under existing conditions which is consistent with the field observations. However, local baselevel change as a result of a recent avulsion can lead to headcutting and upstream incision (Figure A.42).

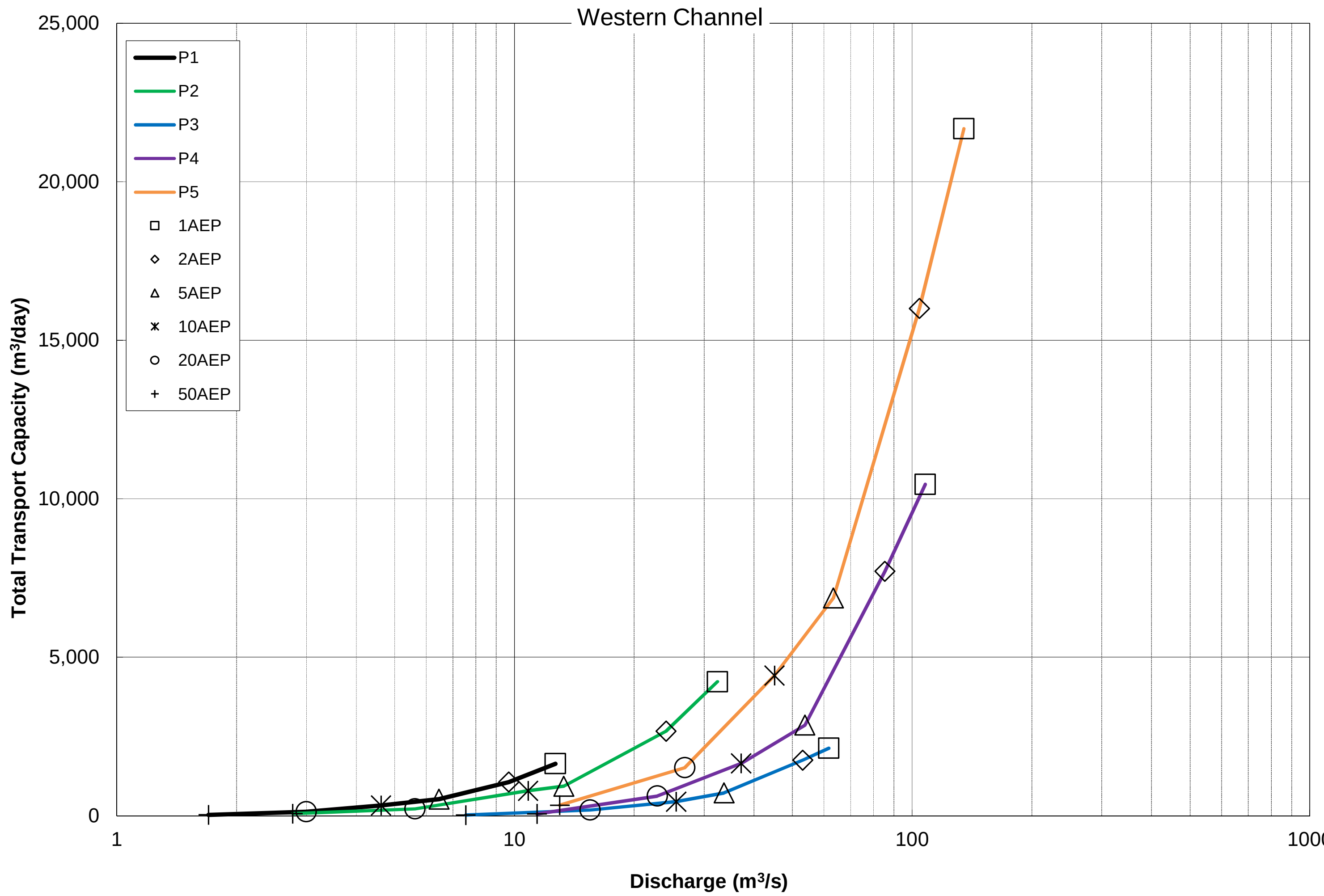

Figure 30. Total bed material sediment-transport capacity rating curves (sediment load as a function of discharge) for the 5 sub-reaches evaluated along Western Channel.

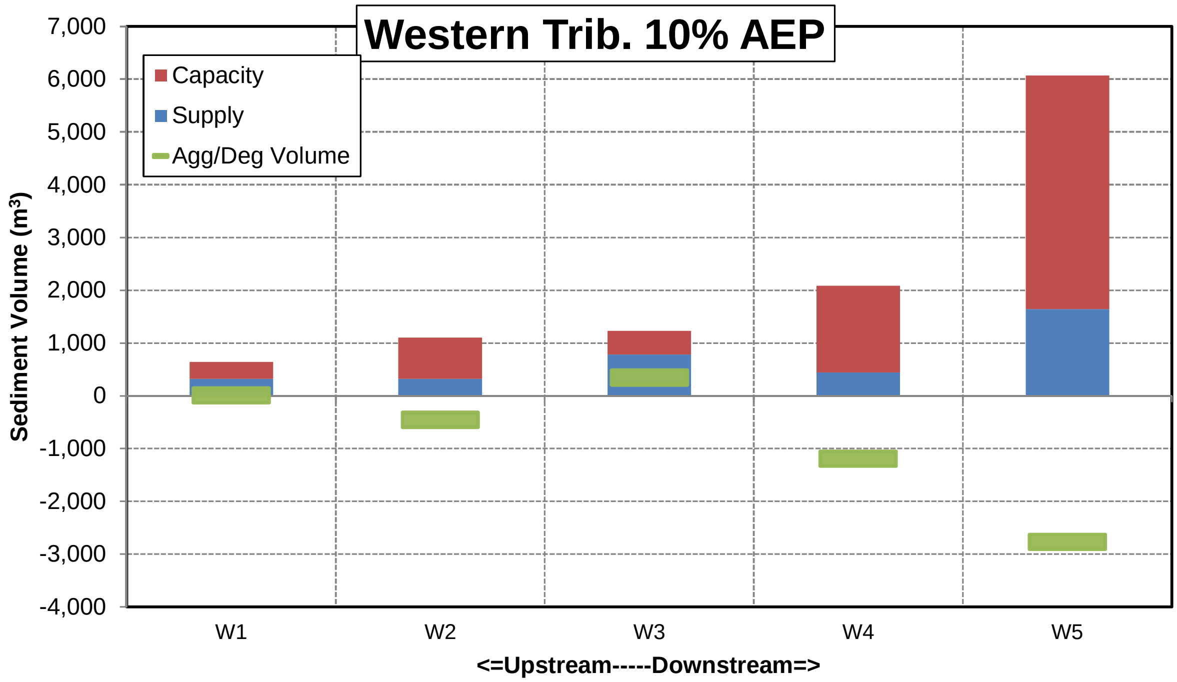

Figure 31. Total sediment supply, transport capacity and the resulting aggradation/degradation volume predicted by the Western Channel sediment-continuity analysis at the 10-percent AEP flow.

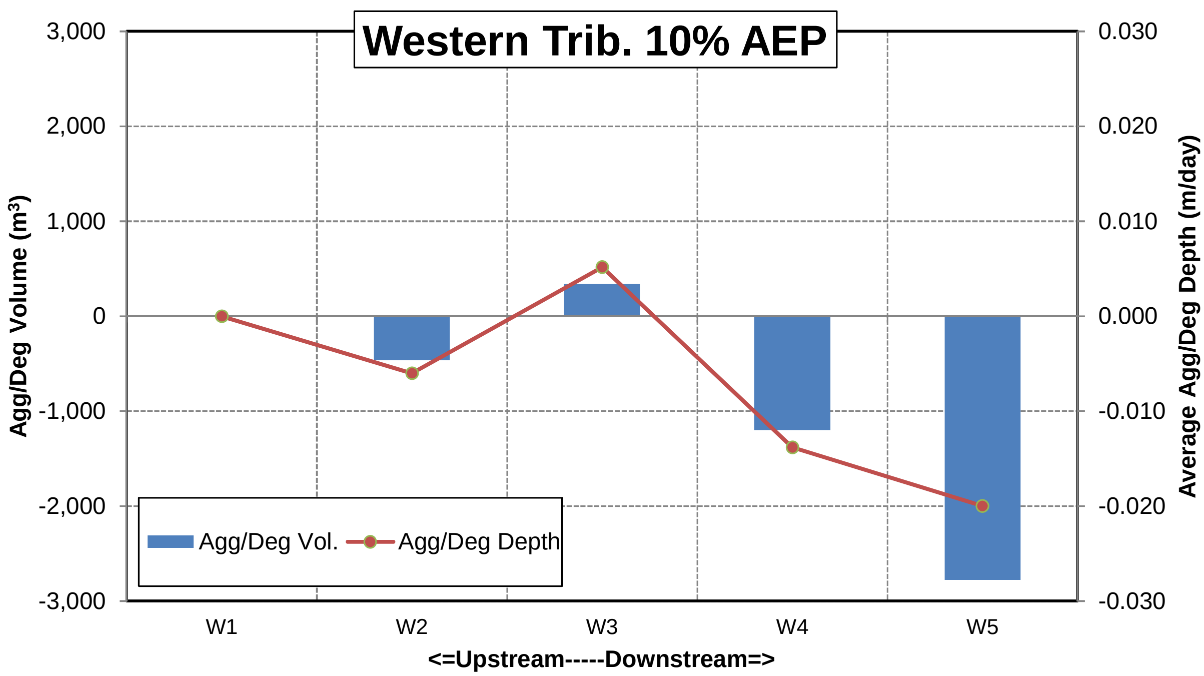

Figure 32. Total sediment supply, transport capacity and the resulting aggradation/degradation volume and depth predicted by the Western Channel sediment-continuity analysis at the 10-percent AEP flow.

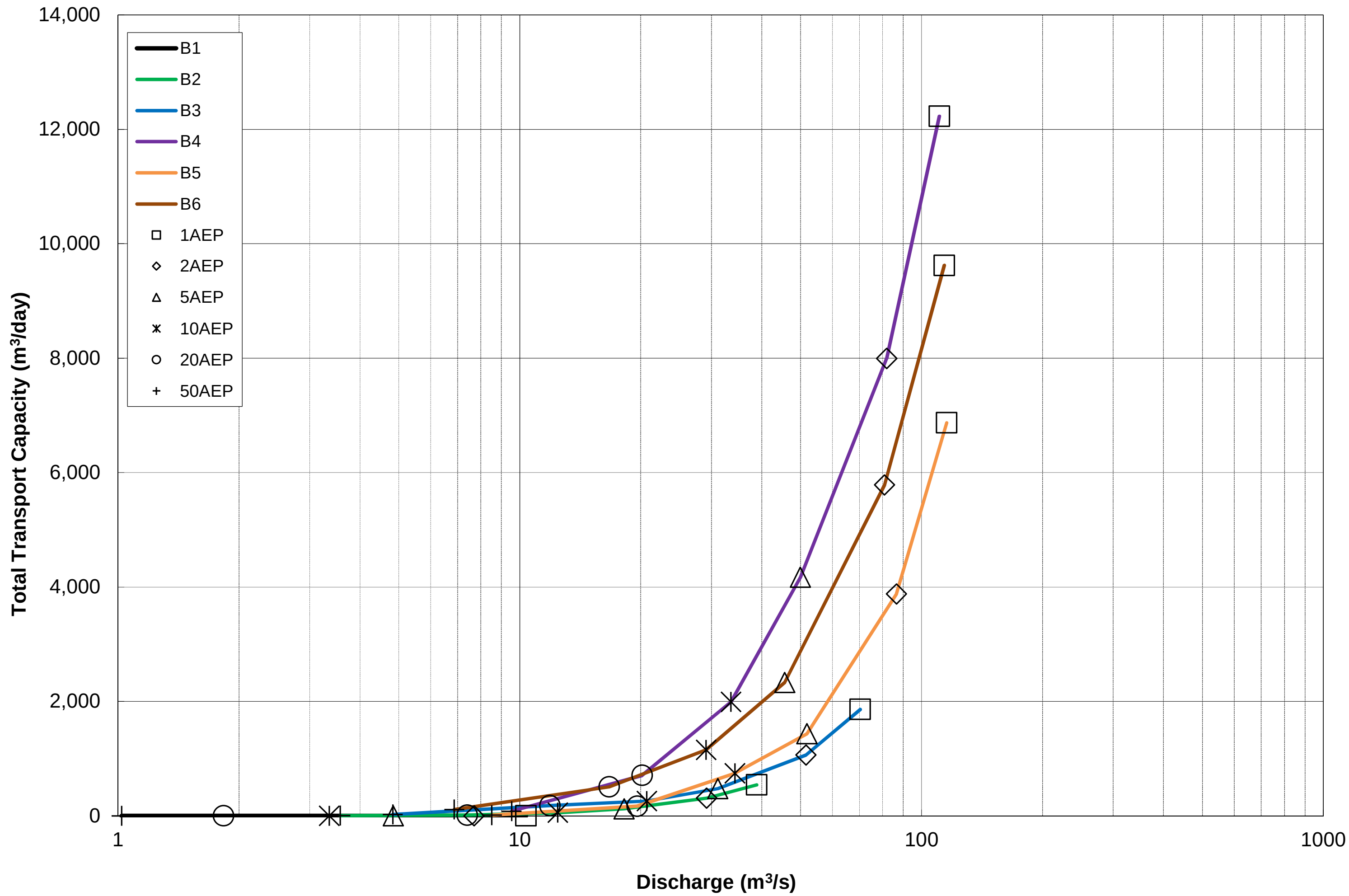

Figure 33. Total bed material sediment-transport capacity rating curves (sediment load as a function of discharge) for the 6 sub-reaches evaluated along Boolgeeda Creek.

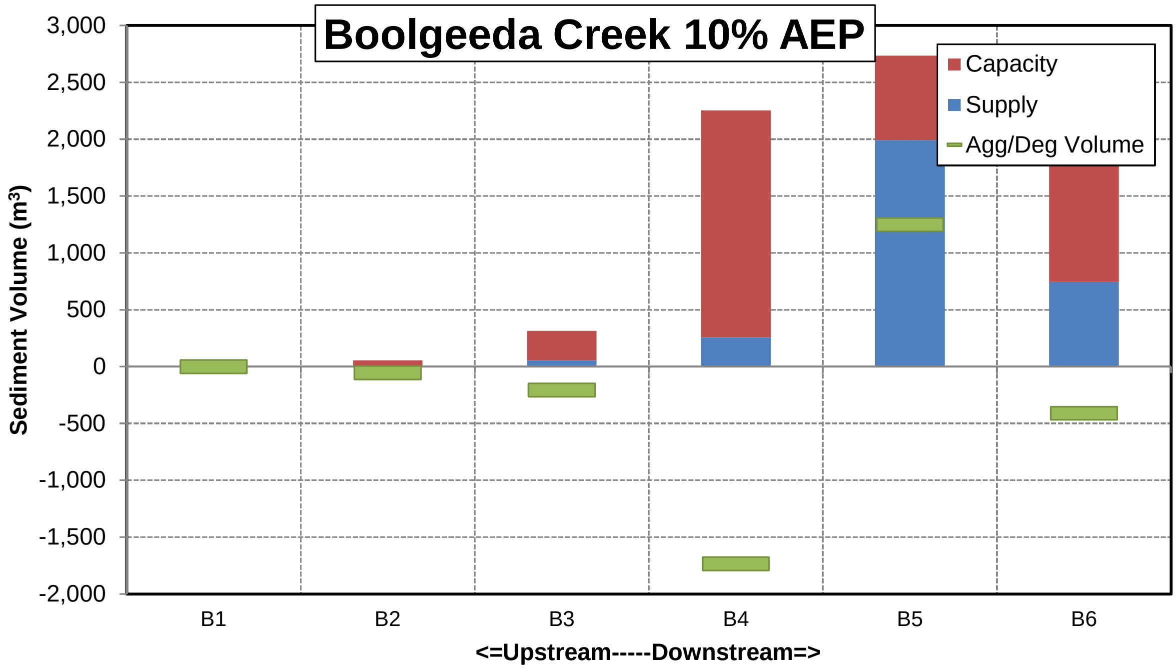

Figure 34. Total sediment supply, transport capacity and the resulting aggradation/degradation volume predicted by the Boolgeeda Creek sediment-continuity analysis at the 10-percent AEP flow.

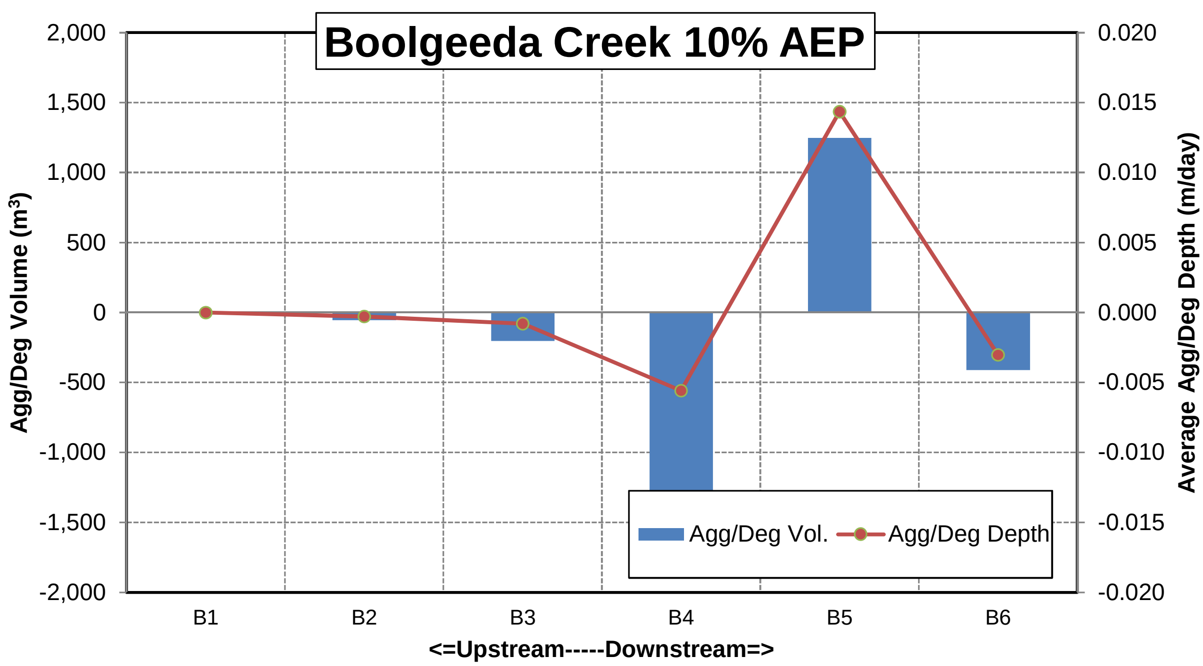

Figure 35. Total sediment supply, transport capacity and the resulting aggradation/degradation volume and depth predicted by the Boolgeeda Creek sediment-continuity analysis at the 10-percent AEP flow.

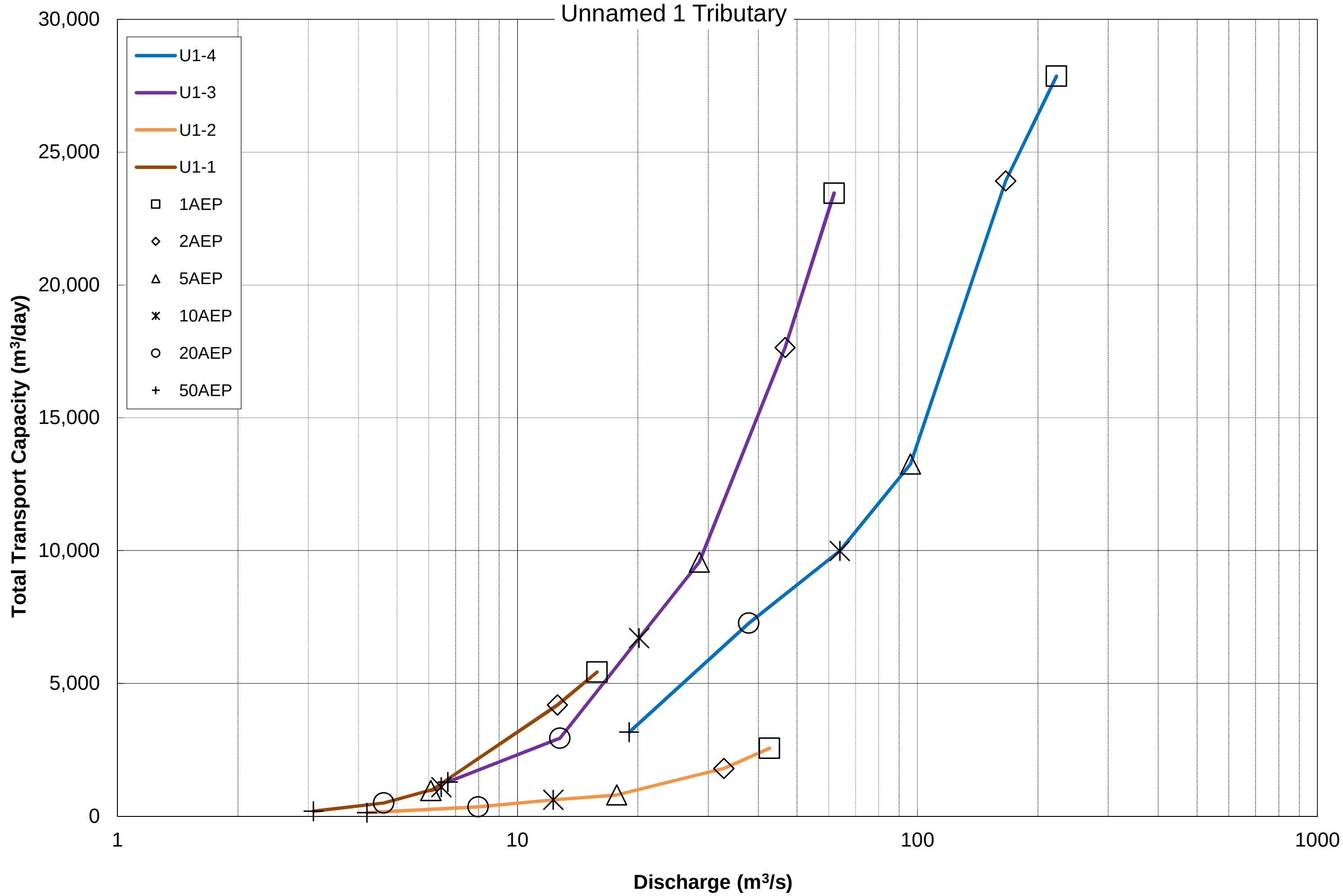

Figure 36. Total bed material sediment-transport capacity rating curves (sediment load as a function of discharge) for the 4 sub-reaches evaluated along Unnamed 1 Tributary.

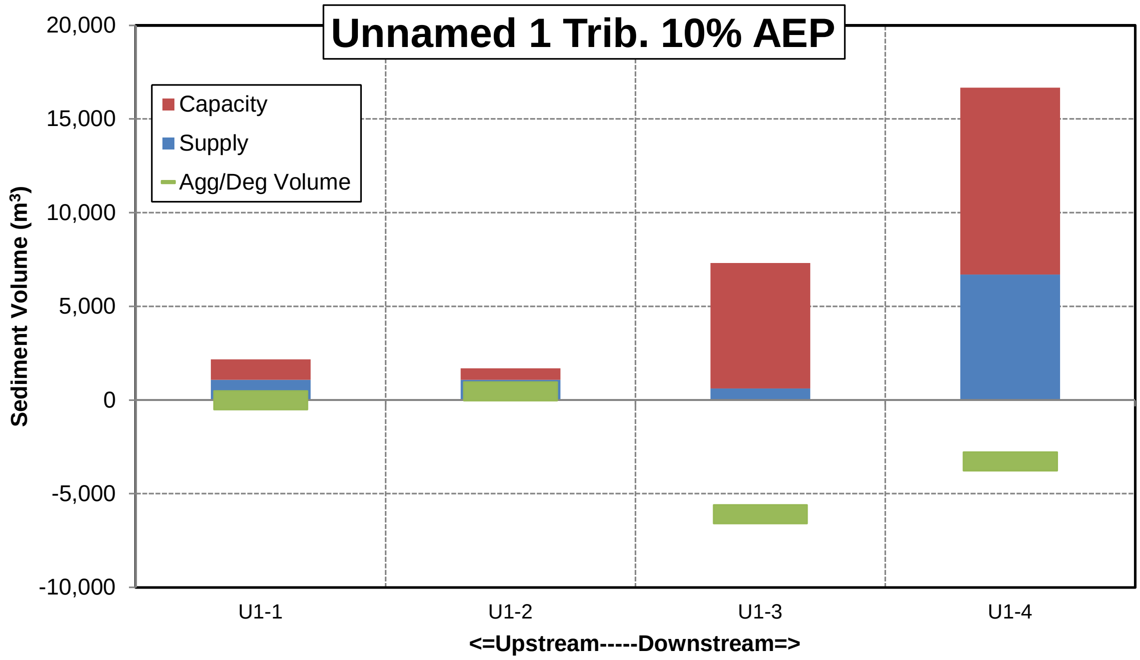

Figure 37. Total sediment supply, transport capacity and the resulting aggradation/degradation volume predicted by the Unnamed 1 Tributary sediment-continuity analysis at the 10-percent AEP flow.

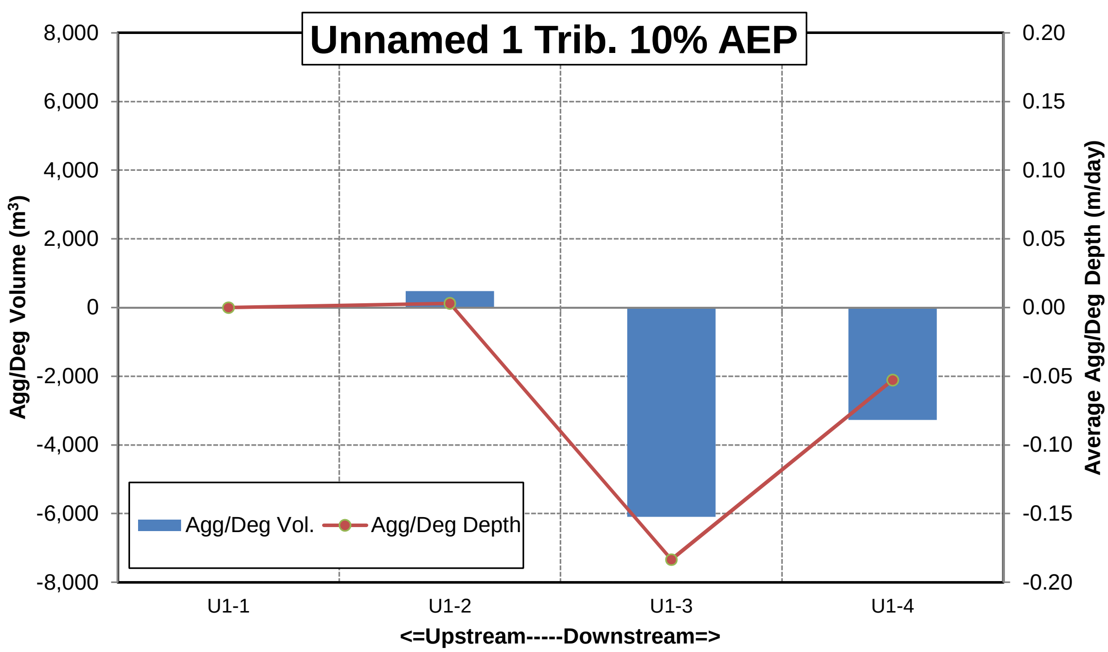

Figure 38. Total sediment supply, transport capacity and the resulting aggradation/degradation volume and depth predicted by the Unnamed 1 Tributary sediment-continuity analysis at the 10-percent AEP flow.

6. CONCLUSIONS

The objective of this reconnaissance-level study was to develop a baseline geomorphic characterization of the channels within the Western Hub project footprint. The study has involved a desktop assessment based on information (pit shells, infrastructure locations, aerial photography, still and video photography) and data (topography, overburden depths, hydrology, TUFLOW model hydraulic output) provided by FMG, a 3-day field based site reconnaissance in which a number of the major channels and their tributaries were observed and that included sampling of both surface and subsurface bed materials, and a preliminary analysis of sediment transport processes. Site hydrology in general is based on a preliminary assessment conducted for FMG by MWH (2011), but the values used in the TUFLOW modelling have been refined by FMG (Table 1). The site geology and groundwater conditions are based on an assessment conducted by Golder Associates (2017) for FMG.

Based on this preliminary assessment of the baseline geomorphic characteristics of the channels within the Western Hub footprint the following can be concluded.

1. There is a high degree of structural control of the drainages in the Western Hub. The majority of the channels where mining is proposed are located within E-W trending strike valleys where there is a high degree of bedrock control including the presence of a number of generally NW-SE trending cross-cutting dolerite dikes and strike-slip faults that may be affecting the depth of overburden along the valley axes occupied by the channels as well as the groundwater.

2. The erosion resistance of the rock units that form the gorges where streams flow down-dip (south) through bounding ridges governs whether the gorge sections create significant baselevel controls for the upstream reaches. Where the rocks are erosion resistant the gorges are narrow and there is extensive bedrock outcrop and large colluvial boulders in the channels. Where the rocks are less erosion resistant the gorges are wider and the valley floor is composed of alluvium.

3. Sediment yields from the areas underlain by the ridge forming, Marra Mamba Iron Fm. and Brockman Iron Fm. geological units are low; the result of extensive presence of bedrock outcrop and gravel armored slopes. Sediment yields from the softer, valley forming rocks (e.g.; Wittenoom Fm., Jeerinah Fm.) are likely to be somewhat higher, but have yet to be quantified.

4. In common with other regions of the Pilbara, the hydrology of the Western Hub catchments is dominated by infrequent, large magnitude, short duration, geomorphically-effective floods that are generated by Tropical Cyclones. Evidence of these floods, including large woody debris piles, imbricate boulders and impact scars on trees, is common in all of the observed channels.

5. Regardless of the channel being considered, the channel characteristics are highly variable spatially. Multi-channel segments tend to be located where the valley floor is less confined. Single channel segments tend to be located where the valley floor is narrower. Where confinement is created by marginal alluvial fans the valley floors tend to be wider and the channels tend to be multi-thread. In contrast, where the confinement is created by soft-rock

pediments and bedrock outcrop the valley floors are narrower and the channels tend to be single thread.

6. In flow expansion zones downstream of the gorges, poorly defined, very coarse grained and heavily vegetated channel segments create self-reinforcing valley floor fans that result in stepped channel profiles and regulate the downstream transport of the larger clasts.

7. Overburden depths under most of the channels where data are available are quite shallow and are frequently less then 10m in depth. The shallow depth of the overburden appears to correlate quite well with the presence of potential GDE riparian vegetation and may suggest that the vegetation is maintained by shallow alluvial aquifers.

8. Where the channels are well defined, initiation of bed material motion occurs at about the 10% AEP flow, which is consistent with the results from other channels in the western Pilbara including Caves Creek (Harvey et al., 2014) and Trinity, Kangeenarina and Zalamea Creeks within the Solomon Hub (Tetra Tech, 2016).

9. The results of the sediment continuity analysis indicate that the channels in the Western Hub under existing conditions are neither aggradational nor degradational which is generally supported by the field observations. Areas of locally high transport capacity are modulated by the presence of bedrock outcrop or coarser bed material.

10. Provided that channel crossings of the tributaries to Duck Creek and Caves Creek for the proposed railway corridor do not significantly affect the continuity of sediment transport, there are unlikely to be any significant downstream geomorphic impacts.

11. Any changes to the flow diversions to either Caves Creek or Weelamurra Creek as a result of construction of the proposed FMG railway corridor to the east of the existing Rio Tinto railway corridor is highly unlikely to have any significant effects on the morphology or stability of the stream channels because of the extensive presence of calcrete in the area and the apparently very low bed material load in the calcrete-dominated channels that traverse the cracking clay grasslands.

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Appendix 3: Eliwana Mine Project Hydrology Study

Fortescue
The New Force in Iron Ore

Report

Hydrology Study

Eliwana Mine Project

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1. INTRODUCTION

This appendix report has been prepared to supplement the Eliwana Mine Project Surface Water Impact Assessment Report. The report describes the hydrologic and hydraulic investigations supporting a Surface Water Impact Assessment for the proposed Eliwana Project.

Outlined is the process developed to characterise surface water flows around the Eliwana project area and methods of validation. The adopted approach was used to model the local catchments around the Eliwana Project, as described in the Eliwana Project Mine Surface Water Impacts Assessment report.

2. HYDROLOGIC MODELLING

A combination of hydrologic modelling approaches have been developed to characterise surface water flows around the Eliwana project area. The approaches include:

- Regional methods – which use regional relationships to derive estimates of peak flows, at a point, from basic catchment statistics (area, centroid location and slope) and basic rainfall data (design rainfall depths),
- Rainfall-runoff routing models – which use complex catchment data (subcatchments, internal flow routing) and complex rainfall inputs (design depths, loss models and storm temporal patterns) to derive estimates of flow hydrographs at pre-defined points, and
- Rain-on-grid hydraulic models – which use highly detailed catchment information (digital terrain models), complex rainfall inputs (design depths, loss models and temporal patterns) and hydraulic properties (eg. surface roughness) to derive estimates of flow hydrographs and flood depths, extents and velocities throughout entire catchment areas.

The ultimate objective of developing aforementioned approaches suited to the areas evaluated is to develop a set of hydraulic models which quantify both hydrologic (catchment scale rainfall, runoff and routing) and hydraulic (flow depth, extent and velocity) processes across the entire Eliwana project area. These models would then be used to assess changes between the baseline and altered conditions. This section describes this process and the adopted assumptions and model setup of the baseline and altered condition models. The following section assesses the changes between the baseline and altered conditions as illustrated by the model results.

2.1 Regional Methods

While the hydraulic models provide the more comprehensive set of outputs, results and input parameters have not been assessed against regional gauging information which were found to be not suitably representative of the project area. For this reason, regional methods and rainfall-runoff models (where Australian Rainfall and Runoff recommends input based on regional streamflow gauging information) have been used to validate the outputs of the hydraulic models.

Regional methods have been applied at several locations in the region around the Eliwana Project area. Methods include:

1. The Regional Flood Frequency Estimation (RFFE) Model from ARR (Ball et al. 2016).
2. Flavell (2012), a regionalised flood frequency procedure.

Each method takes catchment characteristics (such as area, mainstream length and slope) and provides estimates of flows for events ranging in annual exceedance probability (AEP) from 50% to 1%.

2.2 Rainfall Runoff and Routing

The RORB software was used to build a rainfall-runoff model for Duck Creek catchment (to Mount Stuart) and Pinarra Creek catchment (including the strike valley section only). RORB is an event based rainfall – runoff model where a catchment is divided into sub-areas linked by reaches where each sub-area is represented as a conceptual storage that simulates the combined overland flow and channel storage. The model ultimately provides predictive hydrographs that were used comparison with hydraulic modelling.

For this process, a combination of single-event, ensemble event and Monte-Carlo simulations were used. The RORB Monte Carlo tool was used to estimate peak flows only. This involved routing a rainfall depth (with known average recurrence interval), applying one of ten temporal patterns and stochastically varied initial loss values. This was replicated many times to derive a flow-probability distribution. Total probability theorem was used to estimate peak flows for selected annual exceedance probabilities. Single and ensemble event simulations were used to compare hydrographs and for selection of temporal patterns to be used in TUFLOW modelling.

2.3 Rain on Grid Hydraulic Modelling

A distinction is made between standard hydraulic modelling and “rain on grid” hydraulic modelling. Standard hydraulic models examine overland flow over a discrete, local domain, typically for the purpose of design of hydraulic structures, including bridges and culverts. These models commonly rely on input hydrographs developed by a hydrologic model. A “rain on grid” approach models entire catchments, estimating the response of a catchment to rainfall, run-off routing and hydraulics of rainfall excess. The hydraulic modelling software used for this study can incorporate input parameters from typical hydrologic models such as rainfall losses, storm depths and temporal patterns, with the use of digital terrain models effectively representing storage and routing processes.

The TUFLOW GPU hydraulic modelling software was used to estimate flood hydraulics. TUFLOW GPU provides an explicit solution to the 2D Shallow Water Equations (Saint-Venant equations). The software utilised a finite volume scheme, conserving both volume and momentum. TUFLOW provides estimates of hydrology (catchment scale rainfall, runoff and routing) and hydraulics (flow depth, extent and velocity) for both channelized flow and sheetflow. These outputs mean the models allow for comparative assessment of impacts as well as hydraulic design of infrastructure.

Rain on grid modelling was completed in two stages:

1. Modelling of the RORB domains (Pinarra Creek and Duck Creek), and
2. Modelling of the Eliwana Mine Project area catchments (for Surface Water Impact Assessment).

The first stage aimed to develop a standard approach to rain-on-grid hydraulic modelling in the project area, validated by regional methods and rainfall-runoff modelling (section 2.2). The second stage aimed to apply the adopted methodology for the surface water impact assessment.

2.4 Model Inputs

Inputs for the regional methods and hydrologic models are described in this section. This includes common inputs, such as design rainfall and loss models. Other model specific inputs include subcatchment delineation and routing parameters (for RORB) and boundary conditions and surface roughness (for TUFLOW).

2.4.1 Catchment and Mainstream Geometry

Catchment geometry was derived from a range of sources. For the Duck Creek catchment, delineation used a combination of the 1 second SRTM Derived Hydrological Digital Elevation Model (DEM-H) dataset prepared by Geoscience Australia (with a resolution of 1-arc second, or approximately 30m) and 10m and 20m gridded DEM data from Landgate. For the mine area models, several FMG captured LiDAR and photogrammetry datasets were used and complemented with 10m Landgate data where necessary. The terrain data was used to delineate catchments and estimate mainstream lengths and equal area slopes. Catchment parameters are listed in Table 1.

Table 1: Duck and Pinarra Creek Catchment Characteristics

Catchment Name	Area (km^2)	Main Stream Length (km)	Equal Area Slope	No. of Sub Areas	Adopted C
Duck Creek	6804	249	2.32	47	0.59
Pinarra Creek (at reporting hydrograph)	56.5	21.5	6.58	20	0.59

2.4.2 Model Domains

The terrain data described above was used to delineate subcatchments for the Duck Creek and Pinarra Creek RORB models. For the Duck Creek model, 47 subcatchments were used across a 6734km^2 domain, with areas ranging between 44km^2 to 276km^2 and averaging 143km^2. For the Pinarra Creek model, 20 subcatchments were used across a 60.3km^2 domain, with areas ranging between 1.8km^2 to 4.4 km^2 and averaging 3.0km^2. The RORB subcatchments, nodes and reaches are shown on Figure 3 and Figure 4 alongside TUFLOW model domains and downstream outlets.

Some misalignments exists between the delineated catchments for Duck Creek RORB and TUFLOW models, arising from differences in terrain data used in the process. This includes the extent to which Weelamurra Creek and Caves Creek interact in the area around the Weelamurra Flats. The areas involved are a small proportion of the overall catchment size and the models are considered suitable for flow comparisons.

While the Pinarra TUFLOW model outlet is downstream of the RORB model outlet, the peak flow comparisons in the following section are taken at a common point immediately downstream of the Broadway Gorge, where upstream catchment area is approximately 56km^2.

2.4.3 RORB Input Parameters

K_c is the primary routing parameter in RORB, which is used to estimate the flow routing and attenuation characteristics within the catchment. Given the Rio Gorge is an ungauged catchment, the results of other calibrated RORB models within the region can be used to estimate the Kc value for Rio Gorge using the following formula:

$C = K_c/d_{av}$

Where:

C is a constant representing catchment characteristics,

K_c is the RORB catchment storage delay parameter, and

d_{av} is the average flow path distance (km).

Previous studies in the Pilbara have calibrated RORB models to streamflow gauges, which gives a range of estimates for calibrated K_c values (Pearcey, Pettett, Cheng, & Knoesen, 2014). The K_c value can be translated to other nearby catchments of similar characteristics using the relationship above. The constant 'C' is independent of catchment area, but dependant on d_{av}, hence K_c values can be translated to other catchment by scaling with respect to d_{av}.

Pearcey, et al. (2014) investigated 19 Department of Water monitoring sites in the Pilbara, finding that the C value was normally distributed, with a mean of 0.59, and a standard deviation of approximately 0.12. That study also found that Pearcey, et al. (2014) showed that the three steepest catchments from that study (with equal area slope exceeding 7.5 m/km) resulted in the lowest C values, but that given the low sample, concluded that a C value of 0.59 was appropriate for ungauged catchments in the Pilbara.

Duck Creek and Pinarra Creek catchment characteristics are listed in Table 2 alongside the three steepest catchments from the Pearcey, et al. (2014) study. Duck Creek is a significantly larger catchment with a lower mainstream equal area slope as to not to merit comparison. Pinarra Creek is of a similar scale and slightly lower equal area slope, although with a significantly different shape factor. For these reasons, the RORB models presented in this document have followed the overall recommendation of Pearcey, et al. (2014), that a C value of 0.59 is appropriate and not altered based on the two nearby, steep catchments. Alternate C values were modelled as part of a sensitivity analysis.

Table 2: Comparison of Catchment Characteristics

Catchment Name	Area (km^2)	Main Stream Length (km)	Equal Area Slope	No. of Sub Areas	Adopted C
Hardey River @ Mt Samson (706207)	250	33.0	7.60	11	0.47
Robe River @ Palra Springs (707001	174	27.0	8.46	12	0.34
Harding River @ Marmurrina Pool U-S	49.3	10.7	10.3	7	0.44
Duck Creek	6804	249	2.32	47	0.59
Pinarra Creek (at reporting hydrograph)	56.5	21.5	6.58	20	0.59

The RORB m value, the non-linearity exponent parameter, is typically set at 0.8. This value remains unchanged and is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987). It is rare to vary the m value and there were no reasons to do so in this study, particularly given the lack of calibration data.

2.4.4 TUFLOW Input Parameters

The TUFLOW model domains are shown on Figure 3 and Figure 4. For these domains, the Duck Creek model used a 30 metre grid based on SRTM data, whereas the Pinarra Creek model used a 5 metre grid based on captured LiDAR and photogrammetry data. Model inputs included direct rainfall excess are discussed in sections 2.4.5 to 2.4.8.

The downstream boundaries used a single normal flow boundary calculated by TUFLOW from the topography. This type of boundary assumes a uniform flow based on the ground slope of adjoining cells.

The Manning's 'n' roughness parameter impacts on flood velocities, flow paths, flood depths and extents. The Western area is a predominantly natural rural landscape, with altered terrain typically limited to sealed and unsealed roads. The lack of historic flood data for this area and the relative homogeneity of the landscape make it difficult to categorise different roughness areas with any certainty. For this reason, and from previous experience in nearby catchments, a constant manning's 'n' roughness coefficient of 0.05 was selected.

2.4.5 Design Rainfall

The Depth Frequency Duration (DFD) table, showing the design rainfall depths adopted for design AEP events is provided in Table 3. This data has been obtained from the Bureau of Meteorology website (http://www.bom.gov.au/water/designRainfalls/ifd/). These DFDs were published in 2016 and represent the revision of design rainfall estimates adopted by Australian Rainfall and Runoff (2016).

The design rainfalls were applied to the RORB and TUFLOW models as event totals for a range of durations and magnitudes.

Table 3: 2016 BOM Design Rainfall Depths (mm) – Location: 22.479S 116.827 E

	Annual Exceedance Probability (AEP)						
	100%[1]	50%	20%	10%	5%	2%	1%
Duration	**Rainfall Depth (mm)**						
1 min	1.7	2.0	2.8	3.3	3.9	4.6	5.2
2 min	2.7	3.1	4.4	5.2	6.1	7.1	7.9
3 min	3.9	4.5	6.3	7.5	8.7	10.2	11.4
4 min	5.0	5.7	8.1	9.6	11.2	13.3	14.8
5 min	6.0	6.9	9.7	11.7	13.6	16.1	18.1
10 min	10.0	11.5	16.4	19.7	23.0	27.4	30.8

[1] One exceedance per year

	Annual Exceedance Probability (AEP)						
	100%[1]	50%	20%	10%	5%	2%	1%
15 min	12.8	14.7	21.0	25.2	29.5	35.1	39.4
30 min	17.9	20.6	29.1	35.0	40.8	48.5	54.4
1 hour	22.9	26.4	37.3	44.8	52.1	61.9	69.4
2 hour	28.0	32.3	46.0	55.4	64.7	77.2	86.9
3 hour	31.1	36.0	51.8	62.7	73.6	88.4	99.9
6 hour	36.9	43.2	63.7	78.3	93.1	114.0	130.0
12 hour	43.7	51.7	78.6	98.3	119.0	148.0	171.0
24 hour	51.1	61.1	95.4	121.0	149.0	188.0	220.0
48 hour	58.6	70.5	111.0	143.0	176.0	224.0	263.0
72 hour	63.0	75.7	120.0	153.0	189.0	239.0	280.0
96 hour	66.3	79.7	125.0	160.0	196.0	247.0	288.0
120 hour	69.2	83.1	130.0	165.0	202.0	252.0	293.0
144 hour	72.0	86.3	134.0	170.0	207.0	257.0	297.0
168 hour	74.8	89.6	139.0	175.0	212.0	262.0	301.0

2.4.6 Storm Temporal Patterns

Temporal patterns from ARR (Ball et al. 2016) were used in the analysis and extracted from the ARR data hub. As previously described, a Monte Carlo approach was adopted in RORB and the full ensemble of temporal patterns were included within the Monte Carlo simulation. The Rangelands West Zone of temporal patterns was used.

The ARR (Ball et al. 2016) approach using Monte Carlo analysis with various temporal patterns allows for exhibited variability in rainfall events of similar magnitude. The new temporal patterns are based on historical storms using the extensive network of pluviograph data collected by the Bureau of Meteorology (BoM).

The ARR (Ball et al. 2016) design temporal patterns are broken into several AEP groupings, these include:

- Very Rare – Rarest 10 within region
- Rare – Suitable AEP range 3.2% AEP and rarer
- Intermediate – Suitable for AEP range 3.2% - 14.4%
- Frequent – Suitable for AEP range more frequent than 14.4%

Previous assessment would have used a single temporal pattern across all design events. The ARR (Ball et al. 2016) approach recommends that at least 10 temporal patterns be used for each event. These 10 temporal patterns change depending on the duration and frequency of the event considered.

In order to directly compare the RORB and TUFLOW models, a common rainfall event was required. The ensemble approach was used to choose the temporal pattern which most closely approximated the design flows estimated using the Monte Carlo method. In this approach, RORB parameters (kc and continuing loss) were held constant and initial loss and temporal patterns were varied. For each event magnitude, 10 temporal patterns were tested to produce unique hydrographs. The temporal pattern that produced the flow closest to the Monte Carlo estimate of peak flow was selected as the design temporal pattern. Where necessary, adjustment of initial loss was applied.

2.4.7 Rainfall Loss Assumptions

ARR (Ball et al. 2016) provides guidance on loss parameters across Australia. As much of the Duck Creek Catchment has a mean annual rainfall less than 350 mm loss parameters are not available. Other studies including Flavell and Belstead (1986) and Pearcey, et al. (2014), however, have also shown high losses with 'lower bound' estimates of initial losses of 40 to 60 mm and continuing losses exceeding 5 mm/hr in the Pilbara region.

The original ARR (Pilgrim et al. 1987) set out both initial loss/continuing loss method and a proportional loss method. For the Pilbara region, these were based on the work of Flavell and Belstead (1986).

Six separate rainfall loss scenarios were tested on the Pinarra Creek models. The scenarios were developed from a combination of proportional loss and initial/continuing loss recommendations from both the 1987 and 2016 versions of Australian Rainfall and Runoff. Proportional loss values and methodology were published in Flavell (2012). For simplicity, each assumption has been assigned a label as described in Table 4.

The loss scenarios were tested for Pinarra Creek in both RORB and TUFLOW models. In RORB, losses were always removed from the rainfall, with rainfall excess applied to the subcatchments. In TUFLOW losses can be implemented prior to application of rainfall or via soil infiltration after application of rainfall. The former mimics the RORB approach while the latter allows for ongoing infiltration in wet cells after the end of the rainfall event. Only the final loss scenario listed in Table 4 (IL406S) uses the latter approach.

Table 4: Rainfall Scenario

<table>
<tr><th>Scenario Name</th><th>Losses</th><th>RORB Implementation</th><th>TUFLOW Temporal Pattern</th><th>TUFLOW Loss Implementation</th></tr>
<tr><td>PL</td><td>Magnitude Varying Proportional Loss (see Table 5)</td><td>Monte-Carlo Simulation varying temporal pattern only, using Rangelands West point temporal patterns</td><td rowspan="3">GSDM/GTSMR</td><td rowspan="5">Taken from rainfall prior to application on the grid</td></tr>
<tr><td>IL_ARR87</td><td>Magnitude varying initial loss (see Table 5), constant continuing loss of 5mm/hr.</td><td rowspan="2">Monte-Carlo Simulation, varying IL and temporal pattern, using Rangelands West point temporal patterns</td></tr>
<tr><td>IL_606</td><td>Initial loss of 60mm, continuing loss of 6mm/hr.</td></tr>
<tr><td>PL16</td><td>Magnitude Varying Proportional Loss (see Table 5)</td><td>Not modelled</td><td rowspan="3">ARR16 temporal patterns (Rangelands west, 8, 16 and 28)</td></tr>
<tr><td>IL406R</td><td rowspan="2">Initial loss of 40mm, continuing loss of 6mm/hr.</td><td>Single event(s), with ARR16 temporal patterns (Rangelands west, 8, 16 and 28)</td></tr>
<tr><td>IL406S</td><td>Not applicable</td><td>Taken from soils following application of direct rainfall</td></tr>
</table>

In several cases listed in Table 4, the initial loss or proportional loss components were varied according to event magnitude. This follows the recommendations of Australian Rainfall and Runoff (1987), Flavell and Belstead (1986) and Flavell (2012). The values of initial loss and proportional loss varied by magnitude are listed in Table 5. Where events greater than a 1% AEP were assessed, the 1% AEP values for initial loss and proportional loss were used.

Table 5: Magnitude Varying Initial and Proportional Losses

Parameter	Event Magnitude (AEP)					
	50%	20%	10%	5%	2%	1%
Initial Loss (mm)	22	40	52	47	40	32
Proportional Loss (%)	77	75	70	65	56	49

2.4.8 Extreme Rainfall and Runoff

Extreme rainfall depths was estimated using the Generalised Short Duration Method (GDSM) and the Generalised Tropical Storm Method-Revised (GTSMR) developed by BoM. The GSDM has been applied to a 6 hour storm, while the GTSMR has been applied to a 24 hour duration storm. Both methods rely on a site location to determine the Probable Maximum Precipitation depth, with adjustments made based on catchment elevation, ruggedness of terrain and variations in atmospheric moisture content. The adjustment factors are listed in Table 6.

Table 6: PMP Rainfall Depth Estimation Factors

Method	Factor	Value
GSDM	Roughness Factor	1
	Elevation Adjustment Factor	1
	Moisture Adjustment Factor	0.975
GTSMR	Site Extreme Precipitable Water (mm)	102
	Moisture Adjustment Factor	0.85
	Decay Amplitude Factor	0.983
	Topographic Adjustment Factor	1.05

Three methods were used to estimate the Probable Maximum Flood. TUFLOW and RORB models were used to estimate the Probable Maximum Precipitation Flood (PMP Flood). In both cases, no losses were applied and the GSDM temporal pattern was used, with an areal reduction factor of 0.83 applied. These were compared to a third method, a regression formula developed by Nathan (1994), which estimates a probable maximum flood by:

$$Q = 129.1.A^{0.616}$$

Where A is catchment area (in km^2) and Q is flow in m^3/s.

2.5 Flow Comparisons

2.5.1 Regional Methods

Flow estimates derived for a range of methods for Duck Creek at Mt Stuart are shown in Figure 6. The figure includes regional methods from ARR (Pilgrim et al. 1987), including the Regional Rational Method (RRM), the Index Flood Method (IFM). Also shown are more recent methods including the Regional Flood Frequency Procedure (RFFP – after Flavell, 2012) and the Regional Flood Frequency Estimation (RFFE) Model recommended by ARR (Ball et al. 2016).

Figure 5 includes peak flow estimates for the Duck Creek catchment derived from RORB and TUFLOW models. The RORB model used a Monte-Carlo approach with an initial loss of 60mm and a continuing loss of 6mm/hr (equivalent to the IL606 scenario in Table 4). The TUFLOW model was of the 24 hour duration event, using a proportional loss model (equivalent to the PL scenario in Table 4).

Figure 5 shows:

- The older methods (IFM and RRM from ARR (Pilgram et al. 1987)) produce the highest estimates and move further outside the RFFE 90% confidence limits as event magnitude increases,
- TUFLOW, RFFP and RORB estimates converge with increasing event magnitude (although this is in part the effect of using a Log-Log plot) and typically remain within the RFFE 90% confidence interval,
- The RFFE estimates are typically among the lowest and are the lowest for the 2% and 1% AEP estimates,
- RORB estimates of the 50% and 20% AEP flows are low and outside the RFFE 90% confidence interval (the 50% value is zero and cannot be plotted), reflecting cases where the initial loss (including those stochastically generated in the Monte-carlo simulation) is greater than te design rainfall.

Figure 6 shows flow estimates for Pinarra Creek just downstream of Broadway gorge. The same set of comparisons are made as with Duck Creek in Figure 5, with both new and old regional methods shown along side Monte-Carlo RORB estimates and TUFLOW estimates. The one difference is that the 6 hour event is shown, as this was the critical duration at the catchment outlet.

Figure 6 shows:

- The older methods (IFM and RRM from ARR (Pilgram et al. 1987)) produce the highest estimates but remain within the RFFE 90% confidence limits,
- While TUFLOW, RFFP and RORB estimates are typically lower than that of the RFFE, these methods converge with increasing event magnitude with the 1%AEP flow estimates ranging from 179 to 215 m^3/s,
- The RFFP and RORB estimates of the 50% and 20% AEP flows are low and near the RFFE 5% confidence limit (the RORB 50% value is zero and cannot be plotted).

The comparisons between the Duck Creek RORB and TUFLOW models were used to guide futher sensitivity testing in the Pinarra Creek models. This included full suite of loss scenarios (from Table 4) and variation of the RORB C parameter. The change assessment modelling approach was determined from the outcomes of sensitivity testing on the Pinarra Creek catchment. This was due to Pinarra Creek catchment being a similar size to the other mine area catchments with Pinarra Creek model parameters being more applicable than those from Duck Creek.

2.5.2 Effect of Rainfall Losses

Figure 7 shows the distribution of estimates using the TUFLOW model, for the range of loss assumptions listed in Table 4. The peak flow values are also listed in Table 7.

The initial loss assumptions have a major impact on flow estimates for frequent events. For the Pinarra Creek catchment, the critical duration (6 hour) rainfall depth (from Table 3) is 43mm and 64mm for the 50% and 20% AEP events respectively. This means the initial loss for the IL406S, IL406R and IL606 scenarios (see Table 4) is as large as the entire storm depth for the 50% AEP event and in the case of the IL606 scenario, the 20% AEP event. Table 7 shows zero or near zero flows for these events. The proportional loss assumption and the ILARR87 scenarios (with lower or no initial loss) produce higher flows, more in line with the RFFE and RFFP methods.

Rare event flow magnitudes shown on Figure 7 appear to scale with total rainfall depth. From a 1% AEP6 hour rainfall event of 130mm, rainfall excess has been estimated at 47.3mm, 61.9mm and 73.7mm for the for the IL606, IL406S/R and ILARR87 scenarios. The proportional loss rainfall excess (66.3mm) produces a lower peak flow than the IL406S/R scenarios despite having a lower volume. This is due to the PL scenario having losses distributed evenly throughout the storm rather than being front loaded as is the case with the IL406S/R scenarios.

Table 7: TUFLOW Peak Flow Estimates for Pinarra Creek at Broadway Gorge

Regional Method/ Loss Scenario	Event Magnitude (AEP)					
	50%	20%	10%	5%	2%	1%
RFFP (Flavell 2012)	5.3	14.9	32.7	73.2	132.5	208.3

Regional Method/ Loss Scenario	Event Magnitude (AEP)					
	50%	20%	10%	5%	2%	1%
RFFE (ARR 2016)	17	50	82	119	173	215
PL	13.5	27.3	48.5	76.7	134.0	188.7
IL_ARR87	5.1	14.8	25.7	74.7	171.0	256.2
IL_606	0.0	0.4	10.1	39.8	103.1	168.9
PL16	14.4	28.9	51.7	81.7	132.2	181.3
IL406R	0.0	16.7	49.9	96.9	170.3	240.4
IL406S	0.0	17.1	51.0	98.9	173.4	242.4

2.5.3 RORB versus TUFLOW Estimates

Four sets of flow estimates have been modelled by both RORB and TUFLOW. These are shown in Figure 6. A 1:1 line is shown, indicating equal values estimated by both models. The significant variation away from the 1:1 line can be explained by variations in the model setups.

The IL406R models are the most appropriate for a direct TUFLOW/RORB comparison as they have the same single event implementation and loss assumptions. This set of values indicate that TUFLOW typically predicts slightly higher flows than RORB, with this tendency increasing as flow magnitude increases. Given rainfall excess is the same in both cases, the differences could be the result of variations in routing in the TUFLOW grid versus routing through RORB's conceptualised stream network.

RORB predicts higher flows than TUFLOW for the ILARR87 and IL606 models, particularly for frequent and intermediate events. The RORB estimates are derived from Monte-Carlo simulation with varied initial loss and temporal patterns, whereas the TUFLOW estimates are single event models with fixed initial loss.

The Monte-Carlo approach aims to mimic the variability of antecedent conditions by stochastically varying initial loss. Section 2.5.2 showed that rain on a normal catchment produces zero flow (for frequent events). While rain on a wet catchment would produce higher flow estimates, rain on a dry catchment cannot produce lower flow estimates as these are already zero for normal conditions. In the total probability theorem estimates of flow, this skews design flows higher for all event magnitudes, although this skew diminishes with increasing event size. So in cases where initial loss accounts for a large proportion of the total storm depth, a single event model (either in TUFLOW or RORB) is likely to produce far lower flows than a Monte-Carlo simulation of the same catchment.

2.5.4 Effect of Temporal Patterns

The RORB model was run varying only temporal pattern – effectively an ensemble approach. The flow estimates are the median values derived from routing 10 temporal patterns through the RORB model. The equivalent TUFLOW model is a single event using a separate temporal pattern (GSDM, see Table 4). The close agreement between the two approaches suggests that the choice of temporal pattern does create some variation in flow estimates, but is not as significant as the choice of rainfall loss assumptions.

2.5.5 Effect of Varying C Parameter

Conceptually, the C factor in RORB combines routing delays from a storage delay coefficient (K_c) and transport delay (from average transport distance (d_{av})). A lower C value is expected to reduce the routing delay and increase peak runoff.

Figure 7 shows peak flow estimates from RORB Monte-Carlo simulations using the IL406R scenario (from Table 4) with C values reduced from 0.59 to 0.48 and 0.4. The peak flow estimates from the RFFP and RFFE methods are also shown. For events between the 10%AEP and the 1%AEP, a reduction of C to 0.48 increases flow estimates by 20% above the estimates using a C value of 0.59. Further reduction to a C value of 0.4 increases flow estimates by 40%. The effect of reducing the C value on 50%AEP and 20%AEP flows is diminished as the initial losses result in very low or zero flow estimates.

2.5.6 Extreme Flood Comparison

Three estimates of the probable maximum precipitation flood were derived from the methods described in section 2.4.8. The estimates are listed in Table 8. The values show reasonable agreement, particularly considering the high degree of uncertainty associated with estimated the PMP flood.

Table 8: PMP Flood Estimates for Pinarra Creek at Broadway Gorge

Method	Factor	Flow (m3/s)
Nathan (1994)		1817
RORB Estimate		2432
TUFLOW Estimate		2643

This result is consistent with the IL406R models discussed in section 2.5.3 where TUFLOW models predict slightly higher flows than RORB models given the same input parameters.

2.5.7 Terrain Data and Grid Size

Two TUFLOW estimates of Pinarra Creek flows at Broadway gorge are available for comparison. The first is from the Pinarra Creek model where a 5 metre grid based on FMG captured LiDAR is used. The second is from the Duck Creek model where a 30 metre grid based on hydrologically enforced SRTM data is used. Both models use a magnitude varying proportional loss with the GSDM temporal pattern (PL scenario from Table 4). Flows from the same reporting hydrograph location is shown in Table 9. The finer resolution model predicts flows 7% to 18% higher than the coarser resolution model (15% higher on average) with no apparent trend associated with event magnitude. The higher flow estimates are possibly a result of better definition of the channels in the main stream and tributaries, resulting in a greater hydraulic efficiency and a more rapid catchment response to rainfall.

Table 9: Comparison of TUFLOW Grid Size and Terrain Data affecting Peak Flow Estimates

Model	Flow Estimates for Pinarra Creek @ Broadway Gorge (m^3/s)					
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Duck Creek Model (30m Grid)	12.6	23.9	41.5	65.0	114.9	163.1
Pinarra Creek Model (5m grid)	13.5	27.3	48.5	76.7	134.0	188.7

2.6 Adopted Modelling Approach

Based on the comparison of flows, TUFLOW models were built to assess changes arising from the development of the Eliwana Project. These models used the PL16 loss approach where:

- A magnitude varying proportional loss model is used based on the values in Table 5,
- The rangelands west temporal patterns were used, specifically patterns 8, 16 and 28, and
- In TUFLOW, losses were extracted from the rainfall hyetograph, with rainfall excess applied across the model domains.

The Regional Flood Frequency Procedure and the RORB Monte-Carlo approach are considered best practise methods for estimating peak flows. Figure 6 and Figure 7 suggest that the TUFLOW proportional loss approach results in a reasonable match with the two best practise methods at the rare and intermediate scale events (10% AEP and larger). The closeness of this fit gives confidence that the TUFLOW PL16 approach adequately replicates flow estimates for two methods considered best practise.

However, for assessment of impact, frequent events (AEP => 20%) are considered more important (as discussed in the Surface Water Impact Assessment). The design flow estimates for frequent events (particularly those from RORB) are affected by extreme initial losses estimated for the Pilbara region. For Pinarra Creek at Broadway Gorge, the TUFLOW PL16 approach predicts 50%AEP flows equivalent to the 20%AEP flows predicted by RFFP and

RORB. Both of those methods predict very low or zero flows for the 50% AEP (see Table 7 and Figure 6), reducing the meaningfulness of any change assessment. Therefore the 50% AEP as predicted by the TUFLOW PL16 model has formed the basis of the change assessments. This is considered to be an event that produces some runoff at a frequency and temporal scale likely to determine ecosystem health as affected by water availability and hydrological processes.

3. CONCLUSIONS

This document presents the hydrologic and geomorphic characteristics of the Eliwana Project area and describes the process by which the potential impacts of the development on the hydrological regime were estimated. A range of model approaches were tested with the aim of developing a single approach to apply to the local catchments within the project area. Through this process:

- A range of assumptions for estimating rainfall loss and storm temporal patterns were tested,
- Model parameters (such as RORB C values and TUFLOW grid size) and terrain data inputs were varied,
- Resulting peak flows were compared to standard industry practise methods and regional estimation techniques, and
- A single appropriate approach was adopted based on a rain-on-grid hydraulic model driven by design rainfall and storm temporal patterns developed for the 2016 release of Australian Rainfall and Runoff with proportional rainfall losses applied.

The adopted approach was used to model the local catchments around the Eliwana Project, as described in the Eliwana Project Mine Surface Water Impacts Assessment report.

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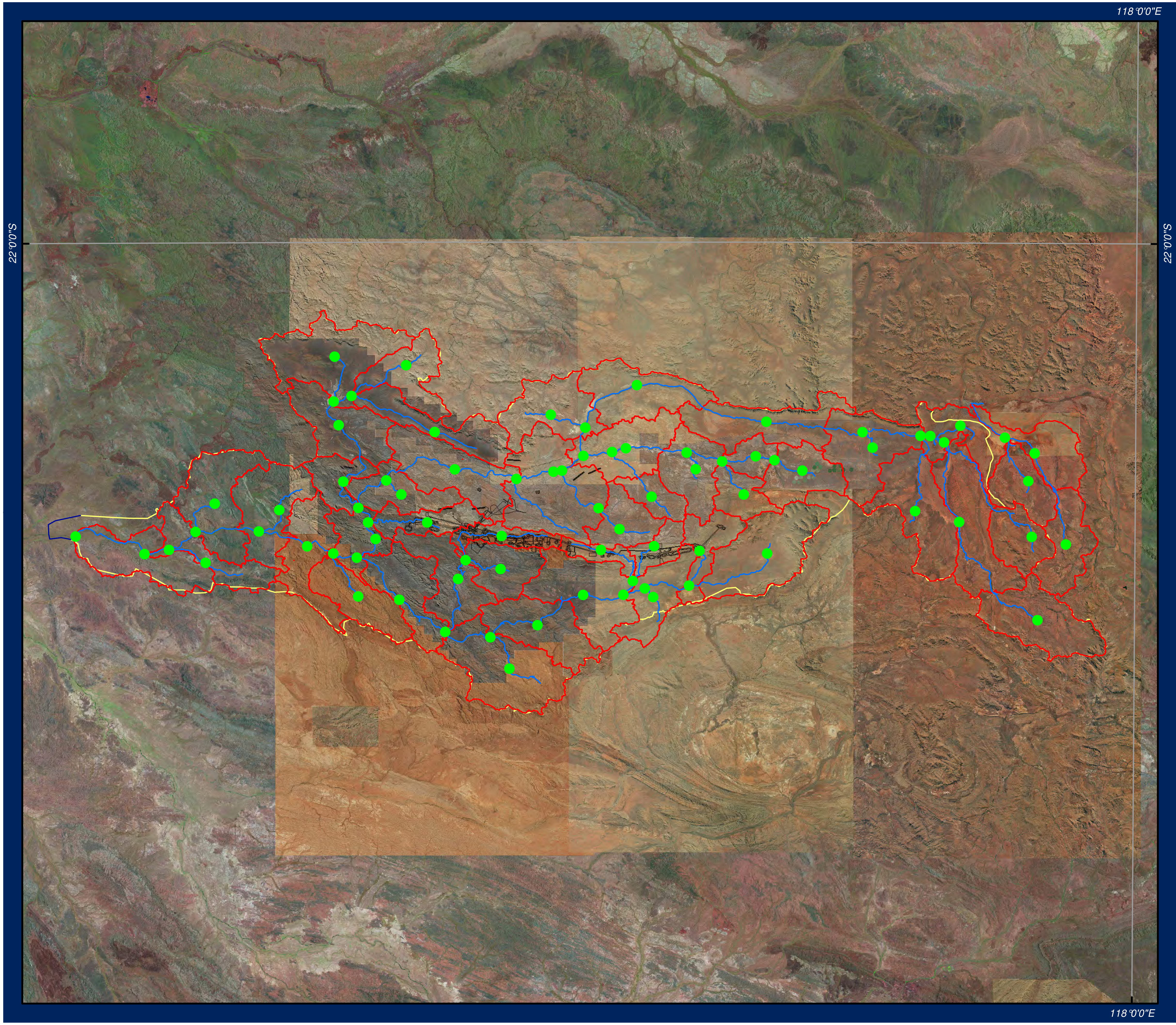
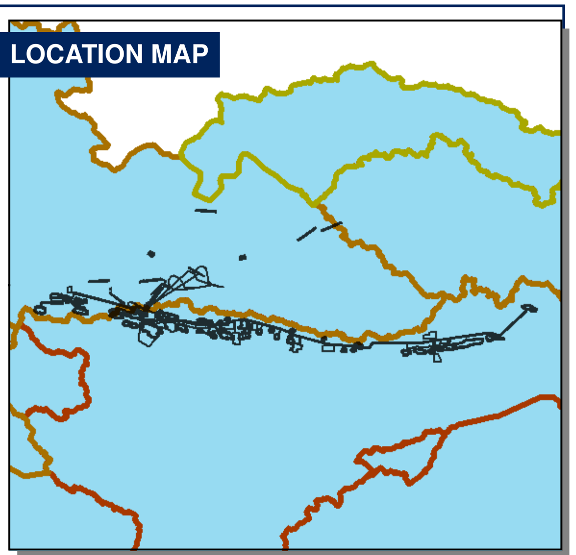
Figures



LOCATION MAP



LEGEND

- RORB Nodes
- RORB Streamlines
- RORB Subcatchments
- TUFLOW Model Boundary
- TUFLOW Outflow Boundary
- Proposed Mine Options

N

0 5 10 20 30 40 Kilometers

Duck Creek RORB and TUFLOW Model Domains

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Drawn By: XX
Revised By: pbussemaker
Approved By: XX
Scale: 1:671,214
Coordinate System: MGA50
Document Name: Duck Creek RORB and TUFLOW Model Domains

Date: 30/08/2017
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Revision: 2
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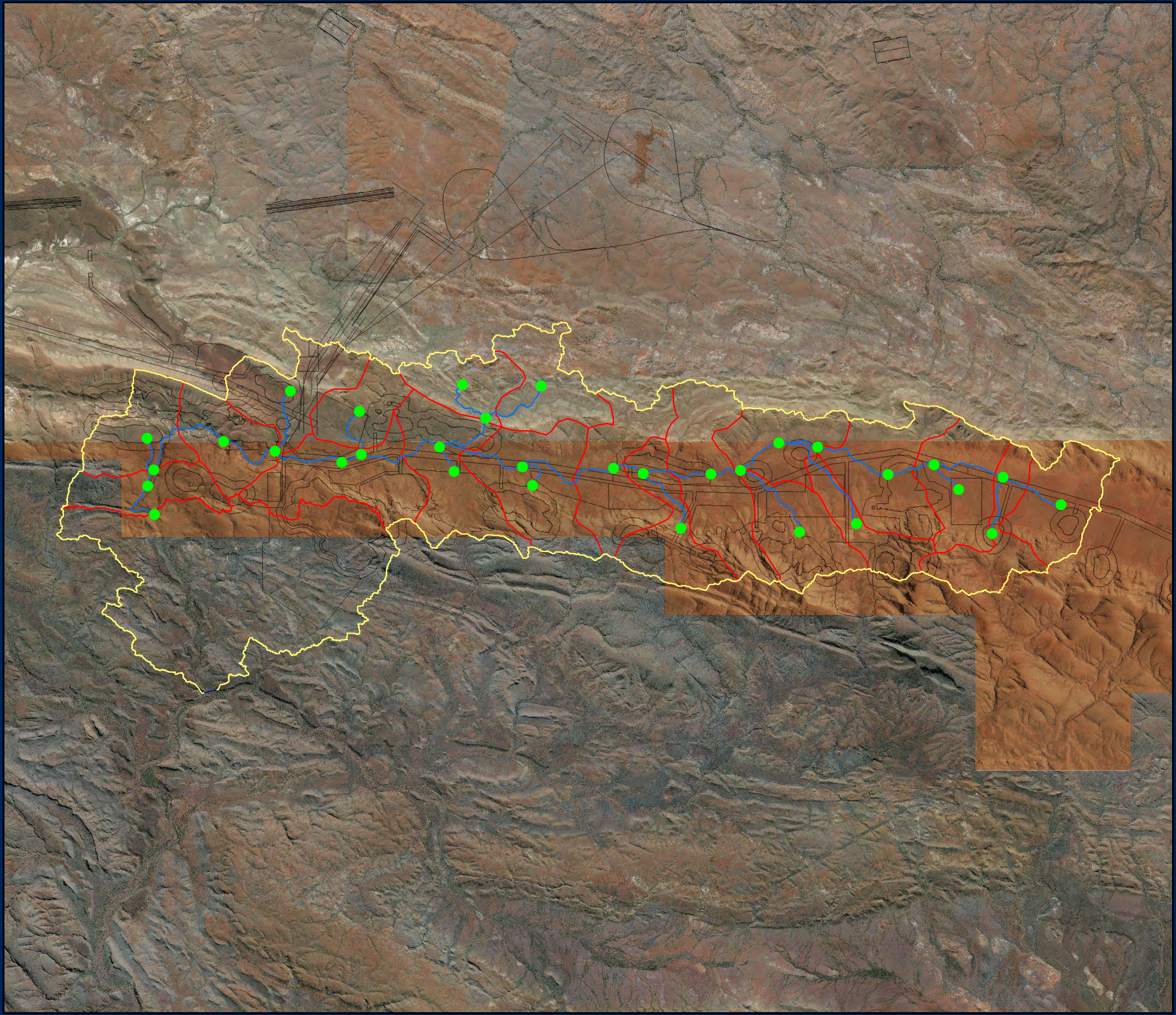
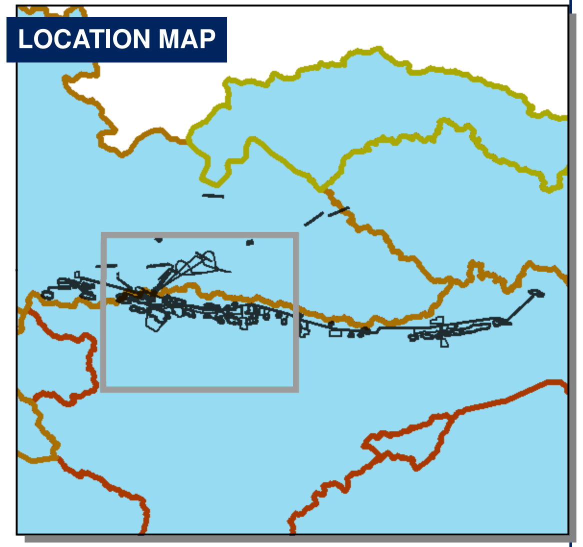
The New Force in Iron Ore





LEGEND

- RORB Nodes
- RORB Streamlines
- RORB Subcatchments
- TUFLOW Model Boundary
- TUFLOW Outflow Boundary
- Proposed Mine Options

N

0 0.5 1 2 3 4 Kilometers

Pinarra Creek RORB and TUFLOW Model Domains

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Drawn By: XX
Revised By: pbussemaker
Approved By: XX
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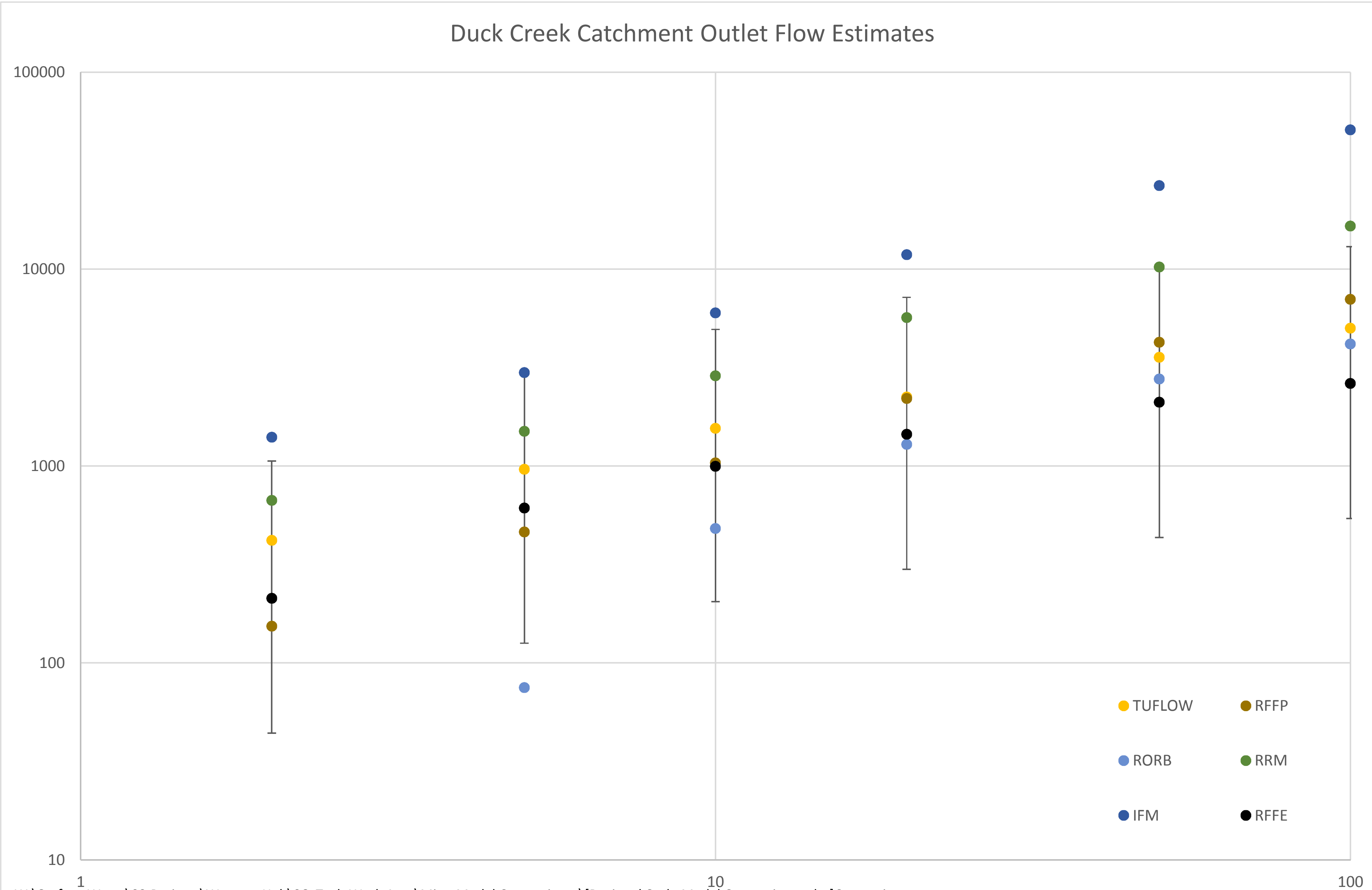

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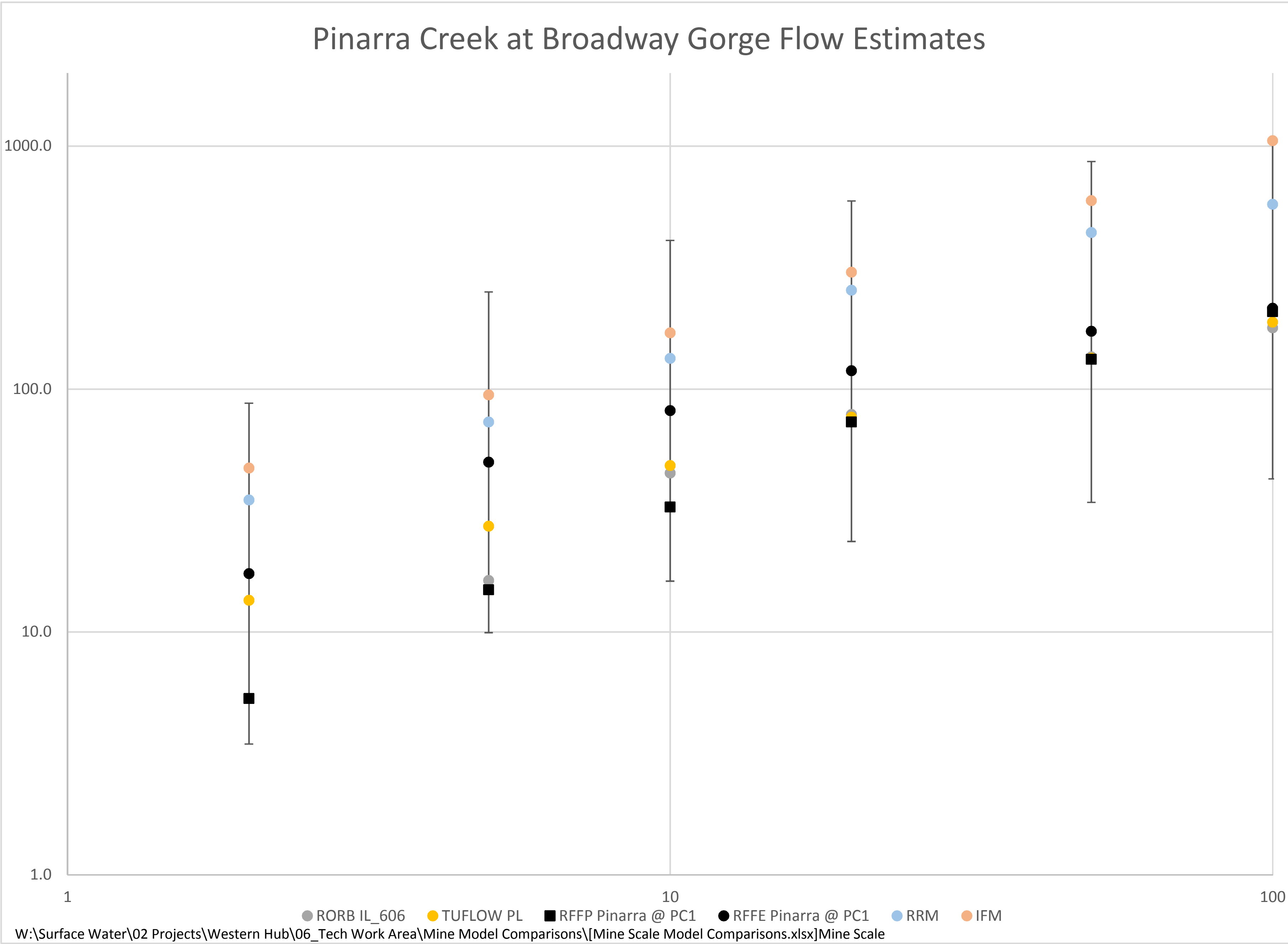

Pinarra Creek at Broadway Gorge Flow Estimates
1000.0
100.0
10.0
1.0
1
10
100
RORB IL_606
TUFLOW PL
RFFP Pinarra @ PC1
RFFE Pinarra @ PC1
RRM
IFM
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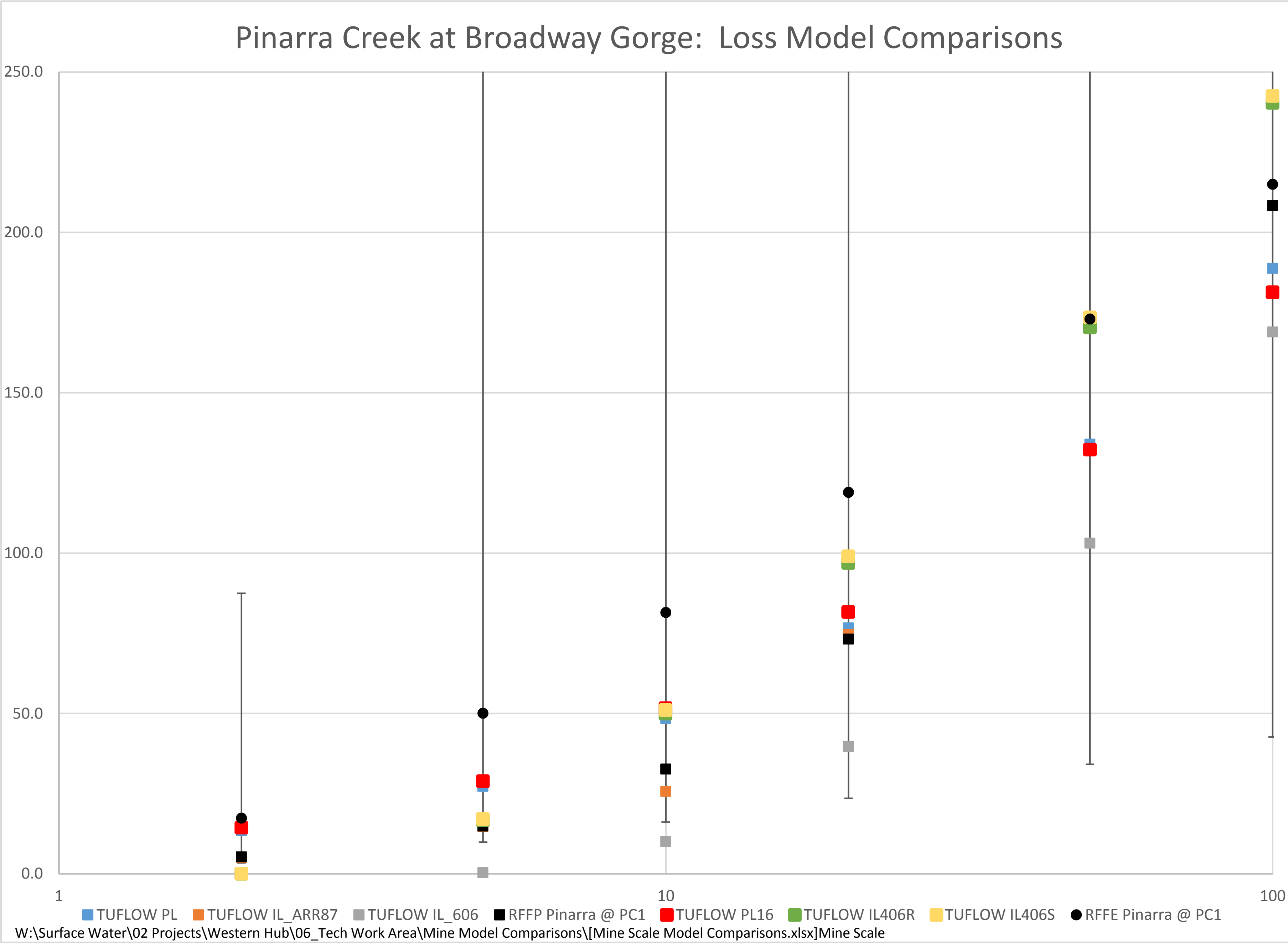

Pinarra Creek at Broadway Gorge: Loss Model Comparisons
250.0
200.0
150.0
100.0
50.0
0.0
1
10
100
TUFLOW PL
TUFLOW IL_ARR87
TUFLOW IL_606
RFFP Pinarra @ PC1
TUFLOW PL16
TUFLOW IL406R
TUFLOW IL406S
RFFE Pinarra @ PC1
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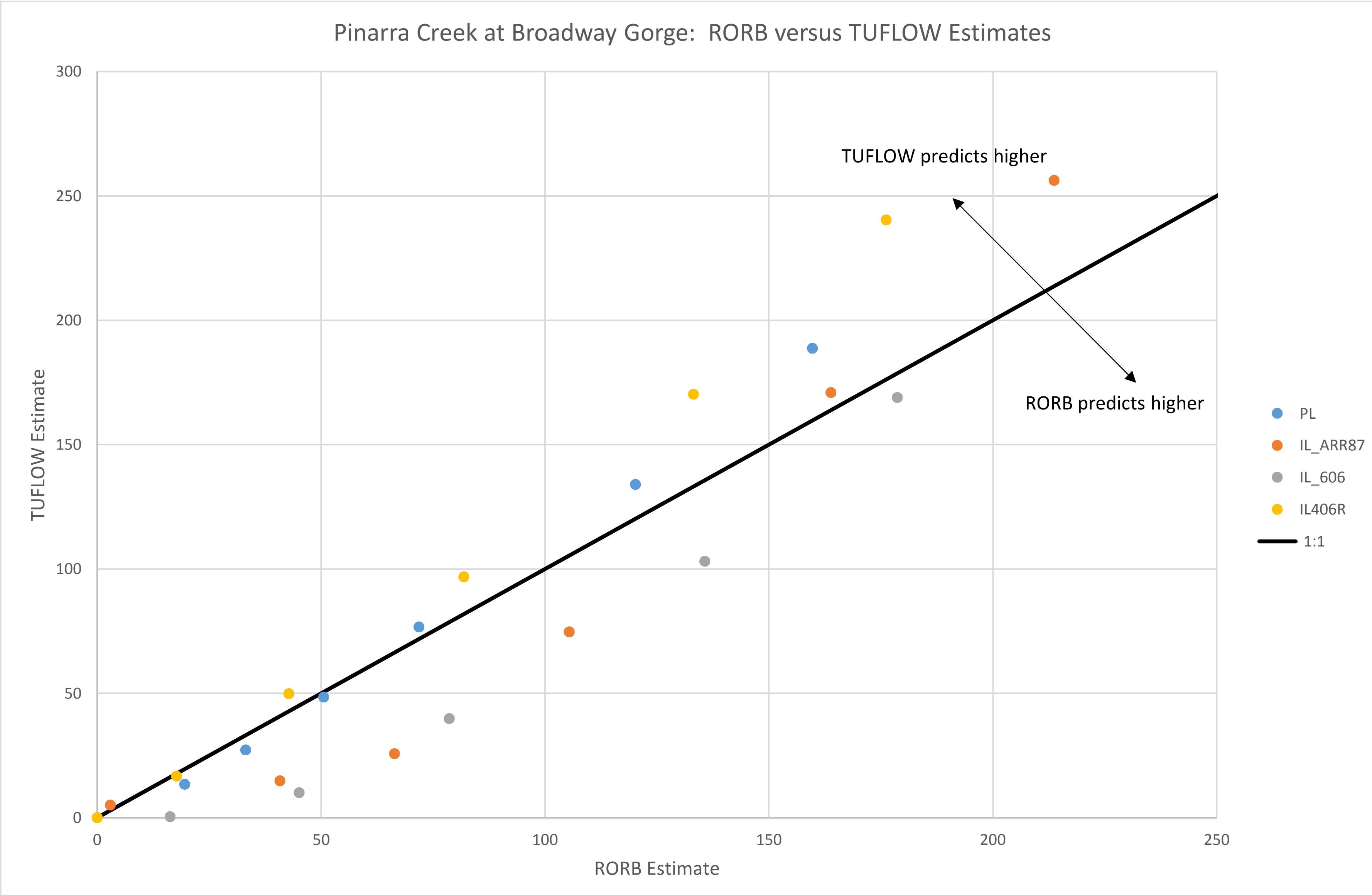

Pinarra Creek at Broadway Gorge: RORB versus TUFLOW Estimates
TUFLOW Estimate
RORB Estimate
0
50
100
150
200
250
300
0
50
100
150
200
250
TUFLOW predicts higher
RORB predicts higher
PL
IL_ARR87
IL_606
IL406R
1:1