Fluvial Geomorphology Technical Report: Upper Liddell Seam, Longwalls 1-8 Extraction Plan

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For

Ashton Coal Operations Limited

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FLUVIAL SYSTEMS

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Executive Summary

Introduction

This technical report has been prepared in support of the Extraction Plan for Longwalls (LW) 1-8 in the Upper Liddell Seam (ULD) prepared by AECOM and Ashton Coal Operations Pty. Limited (ACOL). This report addresses aspects of the fluvial geomorphology of parts of lower Bowmans Creek and Glennies Creek that are in the vicinity of the area to be mined.

This report did not require a re-analysis of hydrological, hydraulic or geomorphic work undertaken in association with the fluvial geomorphology investigation for the Bowmans Creek EA. Four issues arose after preparation of the Bowmans Creek EA that required consideration in this report:

- A significant flow event occurred in Bowmans Creek in June 2011. This event was investigated to ascertain its relative geomorphic impact and to check the hydraulic model predictions made in the EA (Hyder 2009; Gippel 2009).
- To meet Condition 1.18 of the Development Consent, there was a need to define a 40 metre buffer from the high bank of Bowmans Creek underneath which longwall voids are not created,
- ULD LW1 lies in the vicinity of Glennies Creek, which was not considered in the Bowmans Creek EA.
- The revised subsidence predictions indicate greater subsidence than previously predicted to areas of Bowmans Creek terrace that lie above ULD LW1-8.

Existing Environment

The Bowmans Creek diversion channels were designed to have similar levels of stability as the existing creek. Thus, the diversion channels are expected to change in morphology at the same rate as the existing creek.

Observations made at Bowmans Creek on 16 June and 11 July 2011 following a 1 in 12.5 year ARI flood event (which occurred over 15-16 June 2011) suggested that there was very little change to the bed and banks. While the event caused some bending of immature casuarinas and disruption to some macrophytes, in most places the geomorphological impact was either negligible, or consisted of deposition of a thin layer of sand and/or gravel on the benches. By 11 July, aquatic plants had re-established on the bed of the creek.

The stability of the channel is likely to be due to armouring of the bed material, and almost complete grass cover on the banks and benches.

Statutory Requirements

Development Consent (DA No. 309-11-2001-i) Condition 3.9 states that:

> "*The Applicant shall ensure that underground mining does not cause any exceedances of the performance measures in Table 1, to the satisfaction of the Director-General*"

The revised subsidence predictions of SCT (2011) predict greater subsidence than indicated in the documents referred to in condition 1.2ac. However, this subsidence will not impact the permanent alignment of Bowmans Creek (i.e. the creek with the diversions in place), because the creek itself is not impacted by subsidence (because there is no mining underneath the creek). The diversions were designed to have the same relative stability as the sections of Bowmans Creek that they replace. The revised subsidence predictions of SCT (2011) have no implications for the stability of the diversions because there is no mining underneath the diversions.

Development Consent (DA No. 309-11-2001-MOD6) Condition 1.18 states that:

> "*The Applicant shall design underground workings to ensure that longwall voids do not result closer than 40 metres from any point vertically beneath the high bank of Bowmans Creek (except those sections of channel made redundant by the diversion).*"

The intention of the definition of “high bank” in the Water Management Act 2000 is to mark the edge of the stream zone which is clearly aquatic (i.e. wet most of the time, and frequently subject to fluvial processes). The methodology used by the surveyor delineated the “high bank” according to the edge of the terrace, which is infrequently inundated. Thus, it was considered a conservative approach to delineation of the high bank.

Subsidence Impacts

The revised subsidence predicted for ULD LW1-8 has no implications for fluvial geomorphological processes in Bowmans Creek. Subsidence affects the land surrounding Bowmans Creek, not the Creek itself (including a buffer of 40 m from the high bank). The diversions are designed to spill into the former channel for events greater than 1 in 5 year ARI. The higher subsidence will simply mean deeper water in the former channels in the event of high flows spilling into them. Velocities would be relatively low in the former channels – they would tend to be depositional zones rather than zones of sediment scour.

The chance of avulsion is very slight because high flood flows will spill in a controlled way over block banks, not over the banks of the diversion channels. Additionally, the bed and banks of the diversion channels were designed to be stable.

Subsidence might present a small risk of mass movement on the valley wall of Glennies Creek, but that is primarily a geotechnical matter that is outside the scope of this report and which is considered elsewhere in the Extraction Plan.

Monitoring and Management

The existing measures are adequate to address revised subsidence estimates, because the revised estimates have no bearing on the stability of the creek in its permanent alignment (i.e. with diversions in place).

Recommendations

The performance measures previously defined in the Bowmans Creek EA (Evans and Peck 2009) for Bowmans Creek and the Eastern and Western Diversions remain appropriate. The essential performance requirement of the creek and diversion channels is that they remain on the current geomorphic trajectory, and adjust in physical form and process within the natural range expected of the existing creek. The current trajectory is towards continued incision and widening, but evidence from a 1 in 12.5 year ARI flood event on 15-16 June 2011 (which had little observable geomorphic impact) suggests that the rate of incision and widening is slow.

The proposed measures to ensure compliance with the fluvial geomorphology-related performance measures remain appropriate. There is no need to specify these in more detail at this stage. The only detail that remains to be specified is the locations on the diversion channels of the cross-sections for survey, and the locations of points on the bed for bed material sampling. This is a matter that is best decided after the diversion channels are constructed and the final detailed form is known.

Conclusions

The revised subsidence predicted by SCT (2011) has no implications for fluvial geomorphological processes in Bowmans Creek. There are no direct implications for Glennies Creek, although this depends on the perceived geotechnical risk of mass movement of soil from the valley wall into the creek by others.

The performance measures previously defined in the Bowmans Creek EA (Evans and Peck 2009) for Bowmans Creek and the Eastern and Western Diversions remain appropriate.

1.0 Introduction

This technical report has been prepared in support of the Extraction Plan for Longwalls (LW) 1-8 in the Upper Liddell Seam (ULD) prepared by AECOM and Ashton Coal Operations Pty. Limited (ACOL). This report addresses aspects of the fluvial geomorphology of parts of lower Bowmans Creek and Glennies Creek that are in the vicinity of the area to be mined.

A general description of the site locality and Extraction Plan Application Area is provided in Section 1.1 of the Extraction Plan main document. The Extraction Plan describes the operation of the underground mine to date, details of the updated mine plan and Bowmans Creek diversion.

An updated assessment of potential subsidence movements related to ULD LW1-8 has been prepared by SCT Operations Pty Ltd (SCT 2011). These subsidence predictions have been used as a basis for the updated assessment of impacts contained within this report. SCT's analysis and results are contained, in full, as an appendix to the Extraction Plan.

1.1 Scope of work

The key tasks for the fluvial geomorphology assessment are to:

- Propose performance measures/indicators for Bowmans Creek and the Eastern and Western Diversions that are consistent with the Development Consent;
- Determine fluvial geomorphology impacts on the basis of the revised subsidence predictions by SCT (2011) and recommend mitigation management measures if impacts are different to those presented in the EA (Evans and Peck 2009); and
- Propose measures to ensure compliance with the performance measures (i.e. mitigation/monitoring/contingency response).

The study area includes those parts of lower Bowmans Creek and Glennies Creek potentially impacted by ULD LW1-8.

1.2 Methodology

This report did not require a re-analysis of hydrological, hydraulic or geomorphic work undertaken in association with the fluvial geomorphology investigation for the Bowmans Creek Diversion Environmental Assessment (EA) (Gippel, 2009). That investigation involved a description of existing conditions, design of creek diversions, and a description of conditions with the diversions in place. The future permanent Bowmans Creek channel (i.e. the existing creek with the diversions in place) is unaffected by subsidence from ULD LW1-8 because the area underneath the creek is intentionally not being mined. However, four issues arose after preparation of the Bowmans Creek EA that required consideration in this report:

- A significant flow event occurred in Bowmans Creek in June 2011. This event was investigated to ascertain its relative geomorphic impact and to check the hydraulic model predictions made in the EA (Hyder 2009; Gippel 2009);
- To meet Condition 1.18 of the Development Consent, there was a need to define a 40 metre buffer from the high bank of Bowmans Creek underneath which longwall voids are not created;
- ULD LW1 lies in the vicinity of Glennies Creek, which was not considered in the Bowmans Creek EA; and
- The revised subsidence predictions (SCT, 2011) indicate greater subsidence than previously predicted to areas of Bowmans Creek terrace that lie above ULD LW1-8.

Investigation of the 15-16 June flood event was reported in Gippel (2011a). That report included a detailed description of the methodology employed and the results. Briefly, the method involved undertaking a flood mark survey by a professional surveyor (Stephen Eccles, Pegasus Technical Pty Ltd) over a period within 5 weeks of the event. This survey comprised 527 points over a channel length of about 6 km. The profile derived from the survey was then compared with water surface profiles and flood extent previously modelled for the Bowmans Creek EA using HEC-RAS and TUFLOW. Unfortunately the gauge on Bowmans Creek failed to properly record levels during the peak of the event. The water surface profile derived from the flood mark survey was used to estimate the peak water level near the gauge, and the gauge rating curve was then used to estimate the flood magnitude. The flood frequency analysis undertaken for the Bowmans Creek EA (Gippel 2009) was then used to estimate the average recurrence interval (ARI) of the event. In addition, the creek was inspected on two occasions (16 June and 11 July) for evidence of geomorphic change. This was based on visual examination, and comparison of photographs taken before (in 2009) and after the June 2011 event.

The definition of the 40 m buffer area hinges on the definition of “high bank”. A line was marked by a surveyor to indicate the position of the high bank. This followed the top edge of the macro-channel, which in Bowmans Creek represents an incised channel form.

Revised subsidence predictions for ULD LW1-8 were provided by SCT (2011). These predictions were compared with the previous predictions made for the Bowmans Creek EA (SCT 2009) with a view to considering the possibility of any additional implications for fluvial geomorphic processes in terrace areas adjacent to future permanent Bowmans Creek channel.

2.0 Existing Environment

The following summary of existing conditions was mostly sourced from the Bowmans Creek EA Appendix 7 (Gippel 2009). As the existing environment for ULD LW1-8 will involve the Bowmans Creek diversions being in place, the environment post-construction of diversions is described. A description of existing fluvial geomorphological characteristics is concerned not just with static conditions on the day of inspection and survey, but with the trajectory of geomorphic change. The following description includes discussion of geomorphic trajectory of Bowmans Creek. The description of the fluvial geomorphology of the existing environment does not include the Hunter River and Glennies Creek because the mine plan was located such that there would be no subsidence cracking under the Hunter River and its alluvium or under Glennies Creek and its alluvium (HLA-Envirosciences, 2001, Section 3, p. 20).

Bowmans Creek remains on a trajectory of incision and widening, which probably began up to 60 years ago. The rate of incision has been slowed by exposure of a number of bedrock outcrops. At their junction, Bowmans Creek has incised down to the bed level of the Hunter River. The thalwegs of the creek is about 11 - 12 metres below the surrounding floodplain level. Bowmans Creek is incised down to the bed level of the Hunter River only near its lower end. At a creek distance of 4 - 6 km from the Hunter River junction, Bowmans Creek is incised about 4 m into the floodplain.

The macro channel of Bowmans Creek has steeper and higher sideslopes in the lower 3 km compared to the upper 3 km. The walls of the macro channel are fine grained alluvium. The macro channel width (where macro channel meets the terrace level) is narrower in the lower half (around 30 - 60 m wide) compared to the upper half of the study reach (around 45 – 75 m wide). Within the macro channel there is a discontinuous inset depositional bench (composed of sand/gravel/cobble material and covered with grass), and a lower bed formed in gravel/cobble that comprises a low-level floodplain, gravel bars, and a distinct low flow channel with pool-riffle morphology. The low flow channel varies in width, being narrower at riffles (particularly in the lower half of the study reach). The bank top level of the low flow channel is about 0.5 – 1.5 m above the level of the thalweg. Pools at median low flow conditions were 0.5 – 0.7 m deep on average, and up to 1.2 m deep. The upper half of the study reach was characterised by more variable width and depth of the low flow channel compared to the lower half (i.e. there were relatively more pools and shorter pools in the lower half).

The median particle diameter was very coarse gravel, but cobble-sized material down to fine gravel and coarse sand was present at all sites. Eight of the ten sampled sites had similar particle size distributions (median diameter 45 – 50 mm), and two sites towards the lower end of the study area were noticeably coarser (median diameter 60 – 70 mm).

Bed material in the channel is predicted to be mobile during flood events of ≥ 1 – 3 yr ARI, while the grass covered bars and benches are mostly stable. The bed stability index was highly variable along the study reach, but overall, the channel was less stable in the lower half of the study reach.

The grassed banks are predicted to be generally stable for floods up to the 5 year ARI event, but for higher events the banks are likely to be subject to fluvial erosion in places. Bare banks are likely to erode during flood events of ≥ 1 – 3 yr ARI. There was no downstream pattern to the fluvial erosion bank stability index, but it is likely that mass wasting erosion would be more prevalent in the downstream, more incised, half of the study reach.

Active layer scour depth was predicted to be shallow, of the order of 0.1 – 0.3 m at most, while predictions of general scour depth matched the observed variations in bed level. Scour holes associated with large woody debris were observed to be highly localised and relatively small (<0.4 m deep). Modelling suggested that pools in the creek have the capacity to be self-sustaining through the process of velocity reversal under high flow conditions. Direct observations of these scour processes have not been made in this or previous studies, but the field observations did not contradict these model predictions.

Flood frequency analysis undertaken for this study suggested that the June 2007 flood was a 34 year ARI event in lower Bowmans Creek. The ARI of this event varied along the length of the Hunter River; it was estimated to be 34 year ARI at Greta, 47 year ARI at Singleton, and 10 year ARI at Maitland (Gippel and Nanson 2010). In an event of this magnitude, in Bowmans Creek, the bed material would be expected to be mobile, bedforms would be expected to change, and areas of bank erosion would be expected. Observations consistent with these expectations were made by Marine Pollution Research (2008) during an ecological survey in late June 2008. At the surveyed cross-sections, compared to surveys made in the year prior to the flood of 2007, scour of the bed was up to 0.9 m and deposition was up to 0.4 m (Maunsell Australia 2008). Cross-sections with scour outnumbered those with deposition, but Maunsell Australia (2008) did not analyse the data statistically so a firm conclusion cannot be drawn. Maunsell Australia (2008) also observed areas of bank erosion and deposition. Although Maunsell Australia (2008) did not regard the changes as “significant”, the magnitude of the changes provides some indication of the expected rates of change. As a result of this high magnitude event, even though bed scour and bank erosion processes would have been active, there was no observed catastrophic channel change. Thus, although the channel is unstable during high flow events, in terms of the bed stability and bank stability indices used here, the channel has an inherent high resistance to gross change. This resistance is imparted by good vegetation cover, the presence of rock bars, the bed material containing a fraction of cobble size material, and presumably, a supply of bed material into the reach from upstream.

The diversion channels were designed to be (as close a possible) carbon copies of the two sections of the existing channels that they will replace. The rationale for adopting this approach was that the diverted sections of Bowmans Creek should behave similarly to the existing sections that they will replace. Provision of near identical morphology and sediment transport processes will also mean minimal change to the availability of hydraulic habitat for biota. In the long term, the diversions would not be expected to result in any interruption to bed material sediment supply from upstream, or from within the channel itself. The diversion channels will be deformable, allowing for natural adjustments of the bed and banks within the range of existing rates of change.

The diversion channels were designed to accept all flows up to the 1 in 5 year ARI event (although this would be staged to allow for establishment of vegetation). Larger floods would flow down both the existing and the diversion channels. Thus, for these larger floods, shear stresses in the diversion channels are expected to be lower than in the existing channel.

The low flow channel will be lined with a buried waterproof layer, and then overlain with approximately 600 mm depth of gravel/cobble bed material. The depth of this bed material is expected to adjust over time. The liner will be located deeper in some sections underneath large woody debris structures, as these are likely to create scour holes.

The bed material of the channels will be composed of a particle size distribution similar to that in the sections of creek that the diversions will replace. The bed material will be scavenged from the excavation and sorted, with coarser material placed on the creek bed surface, to emulate the armour layer.

The predicted relative stability of the beds of the channels of the proposed diversions was similar to that of the reaches of the existing channels that would be diverted, although a direct comparison was not possible because fewer, and generally more widely spaced, transects were available for the existing channel. The analysis of bank stability potential indicated a low likelihood of bank instability for the diversions for all modelled flows.

In the foreseeable future, Bowmans Creek would be highly unlikely to adopt an alternative alignment to that of the proposed diversion channels. While the channel will continue to move within the defined diversion macro-channel corridor, and the side slopes of that macro-channel may occasionally erode as the channel widens its corridor, the chance of an avulsion under high flood conditions is remote.

Avulsions typically occur on highly sinuous and low gradient streams, perched on an active (frequently flooded) floodplain. Bowmans Creek is incised into a terrace and contains most of the flow during high flood events, so there is little spare energy available to cut a new course through the terrace.

In summary, the Bowmans Creek diversion channels were designed to have similar levels of stability as the existing creek. Thus, the diversion channels are expected to change in morphology at the same rate as the existing creek.

2.1 Impacts of June 2011 Flood Event

An opportunity arose to evaluate the stability of the existing creek when a flood event occurred on 15-16 June 2011. Based on consideration of data from a number of sources, the event of 15 - 16 June 2011 in Bowmans Creek was deemed to correspond to a flood recurrence interval of 1:12.5 years ARI (Gippel 2011a).

The HEC-RAS and TUFLOW hydraulic model results reported in the Bowmans Creek EA (Evans and Peck 2009) were not contradicted by the water surface profile observed for the event of 15 – 16 June 2011, however, localised sections of the HEC-RAS modelled profile did not conform with the observed profile. The differences were not so great that they would have compromised the integrity of the geomorphological and hydraulic analysis that was used to aid design of the diversion channels (Gippel 2011a).

Observations made at Bowmans Creek on 16 June and 11 July 2011 suggested that there was very little change to the bed and banks in response to the flood event. While the event caused some bending of immature casuarinas and disruption to some macrophytes, in most places the geomorphological impact was either negligible, or consisted of deposition of a thin layer of sand and/or gravel on the benches. By 11 July, aquatic plants had re-established on the bed of the creek (Gippel 2011a).

The stability of the channel is likely to be due to armouring of the bed material, and almost complete grass cover on the banks and benches (Gippel 2011a).

3.0 Statutory Requirements

Development Consent (DA No. 309-11-2001-i) Condition 3.9 states that:

> "*The Applicant shall ensure that underground mining does not cause any exceedances of the performance measures in Table 1, to the satisfaction of the Director-General*"

The section of Table 1 (referred to above) relevant to fluvial geomorphology is reproduced below.

Table 1: Subsidence Impact Performance Measures.

Watercourses	
Bowmans Creek	No greater subsidence impact or environmental consequences than predicted in the documents referred to in condition 1.2ac
Bowmans Creek – Eastern and Western Diversions	Hydraulically and geomorphologically stable

The revised subsidence predictions of SCT (2011) predict greater subsidence than indicated in the documents referred to in condition 1.2ac (see following section of this report). However, this subsidence will not impact the permanent alignment of Bowmans Creek (i.e. the creek with the diversions in place), because the creek itself is not impacted by subsidence (because there is no mining underneath the creek). The Eastern and Western Diversions were designed to have the same relative stability as the sections of Bowmans Creek that they replace. The revised subsidence predictions of SCT (2011) have no implications for the stability of the Eastern and Western Diversions because there is no mining underneath the diversions.

Development Consent (DA No. 309-11-2001-i) Condition 1.18 states that:

> "*The Applicant shall design underground workings to ensure that longwall voids do not result closer than 40 metres from any point vertically beneath the high bank of Bowmans Creek (except those sections of channel made redundant by the diversion).*"

Delineation of the boundary of the area that excludes longwall voids depends on defining the position of the "high bank". Gippel (2011b) reviewed the relevant legal and geomorphological literature in order to clarify the definition of the "high bank" as it applies to this case, and makes a recommendation regarding the correct location of the "high bank" with respect to the relevant river management legislation.

The top of the bankfull channel (i.e. the geomorphologically active channel) is located within, and at a lower level, than the macro channel boundary. The intention of the definition of "high bank" in the Water Management Act 2000 is to mark the edge of the stream zone which is clearly aquatic (i.e. wet most of the time, and frequently subject to fluvial processes), and not surfaces infrequently inundated by floodwaters. This is consistent with the normal definition of a stream that has been previously applied in Australia (Gippel 2011b).

The methodology used by the surveyor delineated the "high bank" according to the edge of the terrace, which is infrequently inundated. Thus, it was considered a conservative approach to delineation of the high bank (Gippel 2011c).

4.0 Subsidence Impacts

As part of the Bowmans Creek EA (Evans and Peck 2009), subsidence prediction for LW5-8, considering the combined impact of Pikes Gully and Upper Liddell Seams was for a cumulative maximum of 3.7 m. Revised subsidence predictions provided by SCT (2011) indicate cumulative maximum subsidence ranging from 4.6 to 5.3 m across ULD LW1-8 (Table 1).

Table 1: Summary of revised subsidence predictions (SCT 2011).

Seam	Maximum Subsidence (85% of Combined Seam Thickness) (m)	Max Tilt (mm/m)	Max Strain (mm/m)	Incremental Subsidence From Mining ULD Seam (m)	Incremental Max Tilt (mm/m)	Incremental Max Strain (mm/m)
LW1	5.2	276	111	3.7	231	93
LW2	4.7	222	89	3.2	178	71
LW3	4.7	190	76	3.2	152	61
LW4A	4.6	150	60	3.1	119	48
LW4B	4.6	178	71	3.1	141	56
LW5	4.7	121	48	3.2	97	39
LW6A	4.7	118	47	3.2	94	38
LW6B	5.1	155	62	3.6	129	51
LW7A	4.7	105	42	3.7	98	39
LW7B	5.3	137	55	3.8	115	46
LW8	5.2	126	51	4.5	129	52

The revised subsidence estimates have been prepared based on a conservative empirical method outlined by Li et al. (2010). These values are considered to represent a “worst case” and it is expected that actual subsidence will be less than the values presented in Table 1 (above), as indicated by numerical modelling conducted by SCT (2011).

The revised subsidence predicted by SCT (2011) has no implications for fluvial geomorphological processes in Bowmans Creek. Subsidence affects the land surrounding Bowmans Creek, not the creek itself (including a buffer of 40 m from the high bank). The diversions are designed to spill into the former channel for events greater than 1 in 5 year ARI. The higher subsidence will simply mean deeper water in the former channels in the event of high flows spilling into them. Velocities would be relatively low in the former channels – they would tend to be depositional zones rather than zones of sediment scour.

Additional subsidence will not increase the chance of avulsion of the channel diversions. The chance of avulsion is very slight because high flood flows will spill in a controlled way over block banks, not over the banks of the diversion channels. Additionally, the bed and banks of the diversion channels were designed to be stable, through provision of rock beaching on the outside of bends, large woody debris in the bed to help trap bed sediment, and dense riparian vegetation to stabilise the banks.

ULD LW1 is in the vicinity of Glennies Creek. However, the edge of the subsidence effects is around 120 m west of Glennies Creek at its closest point. Here, Glennies Creek abuts the valley wall and has no alluvium on the western side. Subsidence might present a small risk of mass movement on the valley wall, but that is a geotechnical matter that is outside the scope of this report and which is considered elsewhere in the Extraction Plan. In the unlikely event of mass movement of a substantial volume of material into Glennies Creek there will be a temporary blockage. This may cause localised flooding. Eventually the creek would scour the blockage, but this process could be expedited by excavation.

5.0 Monitoring and Management

The Development Consent Conditions include the following fluvial geomorphology-related performance measures:

- Bowmans Creek: no greater subsidence impact or environmental consequences than predicted in the documents referred to in condition 1.2ac (listed below):
    - Documents titled *Ashton Coal Bowmans Creek Diversion Environmental Assessment* dated 3 December 2009, prepared by Evans & Peck,
    - *Ashton Coal Bowmans Creek Diversion Response to Submissions*, prepared by Wells Environmental Services, dated May 2010, and
    - *Ashton Coal Bowmans Creek Diversion Statement of Commitments*, dated December 2010 (see Schedule C)
- Bowmans Creek – Eastern and Western Diversions: hydraulically and geomorphologically stable

The three documents listed above contain the same information concerning performance measures.

The Bowmans Creek diversions were designed on the principle of mimicking the existing creek (Gippel 2009). While the diversions will differ in some respects from the existing creek, these differences are inconsequential from the perspective of expected geomorphological performance. Both the diversion channels and the existing creek are expected to remain on the current geomorphic trajectory of the creek, and to adjust in physical form and process within the natural range expected of the existing creek. So, here, the phrase "hydraulically and geomorphologically stable" means a state of dynamic stability within the expected natural range, rather than absolute stability, which is undesirable from an ecological perspective, and ultimately unachievable from a geomorphological perspective.

The three documents listed above also contain a number of proposed measures to ensure compliance with the fluvial geomorphology-related performance measures. These are listed below, using paragraph numbers from *Ashton Coal Bowmans Creek Diversion Statement of Commitments* (2010):

> "7.1 The bed and bank of the diverted creek will be surveyed:
>
> - Six months, one year and two years after completing construction of the diversion channels.
> - At five yearly intervals, or immediately after a flood with a peak flow greater than 150 m^3/s (about 5 years ARI), at existing cross sections in the retained sections of the existing creek. For purposes of this commitment, flow will be determined from the Office of Water gauging station.
> - At five yearly intervals, or immediately after a flood event with a peak flow greater than 150 m^3/s (about 5 years ARI), at ten new cross section locations and along the thalweg of each diversion channel. The cross section locations will be established to be representative of the various geomorphic forms within the diverted channels.
>
> 7.2 At the same time as cross sectional and longitudinal (thalweg) surveys, bed samples will be collected from four locations in each diversion channel (two pools and two riffles). Samples will also be collected from eight comparable representative sites in the remaining functional sections of the creek for statistical comparison. If there is a variation of more than 20% in the statistics of the data from the diversions compared to the existing channel, ACOL will commission an appropriately qualified geomorphologist to investigate the causes and recommend any remedial actions.

9.1 Subsidence troughs will be rehabilitated to provide a free draining surface.

9.3 Flood damage to the constructed channels will be remediated to restore hydraulic and geomorphic function."

The above measures are adequate to address revised subsidence estimates, because the revised estimates have no bearing on the stability of the creek in its permanent alignment (i.e. with diversions in place).

6.0 Recommendations

The performance measures previously defined in the Bowmans Creek EA (Evans and Peck 2009) for Bowmans Creek and the Eastern and Western Diversions remain appropriate. The essential performance requirement of the creek and diversion channels is that they remain on the current geomorphic trajectory, and adjust in physical form and process within the natural range expected of the existing creek. The current trajectory is towards continued incision and widening, but evidence from a 1 in 12.5 year ARI flood event on 15-16 June 2011 (which had little observable geomorphic impact) suggests that the rate of incision and widening is slow.

The proposed measures to ensure compliance with the fluvial geomorphology-related performance measures remain appropriate. There is no need to specify these in more detail at this stage. The only detail that remains to be specified is the locations on the diversion channels of the cross-sections for survey, and the locations of points on the bed for bed material sampling. This is a matter that is best decided after the diversion channels are constructed and the final detailed form is known.

7.0 Conclusions

The revised subsidence predicted by SCT (2011) has no implications for fluvial geomorphological processes in Bowmans Creek. There are no direct implications for Glennies Creek, although this depends on the perceived geotechnical risk of mass movement of soil from the valley wall into the creek by others.

The performance measures previously defined in the Bowmans Creek EA (Evans and Peck 2009) for Bowmans Creek and the Eastern and Western Diversions remain appropriate.

The proposed measures to ensure compliance with the fluvial geomorphology-related performance measures remain appropriate.

8.0 References

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