

## **Geomorphic, Hydraulic and Sediment Transport Modelling for Mine-related Channel Realignment – Case Study: Caves Creek, Pilbara, Western Australia**

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*Mining of iron ore deposits in the Pilbara Region of Western Australia frequently requires the realignment of a creek where the proposed mine pit encroaches into the 100 year ARI floodplain of the creek. Realignment designs typically require a diversion channel and a flood control levee. At Caves Creek the primary design objectives were to protect the pit from flooding and to maintain the hydrologic and geomorphic functionality of a downstream threatened ecological community (TEC) and other environmental receptors along Caves Creek.*

*Pilbara Region hydrology is driven by infrequent, large-magnitude cyclonic events, which result in a high degree of channel variability over time and space. The existing, ephemeral-flow Caves Creek system in the project area is dynamic, including both well-defined and poorly-defined channel reaches, with calcrete and silcrete outcrops providing vertical and lateral controls.*

*Hydrologic (RORB), hydraulic (HEC-RAS), and mobile boundary sediment transport (HEC-6T) modelling was performed to establish the design criteria and to assess upstream and downstream effects of the proposed realignment on upstream and downstream sediment continuity. Under existing conditions, the flow-sediment balance in the 40 km long modelled reach is maintained by local base-level control provided by valley floor spanning, thick silcrete deposits located at a constriction immediately downstream of the TEC. The cracking clays and themeda grasslands of the TEC appear to be more dependent on local drainage than on overflows from Caves Creek, which only occur at flows greater than the 20 year ARI event.*

*A low-flow channel was sized along the diversion to mimic the existing channel-floodplain connectivity and maintain sediment continuity. The floodplain constriction caused by the realignment increases sediment transport capacity through the diversion, requiring armoured grade control at periodic intervals. The constriction also creates a backwater extending upstream of the realignment, which affects sediment delivery to the constricted reach.*

*The design sections were adjusted to achieve sediment continuity and minimise impacts to the TEC. Under the final configuration, sediment loading to the TEC reach was nearly identical under existing and realignment conditions, indicating that the stage-discharge-frequency relationship along the TEC would be unaffected by the realignment. Mobile-bed sediment transport modelling was found to be a versatile tool for assessing upstream and downstream impacts of the channel diversion as well as predicting potential scour within the diversion.*

## 1. INTRODUCTION

### 1.1. Context

The development of a mining pit within the Silvergrass deposit area requires the realignment of a 2.4 km reach of Caves Creek, an ephemeral creek system with a catchment area of approximately 1,800 km<sup>2</sup>. This paper highlights findings from geomorphic, hydraulic, and sediment transport modelling efforts that supported the realignment design and the determination of potential impacts to a downstream threatened environmental community (TEC) and other downstream ecologically sensitive areas.

### 1.2. Location

As shown in Figure 1, Caves Creek is located approximately 65 km northwest of Tom Price in the Pilbara Region of Western Australia.

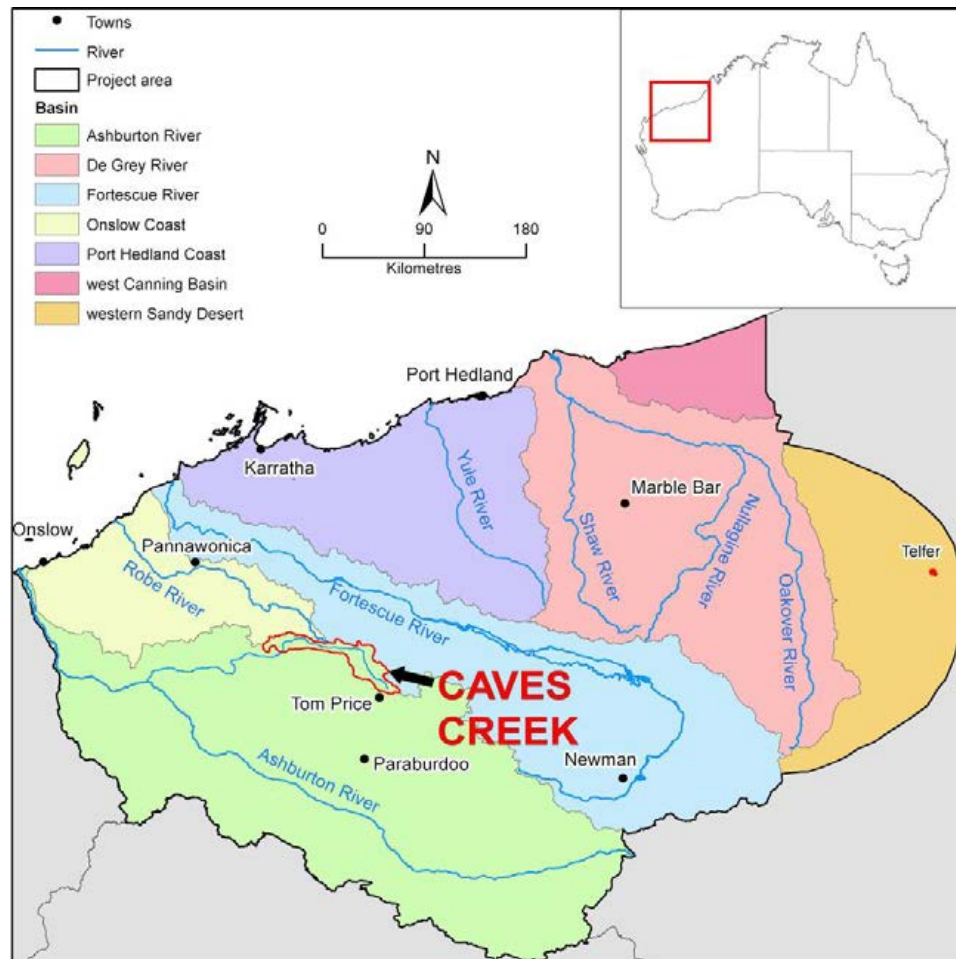


Figure 1. Location of Caves Creek in the Pilbara Region of Western Australia

## 2. EXISTING CONDITIONS

The condition of the existing environment was derived from a review of available topographic and aerial photography data, previous project reports, hydrologic, hydraulic and sediment transport

modelling, a site inspection, and on-site sediment sampling efforts for characterisation of the bed, bank, and floodplain materials.

## 2.1. Environment

Figure 2 shows an overview of the existing site area, including the proposed mining pit and creek realignment along with the TEC downstream of the pit.

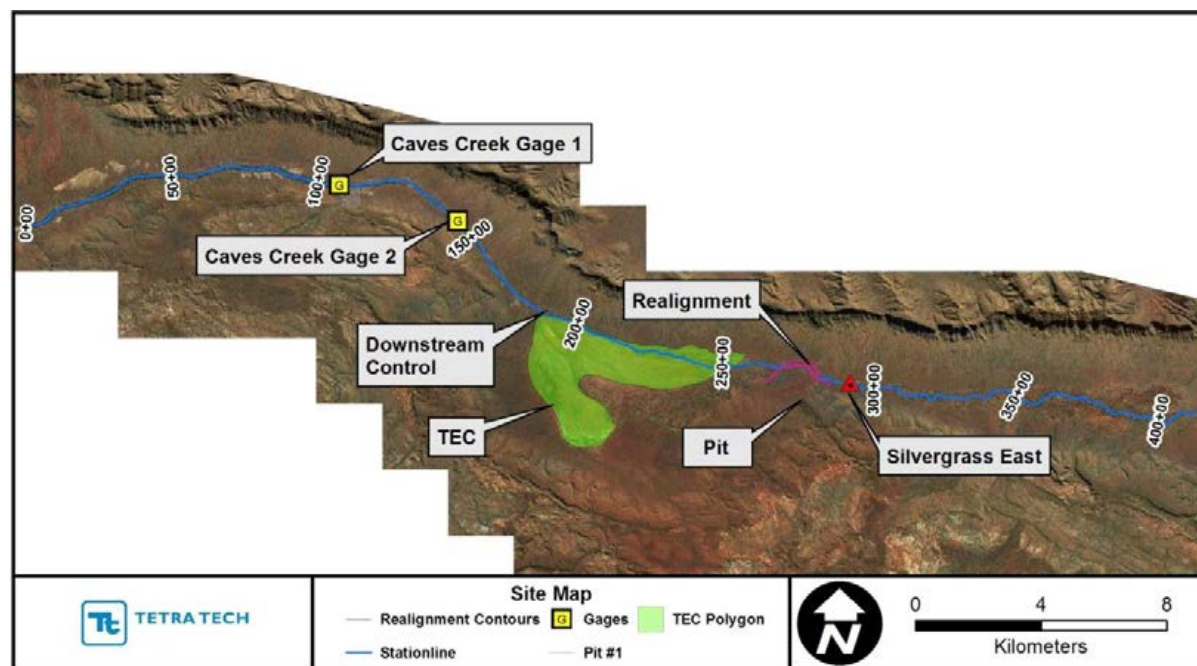


Figure 2. Location of mining pit, creek realignment, and TEC

The TEC is a *Themeda* grassland (Kangaroo grass) with cracking clay. The TEC as a whole is about 6 km in length, about 2.8 km wide and is located in a structurally-controlled, very wide section of the valley upstream of a valley constriction (Figure 2)

## 2.2. Hydrology

A RORB Runoff Routing Model (Laurenson et al, 2010) was used to develop project hydrology. The period of record for nearby gauging stations was insufficient for use in the calibration of peak flow estimates; Flood Frequency Analyses, Monte Carlo simulations, and sensitivity analyses were performed to guide selection of input parameters and to ascertain uncertainties in the RORB model results. Rainfall patterns were applied based on ARR recommendations, with critical durations assessed up to 72 hours. The CRC-FORGE method was used for estimation of long-duration, rare rainfall events up to 1 in 2,000 years, and the Bureau of Meteorology Generalised Tropical Storm Method (Revised) was used for estimating the Probable Maximum Precipitation. Table 1 shows the estimated peak discharge rates and Figure 3 shows flood hydrographs for the 100 year ARI event at selected locations along the creek.

Table 1. Estimated Peak Discharge Rates

2-year ARI	10-year ARI	100-year ARI	Probably Maximum Flood
50 m <sup>3</sup> /s	250 m <sup>3</sup> /s	2,500 m <sup>3</sup> /s	14,000 m <sup>3</sup> /s

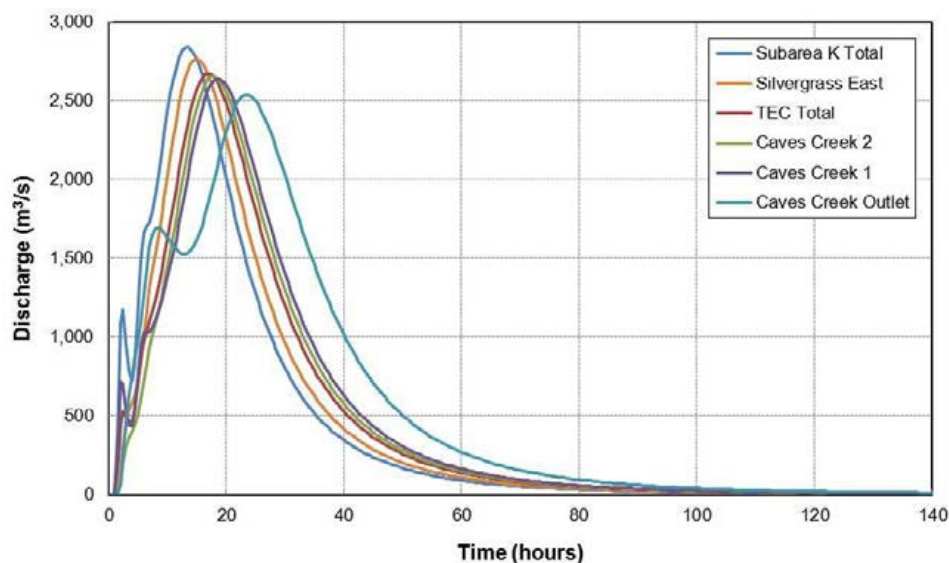


Figure 3. Caves Creek 100 year ARI hydrographs

### 2.3. Streambed Profile

Figure 4 shows the profile of Caves Creek for approximately 42 km along its length. The streambed slope is approximately 0.1% upstream of the TEC, doubling to 0.2% downstream of the TEC.

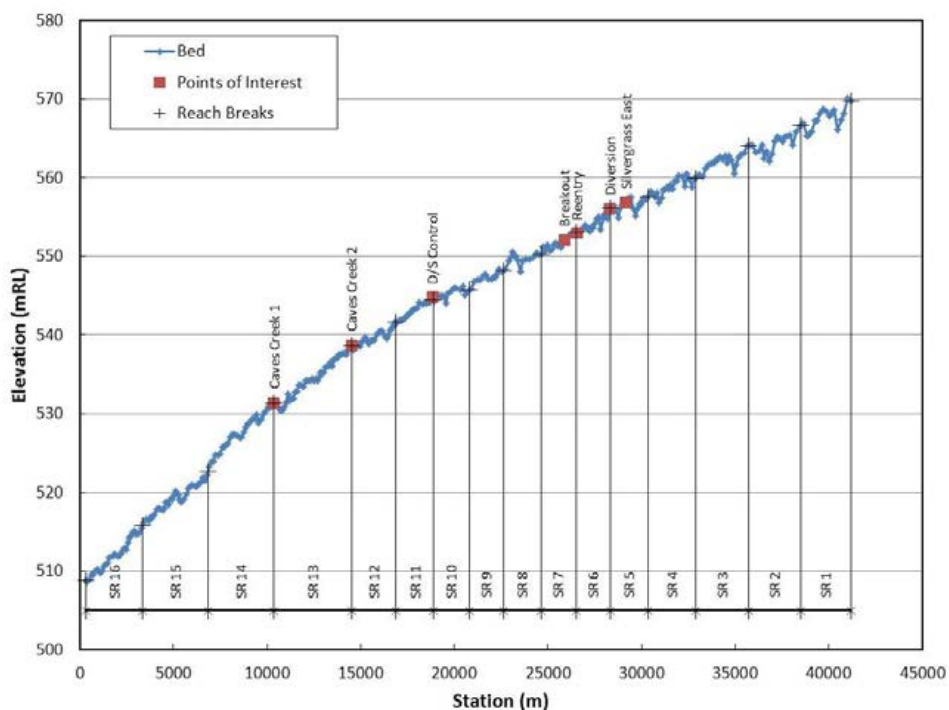


Figure 3. Caves Creek streambed profile

Whilst streambed profiles tend to typically exhibit a concave shape (slope decreasing in a downstream direction), the Caves Creek profile is convex, with the slope increasing in a downstream direction. This results from the extensive presence of calcrete and silcrete along its length.

## 2.4. Sediment

Pebble counts (Wolman, 1954) of the surface armour layer were taken within the channel bed and bulk subsurface samples of the substrate material were collected for sieve analyses. The armour layer exhibited a median ( $D_{50}$ ) size of approximately 22 mm and the subarmour layer  $D_{50}$  varied from 2 to 5 mm. As shown in Figure 5, the alluvial deposits along Caves Creek are relatively thin, overlying an extensive calcrete layer with frequent surface expressions in both the bed and banks of the channel.

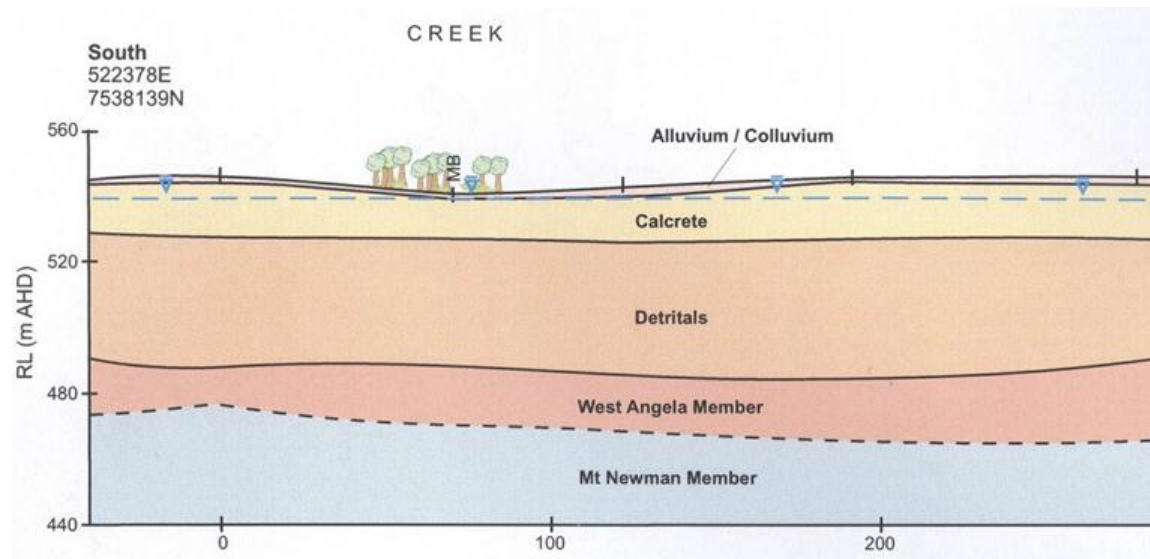


Figure 4. Selected lithological transect (Knight Piesold, 2012)

## 2.5. Site Investigation and Modelling Results

The channel and floodplain geometry, flood hydrographs, and sediment characteristics were entered into hydraulic (HEC-RAS, 2010) and sediment transport (HEC-6T, 2010) models to assess the sediment dynamics of the existing system. Under existing conditions, the TEC becomes inundated at overbank flows between the 10 year peak flow and 20 year peak flow, conveying more than fifty percent of the flow at discharges in excess of the 20 year ARI event. Under existing conditions, the flow-sediment balance is in equilibrium along the TEC, indicating morphologic stability in this area.

Caves Creek is an ephemeral flow channel that is dry most of the time but responds to significant, primarily cyclonic, rainfall events that cause relatively short duration floods. The results of the geomorphic field assessment and modelling efforts indicate that morphologically-significant sediment transport is episodic and that the morphology of the creek is unlikely to represent an equilibrium form, but rather is the result of the last significant flow event. Event-driven sedimentation appears to be the cause of split flow reaches, controlling the changes in channel location through time where the floodplain is wider.

There is a distinct relationship between the distribution of large riparian tree species, recent flood deposits and depth to groundwater. Groundwater monitoring has shown that groundwater is located at shallow depths along Caves Creek. The locations of the trees within the channel appear to control local bed scour and lateral channel erosion, especially if large woody debris is deposited on the upstream side of the trees. The relatively long interval between large flood events enables the trees to become well established within the channel. Eventually the trees become large enough to create significant bed scour and locally reform the channel. Local sediment deposition appears to eliminate well-defined channel reaches and cause sheet flooding that results in the formation of gullies on the valley floor where flows re-enter a defined channel. Upstream extensions of the valley-floor gullies during subsequent flood events cause changes in the location of the primary channel over time. Based on the observations of the highly variable nature of the channel morphology along Caves Creek, the channel capacity, frequency of overbanking flooding, and sediment transport are also locally very variable.

### 3. ALTERED SYSTEM

The geomorphic investigations showed that local sediment deposition and erosion will govern the longer-term morphology of the re-aligned channel and most probably the distribution of riparian vegetation, provided that channel relocation does not significantly affect the depth to groundwater. Output from the uncalibrated HEC-RAS model, for which the Manning n roughness values were based on field assessment of site characteristics and previous experience with similar types of channels, was used to define the floodplain boundaries with and without the project and to evaluate the effects of the diversion on water-surface profiles. Figure 6 shows the modelled effects of the proposed diversion on the 100-year ARI floodplain width in plan view, and Figure 7 shows the effect in profile view. The constriction raises the water-surface elevation, with a backwater effect that extends about 3 km upstream. There is no significant difference in modelled floodplain boundaries or water-surface levels downstream of the pit through the TEC area.

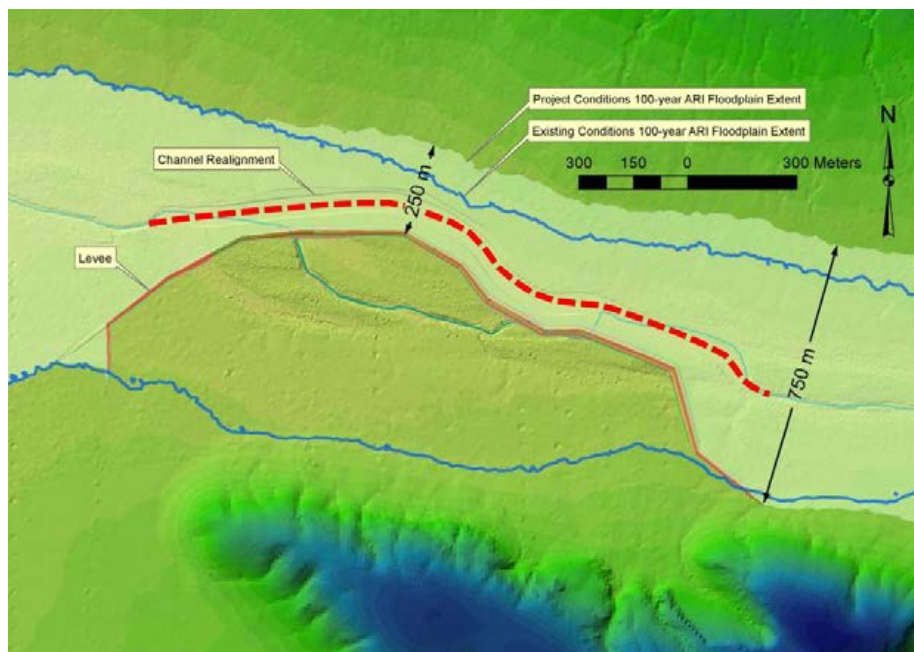


Figure 5. 100 year ARI floodplain with and without relocation

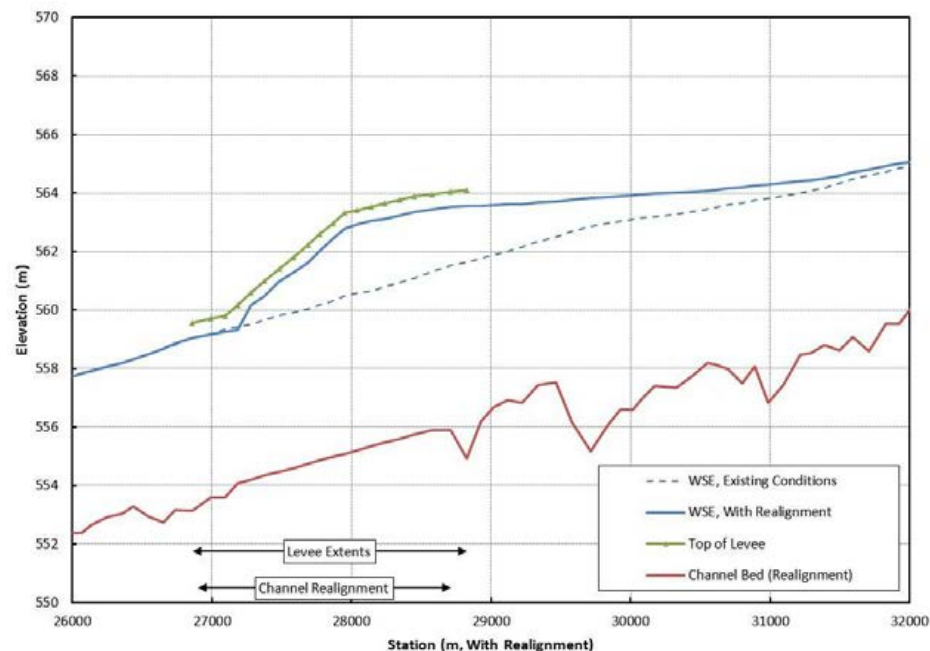
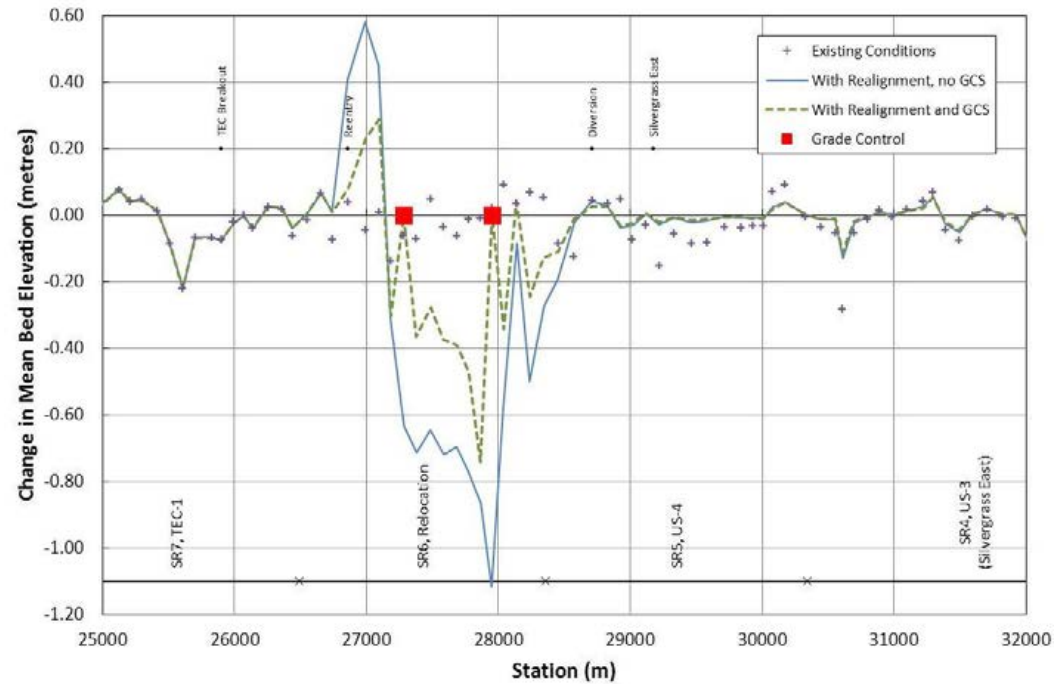


Figure 6. 100 year ARI water surface profile with and without relocation

The constriction decreases velocities in the backwater area and increases velocities in the expansion zone, requiring the application of armour rock. Channel excavation is likely to occur into the calcrete layer, which will provide some limited shear resistance. Armour rock along the levees and channel banks was sized according to Austroads procedures (2013). Figure 8 shows the HEC-6T sediment transport modelling results for the existing condition and with the relocation in place. Based on previous experience with similar channels, the Wilcock and Crowe (2003) transport equation was used in the model because it considers hiding effects in mixed gravel and sand-bed channels. Grade control in the form of two buried rock weirs was provided to limit the erosion depths within the diversion. The grade control weirs reduce the amount of bed degradation between the weirs which in turn reduces the extent of the aggradation immediately downstream of the diversion thereby reducing the impact of the project on the downstream channel. The elevations of the weirs, the number of weirs and the spacing between them was determined iteratively with the model to limit the overall degradation within the diverted channel to less than 0.5 m, except in the immediate vicinity of the rock weir, where additional rock was provided to accommodate the local scour. The total volume of rock required per structure was on the order of 1,000 m<sup>3</sup>, including an allowance for up to 2 m of local scour at the structure.



**Figure 7. Predicted change in mean bed elevation with and without relocation**

The modelling results show that the TEC is inundated by overbank flows from Caves Creek at approximately the 20 year ARI event, and as such the *Themeda* grass ecosystem on the TEC is more likely to be dependent on local inflows from its contributing catchments to the south and east rather than overbank flows from Caves Creek. Field inspection of pits in the immediate vicinity of the TEC indicated the presence of thick clay deposits that contained reduced amounts of coarser rock fragments with increasing distance from the surrounding hillslopes. The presence of the coarser rock fragments suggests a sheet-flood origin for the clay deposits rather than ponding caused by Caves Creek overbank flows. Clearly, overbank flows from Caves Creek could also infrequently contribute clays to the deposit, especially during larger floods when the backwater from the downstream constriction is greatest. Where the cracking clays were present at the ground surface there was no evidence of a surface gravel armour layer, presumably because of the ground disturbance created by the contraction and expansion of the clays on drying and wetting, respectively.

The presence of thick clay deposits identified by drilling and geophysical methods underlying the TEC at depth suggests that the downstream constriction has been present for a considerable period of time and that there must be some form of vertical control to prevent the channel downcutting at the constriction. Field observation indicated that the vertical control was provided by outcrop of silcrete in

the channel bed at the constriction. The modelling results indicate that the stage-discharge relationship in Caves Creek adjacent to the TEC is not significantly impacted by the upstream creek realignment

#### **4. CONCLUSIONS**

Due to the local variability of the flood-controlled channel geometry, the hydraulic capacity of the channel and consequently sediment transport capacity is highly variable. The design of the relocated channel was therefore based on reach-averaged conditions. Post-construction flood-induced changes will determine the longer-term meso-scale channel geometry. Provided that the shallow groundwater table is not significantly affected by either channel relocation or pit dewatering, the riparian vegetation should re-establish itself within and marginal to the relocated segment of the channel.

The presence of thick (~20 m) surface and subsurface calcrete/silcrete deposits across the floodplain of Caves Creek suggests that the channel can be relocated within the northern part of the floodplain into relatively erosion-resistant materials. The TEC appears to be functionally supported by local inflows from the south rather than overflows from Caves Creek. The channel invert elevation at the downstream valley constriction west of the TEC is maintained by outcrop of erosion-resistant silcrete/calcrete. Consequently, there is unlikely to be a change in base level for Caves Creek in the TEC reach or upstream channel relocation reach.

Compared to existing conditions, no change in flood inundation area was identified downstream of the realignment. The sediment-transport modelling of existing conditions indicates that the modelled reach is relatively stable over the range of evaluated hydrographs up to the 100 year ARI event, including the reach adjacent to the TEC. The sediment-transport modelling of project conditions indicated that without any grade control, up to 1.1 m of degradation could be expected during the 100 year ARI event. As such, two grade-control weirs were recommended. Limited degradation between the grade-control structures is anticipated, and would result in moderate aggradation (up to 0.3 m) along the downstream portion of the realignment. However, sediment loading to the head of the TEC is expected to be nearly identical under existing and realignment conditions; the project would therefore have no significant effect on the stage-discharge frequency relationship along the TEC.

#### **5. ACKNOWLEDGMENTS**

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