HANCOCK GALILEE PTY LTD

Kevin's Corner Project Environmental Impact Statement

M | Surface Water

M1 Geomorphology Technical Report

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M4 Surface Water Quality Technical Report

| HANCOCK GALILEE PTY LTD

Kevin's Corner Project Environmental Impact Statement

M1 | Geomorphology Technical Report

Report

Kevin's Corner Mine Proposal: Assessment of Effects on Stream Geomorphology

15 APRIL 2011

Prepared for

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Executive Summary

Project Area

The Kevin's Corner coal mine project is located adjacent to the Great Dividing Range about 70 km northwest of the Central Queensland town of Alpha. It is on the eastern edge of the Galilee Basin coal measures area in a semi-arid part of the catchment of Sandy Creek, a southern tributary of the Belyando and Burdekin Rivers.

The Mining Lease Area (MLA) covers 375 km^2, and mining activities will be concentrated in the western 250 km^2 part of the MLA to the west of Sandy Creek. This latter area is the focus of this report. Mining will include open cut pits covering ~24 km^2, and underground longwall mining covering ~181 km^2. These activities will have effects on watercourse geomorphology.

There are over 100 km of watercourses in the mining area of the MLA. The main stream is Sandy Creek that runs for 13 km from south to north through the MLA. It has a main western tributary in Well Creek, and this in turn is joined by Middle Creek and Little Sandy Creek, and the latter is fed by Rocky Creek.

The landscape is mostly very gently sloping hills or flat valley floors with 62% of the mine area having slopes of <1^o, and a further 34% sloping at <3^o. Maximum total relief from the highest point (394 m in the western Middle Creek sub-catchment) to the lowest (278 m as Sandy Creek leaves the MLA) is 116 m, but most hillslopes are less than 20 m high. Thus the watercourses are generally small with relatively gentle gradients and overall stream energy conditions are low.

The catchments have been partially cleared of trees since the 1970s to improve grazing on the gentler slopes and this has affected about 40% of the mine area. Tree clearing is known to increase natural rates of land degradation and these processes are occurring close to many watercourses and sediment is actively being contributed to these streams.

Watercourse Geomorphology

The geomorphic characteristics of the watercourses are summarised in Tables 1 – 5. The main stream, Sandy Creek is a medium sized, low gradient, multi-thread sand bed stream. It has very low sinuosity and is mainly a ridge anabranching stream with some island anabranching sub-reaches. There are between 2 and 5 active channels each up to 20 m across. Bed sediment is medium – coarse sand with fine sand overbank deposits on the floodplain. The channels are actively transporting bedload in floods, but there is no evidence of significant aggradation suggesting the system is at present able to transport the sediment supplied to it. Most of the sand is supplied from Greentree Creek that joins from the southeast just upstream of the southern boundary of the MLA. Bankfull discharge occurs at around the 10-yr ARI flood when mean stream power is about 25 W/m^2. Extensive floodplain flow does not occur until events of >50-yr ARI magnitude.

Table 1 Sandy Creek geomorphic feature summary

Channel characteristic	Description
Landscape setting	Broad asymmetrical valley with low hills distant ~2 km to the west and adjacent medium hills to east.
Length of channel in MLA	13.2 km
Sinuosity	SI = 1.05, straight
Bed slope	0.17% in upstream 5 km, then 0.11%

Channel characteristic	Description
Channel planform and type	Ridge and island anabranching, 2 – 5 threads. Some short single thread reaches
Active bed character	Sand sheet with semi braided pattern in low flow channel. Several pools 150 – 500 m long in downstream of Well Creek junction.
Width of bed	Anabranches 25 – 50 m wide, total bed width 70 – 85 m.
Typical flow depth in mean annual flood	1 – 2 m
Sediment type	Medium – coarse sand. Overbank sediment fine sand – silt. Not obviously aggrading.
Sediment sources	Greentree Creek, Well Creek
Channel banks	Low, moderately sloping well grassed with some trees. In-channel benches present.
Bankfull conditions	Anabranch ridges and islands mostly covered by 1:5 to 1:10 AEP flood events. Flow depth 3 – 4 m, mean stream power 10 – 30 W/m^2.
Floodplain	Floodplain merges with Little Sandy Creek floodplain in larger than 1:50 AEP events, up to 2.5 km wide. Channel stream power > 50 – 75 W/m^2.

Table 2 Well Creek geomorphic feature summary

Channel characteristic	Description
Landscape setting	Upper reach narrow to moderately narrow valley confined between low hills. Lower reach traverses more open valley floor of Sandy Creek. Catchment tree cover largely intact.
Length of channel in MLA	20.9 km. Catchment area in MLA = 41.9 km^2
Reaches	Upper reach: to Middle Creek Junction (15.3 km) Lower reach: from Middle Creek Junction to Sandy Creek junction (5.6 km)
Sinuosity	Upper reach moderately sinuous irregular meandering channel SI = 1.4. Lower reach slightly sinuous SI = 1.1.
Bed slope	Upper reach 0.28% declining downstream to 0.22% Lower reach 0.17%
Channel planform and type	Single thread with occasional ridge anabranching sub-reaches in lower 2 km
Active bed character	Uniform sand sheet with low point bars. Bed aggrading in upper reach and upstream parts of lower reach. Knick points and small waterfalls formed in duricrusts in upper reach.
Width of bed	Upper reach: 10 – 20 m Lower reach 15 – 25 m
Typical flow depth in mean annual flood	Upper reach ~1 m. Lower reach ~1.5 m.
Sediment type	Coarse sand with occasional gravel lags. Overbank sediment medium to fine sand. Mud drapes in lower reach.

Channel characteristic	Description
Sediment sources	Areas of land degradation close to channel and active bend erosion sites mainly in upper reach, and from Middle Creek.
Channel banks	Upper reach mainly low (<2 m) gentle-moderately sloping with grass vegetation down to bed. In places higher banks (>2m) are vertical and being undercut by the stream. Lower reach similar with higher banks and more tree cover. In channel benches in lower reach.
Bankfull conditions	1:10 to 1:20 AEP events channel 2.5 – 3 m deep. Upper reach mean stream power 50 – 70 W/m^2 Lower reach mean stream power: 30 – 40 W/m^2
Floodplain	Upper reach: Intermittently developed, moderately wide where present – 200 m to 1000 m. Lower reach: well developed and is over 4 km wide where it merges with Sandy Creek floodplain ~ 3.5 km from that stream junction.

Table 3 Middle Creek geomorphic feature summary

Channel characteristic	Description
Landscape setting	Narrow valley confined between low hills. Catchment tree cover mostly intact.
Length of channel in MLA	19.5 km, in a single reach. Catchment area in MLA = 48.3 km^2
Sinuosity	Upstream SI = 1.4, downstream SI = 1.2
Bed slope	Upper reaches 0.52 – 0.37%, lower 12 km 0.27%
Channel planform and type	Single thread confined, with irregular low sinuosity meanders. Some short ridge anabranching sub-reaches.
Active bed character	Uniform sand sheet with low point bars. Bed aggrading. Knick points common, formed in duricrust materials.
Width of bed	5 – 10 m
Typical flow depth in mean annual flood	0.4 – 0.8 m
Sediment type	Medium to coarse sand in bed. Overbank sediment fine sand.
Sediment sources	Areas of land degradation close to channel and active bend erosion sites.
Channel banks	Mainly low (<2 m) gentle-moderately sloping with grass vegetation down to bed. In places higher banks (>2m) are vertical and being undercut by the stream.
Bankfull conditions	1:10 AEP events, channel 1 – 1.5 m deep. Mean stream power 30 – 60 W/m^2.
Floodplain	Not consistently developed. If present less than 100 m wide.

Table 4 Rocky Creek geomorphic feature summary

Channel characteristic	Description
Landscape setting	Upper reach narrow valley in dissected hills. Lower reach 1.5 – 2 km wide valley between low hills. Trees cleared from half of catchment.
Length of channel in MLA	14.5 km. Catchment area in MLA = 32.9 km^2
Reaches	Upper reach 3 km confined between hills. Lower reach 11.5 km in wide flat floored valley
Sinuosity	Both reaches SI = 1.3, moderately sinuous.
Bed slope	0.29%
Channel planform and type	Upper reach single thread confined, meander wavelength 300 – 400 m. Lower reach anastomosing with 2 – 3 meandering channels of wavelength 150 – 200 m
Active bed character	Sand sheet arranged into pools and riffles with low point bars. Duricrust knick points upper reach Large woody debris present in lower reach. Upper reach and upstream parts of lower reach actively aggrading.
Width of bed	Upper reach mean width 8 m Lower reach mean width 13 m
Typical flow depth in mean annual flood	0.75 m
Sediment type	Medium to coarse sand with fine sand overbank deposits. Gravel lags below duricrusts knick point. Mud drapes occur in downstream part of lower reach.
Sediment sources	Active land degradation sites along both reaches, and active bank erosion on outside of meander bends.
Channel banks	Moderately steep, partly vegetated with grass and some trees
Bankfull conditions	Upper reach: 1:50 AEP event, 2.5 – 3 m deep, mean stream power 30 – 35 W/m^2. Lower reach: 1:20 to 1:50 AEP events declining to 10 – 20 yr ARI, 1.5 – 2.5 m deep, mean total stream power <10 W/m^2.
Floodplain	Not present in upper reach. Lower reach: extensive floodplain up to 1 km wide, 1.5 km where it merges with Little Sandy Creek floodplain. Upstream parts only active in larger than 1:50 AEP events, downstream active in larger than 1:10 AEP events.

Table 5 Little Sandy Creek geomorphic feature summary

Channel characteristic	Description
Landscape setting	Upper reach narrow valley in dissected hills. Lower reach 1.5 – 2 km wide valley between low hills. Trees cleared from half of catchment. 63%
Length of channel in MLA	34.8 km. Catchment area in MLA = 72.6 km^2

Channel characteristic	Description
Reaches	Upper reach 4.3 km confined between hills. Upper middle reach 11.1 km in wide flat floored valley Lower middle reach 16.4 km in wide flat floored valley Lower reach 3.0 km in wide flat floored valley
Sinuosity	Upper reach SI = 1.2, sinuous. Upper middle reach SI = 1.6, meandering. Lower middle reach SI = 1.4, moderately meandering. Lower reach SI = 1.7, meandering.
Bed slope	Upper reach 0.63% Upper middle reach 0.2% Lower middle reach 0.16% Lower reach 0.07%
Channel planform and type	Upper reach single thread confined Upper middle reach single thread, meander wavelength 200 – 300 m. Lower middle reach anastomosing with 2 – 3 meandering channels of wavelength 300 – 400 m. Lower reach single thread meander wavelength 100 – 150 m
Active bed character	Upper reaches have coarse sandy bed with pools and riffles. Lower reaches have finer sand and long pools. Duricrust knick points occur in upper reach. Large woody debris present in lower reaches. Upper and upper middle reaches actively aggrading.
Width of bed	Upper reach 5 – 10 m Upper middle reach 10 – 15 m Lower middle reach 15 – 20 m Lower reach 10 – 15 m.
Typical flow depth in mean annual flood	Upper reach ~0.5 m Upper middle reach ~0.75 m Lower middle reach ~1.2 m Lower reach ~1.5 m.
Sediment type	Upper and upper middle reaches have medium to coarse sand with fine sand overbank deposits. Finer sands in downstream reaches with mud drapes.
Sediment sources	Active land degradation sites along both upper and upper middle reaches, and active bank erosion on outside of meander bends.
Channel banks	Moderately steep to steep, partly vegetated with grass and some trees. Erosion on outside of bends. In-channel benches and levees occur in lower reach.

Channel characteristic	Description
Bankfull conditions	Upper reach: larger than 1:50 AEP event, 2.5 – 3 m deep, mean stream power 30 – 35 W/m^2. Upper middle reach: variable from 1:10 to 1:50 AEP events, 1 – 2 m deep, 15 – 35 W/m^2 Lower middle reach: 1:10 to 1:20 AEP events, 2 – 2.5 m deep, mean total stream power <10 W/m^2. Lower reach: 1:5 to 1:10 AEP events, 2.5 – 3 m deep, mean stream power 2 – 7 W/m^2.
Floodplain	Not present in upper reach. Lower reaches: extensive floodplain up to 1 km wide, 2.0 km where it merges with Sandy Creek floodplain. Upstream parts only active in larger than 1:20 AEP events, downstream active in larger than 1:10 AEP events.

The watercourses of the tributary streams (Well Creek, Middle Creek, Rocky Creek and Little Sandy Creek) are much smaller than Sandy Creek. In total they drain 196 km^2 of the MLA and comprise 87.9 km of watercourses. All have contrasting characteristics to Sandy Creek.

Well Creek is the largest tributary and by the time it joins Sandy Creek at about 5.6 km south of the northern boundary of the MLA, it has collected all of the other tributaries. Through most of its course it is a relatively small, moderately steeply sloping single thread sand bed stream with moderate to low sinuosity. Bed sediment is medium – coarse sand with fine sand overbank deposits on the narrow floodplain. The channel is actively transporting bedload in floods, and aggradation is occurring in the upper reach. Middle Creek delivers some sand to the lower reach, but its other main tributary Little Sandy Creek does not. There are is no evidence of significant aggradation in the lower reach although the creek is actively delivering sediment to Sandy Creek. Bankfull discharge occurs in floods of >10-yr ARI magnitude and stream power is between 30 – 70 W/m^2.

Middle Creek is a tributary of Well Creek. It is a small bedrock confined stream, relatively steeply sloping, and single thread. The narrow sand bed is actively transporting coarse sand, and aggradation is starting to occur in some sub-reaches. Bankfull discharge occurs at around 10-yr ARI magnitude floods and stream power is relatively high at 30 – 60 W/m^2.

Rocky Creek is a tributary of Little Sandy Creek. Downstream of a short upper confined reach the valley opens out and a moderately sinuous multi-thread anastomosing channel system with a wide floodplain occurs. There are 2 – 3 active channels and their beds are 5 – 15 m across. The upper reaches are actively aggrading and the medium – coarse sand bedload contrasts with the cohesive fine sand and silt of the floodplain sediments. Bankfull discharge conditions occur in floods of magnitude >10-yr ARI and overall stream power is typically low at <10 W/m^2.

Little Sandy Creek is a tributary of Well Creek, and like Rocky Creek has a long reach with an anastomosing channel system and a wide floodplain. Bed slope is relatively gentle. The upper reaches are actively aggrading, but this sediment has not reached all the way downstream as the lower reaches are carrying little bedload, and at the junction with Well Creek the channel sediment is characteristically muddy. Bankfull discharge occurs in floods around the 10-yr ARI magnitude, and overall stream power is low at <10 W/m^2.

Assessment of Potential Geomorphic Effects

The Kevin's Corner Project has the potential to affect several aspects of the watercourse geomorphic environment, including on the hillslopes that direct surface runoff to the channel, within the watercourses, and on the floodplains.

Subsidence effects

Spatially the widest effects would arise from subsidence of the underground longwall mining panels affecting the catchment hillslopes. By the end of the mine life this will have affected 181 km^2 of the catchments of Well Creek, Middle Creek Rocky Creek and Little Sandy Creek. Surface subsidence of 0.5 m to 3 m will occur in 27 rows of north-south oriented panels, introducing a regular 300 m spaced waveform across the landscape. This could change surface runoff patterns, concentrating flow and forming gully erosion that would increase sediment delivery to watercourses. However, the hillslopes here are mostly quite gentle and if gullying did begin to develop surface water and sediment runoff remedial measures could be implemented.

Subsidence in the watercourses will lower the stream beds in a regular 300 m long by 0.5 m – 3 m high wave-like pattern to form long pools. Most of the streams drain west to east, thus the subsidence will be perpendicular to watercourses. The affected streams currently carry significant sand bedload and in floods this will be transported into the pools to restore the original bed profile. This will temporarily reduce total downstream sediment transport, although it may only take a flood or two to achieve bed restoration particularly where the subsidence is <1 m. While the bed level will have recovered, the adjacent floodplain will not, and thus the channel capacity will have been reduced, and more frequent floodplain flow will result.

Channel banks may be weakened by the surface cracking associated with subsidence. These could become preferential sites for accelerated bank erosion or development of pipeflow and tunnel gullies. These processes will increase the channel width and deliver increased sediment load to the watercourses.

Subsidence under the floodplains will change inundation patterns, increasing inundation depth in some places, and reducing it in others. The main geomorphic effect will be associated with return flow from the floodplains back to the watercourses. The subsidence will create preferential flow paths for the floodwater, and where this drops back into the channels gully erosion could develop.

Watercourse effects

The proposed mine will have a number of direct effects on watercourses. The main pit will remove 8.6 km of the Little Sandy Creek channel, and in some reaches of Rocky and Little Sandy Creeks the channel will remain but will carry greatly reduced or no flow. The main watercourse effects will be associated with the diversion of Rocky Creek and Little Sandy Creek into a 5.6 km engineered channel that will carry the whole flow of these two creeks into Middle Creek. The natural channels of Middle Creek and then Well Creek will therefore carry increased flood flow.

Diversion effects

The diversion will be constructed in the upper-middle valleys of Little Sandy, Rocky, and Middle Creeks. The structure will cross 3 km of the Little Sandy Creek and Rocky Creek floodplains, and then be cut up to 15 m below a low ridge separating the valleys of Rocky and Middle Creeks. A ~20 wide gently sinuous low flow channel will be formed, with a 200 m wide floodplain. The overall gradient of the diversion is low and stream power at 50-yr ARI would average <20 W/m^2. A stable channel should develop under these conditions.

Effects in Middle Creek watercourse

The diversion will increase flow in Middle Creek by up to 2.75 times. Flow width, depth and velocity will all increase and as a result stream power will increase by between 4 W/m^2 and 44 W/m^2 for the 2-yr ARI to 50-yr ARI floods. These increases would lift Middle Creek from a low to a moderate energy stream but it would still be less than half the 220 W/m^2 upper limit for natural channels in the Central Queensland Mining Industry Watercourse Diversions (2008) guidelines. Middle Creek is a bedrock confined stream and moderate to high stream power is consistent with this type of system. While the increased flow regime will probably lead to some channel widening and re-organisation of the small floodplain landforms present, this is unlikely to result in a major long term change to the geomorphic system along the watercourse.

Effects in Well Creek watercourse

The increased flow in Middle Creek will, when it joins Well Creek increase flow in that watercourse 1.2 times above its natural discharge. Effects on stream energy will be largely undetectable until 20-yr ARI floods and greater when mean stream power would increase by 20 W/m^2 to 45 W/m^2. However, these levels will still be less than half the guideline upper limit for natural watercourses. Some small scale reorganisation of the watercourse geomorphology may result.

Effects on Sandy Creek and Well Creek floodplains

The two proposed mine pits will remove ~17 km^2 of floodplain, and 27 km of levees will be constructed around the pits to protect them from floodwaters. The floodplains of Sandy Creek and Well Creek will be constrained by these levees. Sandy Creek floodplain will be reduced by over a kilometre in width. Despite these significant spatial changes there will be no detectable effects of this floodplain constriction on floods up to 50-yr ARI magnitude. This is due to the natural characteristics of the channel and floodplain system whereby significant floodplain inundation does not occur until events greater than 50-yr ARI occur.

The lower Well Creek floodplain merges with Sandy Creek floodplain and it will be constricted between levees in its downstream ~4 km. The constriction will reduce 50-yr ARI flood conveyance space and mean stream power rises ~20 W/m^2. However, this is a generally low energy system, and the elevated stream power is still about 25% of the guideline upper limit.

Stream sediment loads

The upper reaches of streams in the MLA were starting to aggrade under the influence of elevated sediment discharge to the watercourses. This sediment appears to be sourced from land degradation sites that occur close along the watercourses and some bank erosion on the outside of bends. The aggradation was seen in the upper parts of Greentree, Little Sandy, Rocky, Middle and Well Creeks. The lower reaches of Little Sandy and Well Creeks do not appear to be affected, and Sandy Creek, while an active transporter of bedload sediment, is also not aggrading. This increased sediment load probably arises from land use changes and tree clearing over recent decades. The aggradation is expected to make its way downstream and start to affect Sandy Creek probably within the next decade.

Management of the MLA watercourses will need to address this background trend of increasing bed aggradation as it will decrease channel flood conveyance capacity and result in more frequent floodplain inundation.

Mitigation and Monitoring

A variety of potential geomorphic effects could arise in the watercourses, floodplains and hillslopes of Sandy Creek and its tributaries as a result of the Kevin's Corner Project. Many of these effects are related to hydraulic issues covered in detail in the *Hydraulics Technical Report*. Design mitigation concepts have been proposed in that report, and no further geomorphic-specific design is required.

Given the episodic nature of change in this semi-arid fluvial environment and the generally low energy watercourse environments in the MLA, a reactive environmental management regime would be effective. Geomorphic issues can be detected as they occur, and responses tailored to specific problems as they emerge. Crucial to this approach is adequate monitoring which can identify the small changes that are likely to lead on to more significant effects. The monitoring needs to be broad enough to detect landscape-scale changes but also detailed enough to anticipate particular problem sites such as in and around the diversion. A program of monitoring should be developed around the following concepts.

Baseline geomorphic description

A detailed survey of the MLA geomorphology should be undertaken prior to mining activities, supported by:

- Airborne LIDAR survey (accuracy $\pm$ 0.1 m)
- Dry season vertical aerial photography
- Helicopter-acquired high definition digital video of all major streamlines

Various landform, slope, watercourse and other mapping classifications can be developed for inclusion in a GIS database. The watercourse classification should identify knick points and other areas where high stream power conditions are likely to occur

Particular attention should be placed on areas likely to be most affected including the diversion, Middle Creek and Well Creek below the diversion, and Sandy Creek.

Reference watercourse and floodplain reaches of at least 300 m should be documented upstream, within, and downstream of the potentially affected areas. Data gathered should include ground surveyed cross sections, bed sediment samples, floodplain sediment dispersivity, large woody debris, bedforms (pools/riffles/runs/sand sheets/bedrock controls).

Land degradation types and distribution should be mapped across the MLA.

This material should be compiled into a descriptive and interpretive reference geomorphic report supported by relevant GIS databases

Monitoring throughout the mine life

Detailed geomorphic monitoring should occur at 5 yearly intervals throughout the mine life.

Reporting should assess the nature and extent of geomorphic changes that have occurred since the previous survey, and recommend remedial actions to address any mine-related adverse effects on the geomorphic environment. This assessment should cover channel, floodplain, and diversion changes, the extent and effects of subsidence across the landscape, and changes in the nature and extent of land degradation processes.

An important part of these on-going assessments will be appropriate documentation of rainfall, storms, floods and other landforming processes that may have influenced geomorphic processes in the preceding years. It will be necessary to differentiate clearly between those processes that are natural and those that are due to mining or other human activities.

Between each five-yearly survey, annual rapid geomorphic assessments should be carried out to identify occurrences of accelerated erosion, sedimentation, or other landform changes. Appropriate recommendations for site remediation should be included in the reporting of these rapid assessments.

Event-based full scale monitoring should also occur within 6 months after 10-yr ARI or greater floods. This should then be repeated within 2 years to document recovery, and the 5-yearly surveys continued after that.

End of mine survey

A full survey of the geomorphic environment should be undertaken at the end of the mine life prior to relinquishment of the miming licence. The reporting should comprehensively review all previous monitoring and recommend any mitigation that may be appropriate to ensure a stable geomorphic system is able to continue to evolve into the future.

Introduction

1.1 Background

The Kevin's Corner coal mine project is located in the central-eastern Galilee Basin coal measures area about 70 km northwest of Alpha, and 200 km west of Emerald. It is just north of the proposed Alpha Mine. The company is proposing to extract up to 30 million tonnes of steaming coal per year.

The Kevin's Corner Mining Lease is MLA 70425 and it covers 375 km^2, being an irregular rectangle-shaped area up to ~24 km east-west and up to ~21 km north-south. The proposed mining area will be in the western 2/3^{rds} of the MLA. It will comprise surface open cast and underground longwall mining operations which will have effects on stream geomorphology. The purposes of the present report are therefore:

- To document the existing stream and floodplain geomorphic conditions in order to provide a baseline against which to assess:
- The potential effects of the Kevin's Corner Project on the fluvial geomorphic environment.

Several aspects of the project have the potential to affect the fluvial geomorphic environment. These are:

1. Ground subsidence after completion of longwall panel underground mining. This would affect Well Creek, Middle Creek, Rocky Creek, and upper Little Sandy Creek;
2. Open cast operations over the lower parts of Little Sandy Creek; and
3. Stream diversions of Rocky and Little Sandy Creeks into Middle Creek.

This report contributes to aspects of the surface water assessments of the environmental impacts of the Kevin's Corner Project. It is concerned with the fluvial geomorphic environment, in particular the physical process regimes associated with stream flow; sediment erosion, transport and deposition; and the resulting landforms that occur in the watercourses and on their associated floodplains.

The report will cover the following:

- Fluvial geomorphic concepts and previous relevant investigations;
- Kevin's Corner Project and its potential geomorphic effects;
- Landscape setting of the Kevin's Corner Project and Sandy Creek catchment;
- Baseline geomorphic assessment of the channels and floodplains of Sandy Creek and its tributaries Well Creek, Middle Creek, Rocky Creek, and Little Sandy Creek;
- Potential impact of diversions and floodplain levee banks on watercourses;
- Potential impact of subsidence on the geomorphic environments of Well Creek, Middle Creek, Rocky Creek, and Little Sandy Creek; and
- Proposed monitoring and mitigation measures to asses and address impacts on the geomorphic environment.

1.2 Methods and Data Sources

This geomorphic analysis has been carried out from a combination of desktop and field investigations.

1 Introduction

1.2.1 Topographic data

Topographic data has been obtained from a one metre interval contour plot derived from digital orthophotography flown on 5th and 6th of May 2008, and processed by AAMHatch Ltd. Accuracy is estimated to be ±1 m horizontal and ±1 m vertical.

1.2.2 Aerial photography

Historical aerial photographs of parts of the MLA were examined to determine changes in vegetation cover and channel changes. Aerial photographs accessed were:

SVY1385, Jericho, Run, 2 #s 5141 & 5143 (19/6/1952)

SVY1392, Jericho, Run 3, #s 5028 & 5030 (23/6/1952)

CAB7031, Jericho Run 1, #s 79, 83, 87 19/8/1969)

CAB7031, Jericho Run 2, #s 79, 83, 87 19/8/1969)

Q3800, 8151 Edwinstowe, Run 2, #165, (7/9/1980)

Q3800, 8151 Edwinstowe, Run 3, #s22 & 24, (5/9/1980)

Q3800, 8151 Edwinstowe, Run 4, #236, (7/9/1980)

Q4961, Edwinstowe 8151, Run 1, #s 54, 56, 58, 61, & 63, (30/6/1991)

Q4961, Edwinstowe 8151, Run 2, #s 47, 49, 51, 53, (30/6/1991)

Q4962, Edwinstowe 8151, Run 3, #s 7 & 9, (30/6/1991)

Q4961, Edwinstowe 8151, Run 4, #s 247 & 249, (29/6/1991)

QAP5926, Edwinstowe 8151, Run 1, #s 15, 17, 19, 21, (21/11/2001)

QAP5926, Edwinstowe 8151, Run 2, #s 46, 48, 50, 52, (21/11/2001)

QAP5926, Edwinstowe 8151, Run 3, #s 81, 83, 85, & 87, (21/11/2001)

1.2.3 Hydrological modelling

Outputs from hydrological models have also been used, including HEC-RAS and TUFLOW models of Sandy Creek and its tributaries. These models are described in detail in the EIS Appendix M2.2: *Kevin's Corner Project - Hydraulics Technical Report.*

The present report should be read in conjunction with that study.

1.2.4 Fieldwork

Fieldwork was carried out between October 9th – 13th 2010, and included helicopter fly-overs and landings, and 4WD vehicle based surveys from farm tracks. The area had experienced heavy rainfall in the preceding month and some areas were still inaccessible. Site visits were therefore prioritised to achieve a spread of coverage along each stream system, with particular attention to tributary stream junctions where any contrasts between stream environments would be most obvious.

1.3 Study Location and Nomenclature

The location of the Kevin's Corner MLA is described and mapped in the EIS Appendix M2.1: *Kevin's Corner Project - Flood Hydrology Study.* Of particular relevance to the present report are the stream catchments in the MLA that will be directly impacted by the proposed mine operations.

The master stream running from south to north through the MLA is Sandy Creek, and the main channel is located to the east of the centreline of the MLA. Sandy Creek is formed at the junction of Lagoon and Greentree Creeks just a few hundred metres to the south of the MLA. Most of the MLA lies in the catchment of Sandy Creek and its main true left tributary Well Creek. This latter creek has Middle Creek and Little Sandy Creek as tributaries. Little Sandy Creek has Rocky Creek as a tributary. The watercourses of Little Sandy and Rocky Creeks will be diverted as part of the Project.

1.3.1 Model layout and HEC-RAS chainages

This report discusses watercourse geomorphology with reference to locations defined in the HEC-RAS models noted above. Table 1-1 identifies the main elements of the model and the chainages (ch) measured along the channels in metres.

Stream	Description	Chainages
Sandy Creek	Master stream flowing south to north through MLA.	Enters MLA at ch 13214 Leaves MLA at ch 59 Length in MLA 13.15 km
Well Creek	Flows east from foothills of Great Dividing Range. Only major tributary joining Sandy Creek in MLA.	Enters MLA at ch 20936 Joins Sandy Creek at ch 4929 Length in MLA 20.94 km
Middle Creek	Flows east and northeast from foothills of Great Dividing Range. Tributary of Well Creek	Enters MLA at ch 19797 Joins Well Creek at ch 5785 Length in MLA 19.8 km
Rocky Creek	Flows east from foothills of Great Dividing Range. Tributary of Little Sandy Creek.	Enters MLA at ch 14528 Joins Little Sandy Creek at ch Length in MLA 14.5 km
Little Sandy Creek	Flows east then north from foothills of Great Dividing Range. Tributary of Well Creek.	Enters MLA at ch 32766 Joins Well Creek at ch 1600 Length in MLA 32.8 km
Greentree Creek	Flows east from Great Dividing Range. Joins Lagoon Creek to form Sandy Creek 0.77 km south of MLA. Enters south side of MLA in two short meander bends.	Enters MLA between ch 14919 and ch 10337 Joins Lagoon Creek at Ch 14000 Length in model 18.6 km Length in MLA 3.3 km
Lagoon Creek	Master stream flowing north in Alpha MLA immediately to the south of Kevin's Corner MLA. Joins Greentree Creek to form Sandy Creek 0.77 km south of Kevin's Corner MLA southern boundary.	Joins Greentree Creek at Ch 14000 Length in model 26.4 km Length in MLA 0 km

1.4 Scope of this assessment

This assessment considers the western 2/3rds (251 km^2) of the Kevin’s Corner MLA where most of the mining will occur and the mine infrastructure will be located. Watercourses in the eastern part of the MLA, east of Sandy Creek, and in the hills that drain into the adjacent Native Companion Creek are largely unaffected and will not be discussed.

1.5 Outline of this report

Section 2 covers background concepts and an overview of relevant literature.

Section 3 describes mine activities that may affect watercourses and the fluvial geomorphic environment.

Section 4 provides an overview of the landscape geomorphic and hydrological setting.

Section 5 is a baseline assessment of water courses and the fluvial geomorphic environment.

Section 6 assesses potential effects on watercourses and fluvial geomorphology.

Section 7 outlines suggested mitigation and monitoring measures.

Fluvial Geomorphic Concepts

2.1 Fluvial processes and landforms

This assessment considers the fluvial geomorphology of Sandy Creek and its associated tributaries near the proposed Kevin's Corner coal mine, and the potential effects of the project on these environments. The science of geomorphology is concerned with the landforms on the Earth's surface and the processes that shape them. Landforming processes include tectonic forces, volcanic processes; erosion by water, ice, wind, and waves; transport processes that carry erosion products away; and deposition processes that result in sediment build-up. Landforms can result from all stages of these processes.

The main landforming processes addressed in this study are the river (or fluvial) processes that have formed landforms along Sandy Creek and its tributaries.

This study of the landform environment provides a context for other related assessments being carried out for the Kevin's Corner EIS. Landforms provide boundary conditions within which other environmental and human systems operate such as river sediment transport systems, and riparian wetland and groundwater systems.

A major landforming process agent is stream flow that erodes its channel and valley, transports bedload sediment (sand and gravel), and deposits sediment to creates fluvial landforms and floodplains.

The fluvial system is a broad concept that links together the processes, materials and boundary conditions that result in the development of the fluvial environment. It may be conceived as a cascading system starting with rainfall that may infiltrate into the soil and make its way to a channel via slow subsurface pathways and groundwater flow, or it may run directly off the landscape as overland flow and contribute to rapid increases in channel discharge and so cause floods. Once in the channel, water flows rapidly through the system, carrying clay and silt suspended sediment generated from soil erosion, or transporting bedload sand and gravel derived from bank and bed erosion.

Of particular significance in this study are the channel and floodplain landforms that result from these processes of fluvial erosion and deposition.

2.2 The Fluvial System

An useful organising concept is the Fluvial System as proposed by Schumm (1977), which divides a river catchment up into three zones:

Source Zone where water and sediment is delivered to the channel network. This occurs in the headwater parts of the watershed.

Transfer Zone through which water and sediment is being carried with the latter being temporarily stored in floodplains and terraces (long term storage), channel benches (medium tern storage), and channel bars (short term storage).

Sink Zone where water is delivered to a lake or the ocean and sediment permanently deposited in a delta or alluvial fan.

Kevin's Corner project is located near the 'top' of the fluvial landscape and includes elements of both the source zone and uppermost parts of the transfer zones of this fluvial system. Effects arising here can potentially be transferred progressively downstream to the Belyando, Suttor, and Burdekin Rivers and eventually to the Coral Sea and Great Barrier Reef region.

2.3 Fluvial Landforms

There are a great many fluvial landforms, but the three basic ones are:

Hill slopes that direct rainfall and sediment down to the channel network. These are most commonly found in the Source Zone;

Floodplains are near flat surfaces adjacent to the channel and formed of river deposited alluvium (silt, sand and gravel sediments) and is a primary location for the temporary storage of sediment in the Transfer Zone; and

Channel that conveys water and sediment through and eventually off the landscape. These occur in all three fluvial zones in a wide variety of types.

2.4 Hill slopes

Almost everywhere on the Earth’s surface has at least some slope, and water will flow down this, either over the surface or beneath the surface through the soil layers. Rainfall landing on the ground will be either absorbed by infiltration and enter the soil drainage system, or if infiltration capacity is limited overland flow will occur. This latter process is very common in semi-arid environments such as at Kevin’s Corner.

Most slopes in the MLA are very gentle. They will be significantly affected by ground subsidence arising from the underground mining activities. This will potentially affect surface flow paths and soil erosion potential.

2.5 Channels

Stream/river channels can be formed in bedrock or alluvium. Bedrock channels are found often in the source zone and are effectively stable features that do not change shape or location over very long time periods. Alluvial channels are formed in sediments that can be eroded by the water flow and they are thus potentially dynamic where the bed landforms or even the channel location can shift during floods. They are found in the transfer and sink zones.

A stream or river channel carries water flow and in natural systems typically has a capacity sufficient to carry flows up to the magnitude of small floods, but for larger floods water will overflow and spread out over the adjacent floodplain. The point at which this overflow occurs is referred to as the bankfull discharge and this is discussed below.

A channel consists of a relatively horizontal bed flanked by generally steep banks. The bed will contain a variety of sediments that the river flow arranges into many different small-scale landforms. The channel banks vary with height above the bed. The lowest part is the active bank that is often inundated with water and it will be steep or vertical and usually bare of vegetation. Above this the bank slope will become gentler and there is likely to be some soil cover and grass vegetation present. At higher levels shrubs and trees may be able to survive the less frequent and briefer periods of inundation.

Channel geomorphology can be very diverse, and relevant issues include the large scale planform shape along the length of the river (sinuosity, channel type such as straight, meandering, braided, anastomosing, anabranching); sediment characteristics (sand, gravel, boulders, sediment waves or sheets); small-scale in-channel landforms (pools and riffles, bars, benches, terraces); bank landforms (terraces, benches, and levees); and vegetation (large woody debris both living and dead).

2 Fluvial Geomorphic Concepts

In Sandy Creek the present channel bed comprises two or more 20 – 30 m wide sandy channels and there is no flow in the stream most of the time. The channel banks are well vegetated with grass, trees and shrubs right down to the bed level, and a near vertical lower active channel bank is not widely developed. The tributary streams have much smaller channel beds typically less than 15 m across, and a more diverse range of landforms.

2.5.1 Channel planform

Stream channels occur in a wide variety of planforms – straight, sinuous, meandering, single thread, or multiple thread. All of these types occur in the Kevin's Corner MLA.

Straight channels are defined as those whose sinuosity index (SI = channel length ÷ valley length) is less than 1.05. *Sinuous* channels have SI >1.05 and <1.5. *Meandering* channels have SI >1.5.

*Multiple thread channel*s can be braided, anabranching, or anastomosing. Large scale braided channels are particularly associated with gravel bed rivers and have multiple threads branching around bare mid-channel bars or islands that are inundated well before bankfull discharge stage is reached. As such they are not known from Bowen Basin or Galilee Basin Rivers. However, small scale braiding patterns are seen in the sand bed channels of Bowen and Galilee Basin streams but this is completely washed out by even small flows in the channel and is not true channel braiding. The multi thread channels seen in the Bowne/Galilee Basins are either anabranching or anastomosing channels[*].

Anabranching channels are multiple channels characterised by vegetated or otherwise stable alluvial islands that divide flows at discharges up to or greater than bankfull discharge stage (Nanson and Knighton, 1996). The individual channels are typically straight, sinuous or slightly meandering; the island level is usually at about the same level as the floodplain; and with stable banks they persist for decades or centuries and so are often well vegetated. Two anabranching types a common:

- sand dominated island-forming anabranching rivers where generally low stream powers (<15 W/m2) (see Section 2.5 below), and good vegetation cover is required to maintain bank stability; and
- sand dominated ridge anabranching where the islands are narrow linear or slight curvilinear ridges, and stream power is usually higher (15 – 35 W/m^2).

Sandy Creek has both island and ridge anabranching reaches, and Figure 2-1 shows an aerial view of a section of ridge anabranching channel near ch 8500. The view is to the northwest, and three sand bed channels can be seen in the foreground riparian vegetation.

Anastomosing channels are highly sinuous with low gradients and stable cohesive banks. Stream power is usually low (<10 W/m^2). Rocky Creek and Little Sandy Creek have reaches that are anastomosing, and Figure 2-2 shows an aerial view of Little Sandy Creek near ch 11400. The three lines of trees winding away from the camera follow the anastomosing channels.

[*] The ACARP reports on Bowen Basin Diversions refer to braided rivers in Central Queensland. From the context it is unclear where these are intended to be references to classic braided rivers, or the braided pattern that is common across the very low flow sand beds of the rivers, or is a mis-use of the term to refer to multithread anabranching or anastomosing streams. In any event, braided rivers as usually defined in the literature are not known to occur in Central Queensland.

2 Fluvial Geomorphic Concepts

Figure 2-1 Ridge anabranching channel in Sandy Creek near ch 8500

Figure 2-2 Anastomosing channels along Little Sandy Creek

Nanson and Knighton (1996) propose that the functional advantage of the anabranching and anastomosing channel types is that by concentrating flow in the channels the stream increases its ability to transport bedload sediment. Thus, in a low stream energy environment with significant bedload supply, by anabranching the stream is able to maintain a stable form that does not become overwhelmed by aggradation.

2.5.2 Channel forming or bankfull discharge

For geomorphic analysis of alluvial channels, the channel-forming discharge is considered to be that flow which just fills the channel before spreading out onto the surrounding floodplain. This is also known as the *bankfull discharge* and it is generally considered to be a relatively common event typically with an ARI (Average Recurrence Interval) of between one and five years, with a value of 1.5 years widely accepted around the world. However, in Australian conditions a flood of this frequency is rarely large enough to fill the active channel and bankfull discharge is more often associated with floods of ARI 7-yr to ARI 10-yr or even greater.

The channel forming discharge is the most significant event for watercourse geomorphology as most channel change results from these events. While large floods are more dramatic, they do not tend to accomplish as much total work in the geomorphic environment as the bankfull discharge event. Thus this report examines the effects of floods up to and including the 50-yr ARI magnitude event. Larger floods while not as significant in geomorphic terms are very relevant for other assessments and are discussed in the *Flood Hydrology Study* and *Flood Hydraulics Report*.

2.5.3 In-channel benches

A common feature of Central Queensland streams and rivers is the in-channel bench. This is a low terrace-like landform adjacent to and above the stream bed that is within the bankfull discharge channel. It can be semi-stable and vegetated with grass and small trees. During very large floods it is likely to be eroded away, but will re-form during smaller flood events. It acts as a temporary store of sediment and is an important feature contributing to long-term channel stability.

2.6 Floodplains

As the term suggests, the floodplain is an area of generally flat terrain, adjacent to a river channel that is covered by floodwaters when the discharge capacity of the channel has been exceeded. Two basic types of floodplains are recognised: the *hydraulic floodplain* is any surface adjacent to a channel that is subject to river flooding within a given return period; and the *genetic floodplain* that is an alluvial landform constructed by the flow regime of the present river and subject to flooding.

The hydraulic floodplain is an engineering concept that is mainly concerned with the extent of flooding, irrespective of what is being flooded. The genetic floodplain concept is geomorphic and is concerned both with the extent of flooding and the nature of the channel and floodplain landform in and over which this occurs. In particular, it treats the river discharge, channel and the floodplain as being interconnected and the discharge regime is the process agent that forms the channel and floodplain. In this way the floodplain is seen to be formed by the river flow regime.

The channels and floodplains of Sandy Creek and its tributaries in the Kevin's Corner MLA show elements that are relevant to both definitions, with narrow hydraulic floodplains on the up-catchment source zone stream reaches passing downvalley into wider genetic floodplains.

2.6.1 Floodplain processes and landforms

Floodplains result from the deposition of alluvial sediment by the river. Water out of the channel and flowing across the floodplain will deposit generally fine sand and silt as overbank deposits. If the channel is migrating, it will erode the adjacent floodplain on the outside of channel bends while depositing material on the inside of bends. Several styles of channel deposition can therefore contribute to floodplain growth including lateral accretion, and oblique accretion.

Floodplain landforms include levees and scrolls, abandoned channels (palaeo-channels), ox-bows, and backswamps. Levees are low mounds of sediment built up above floodplain level at the junction of the channel and floodplain and are formed by deposition as floodwaters leave the channel. Scrolls are groups of former levees where the channel has migrated away. Abandoned channels occur where the main channel moves away from part of the floodplain often due to a single avulsion event where a flood breakout occurs and a new river course is formed. These may become occupied by backswamps or ox-bow lakes.

The Sandy Creek and tributary floodplains are generally flat and featureless, although a few backswamps, palaeochannels and levees do occur.

2.6.2 Floodplain classification

Nanson and Croke (1992) developed a classification for floodplain types that is relevant for river management. The Kevin’s Corner project will affect floodplain areas along Sandy Creek and its tributaries. It is therefore important to establish the floodplain context within which this will occur.

The classification scheme links the floodplain with its associated channel and takes a force and resistance approach, with the force represented by stream power at bankfull discharge stage, and resistance represented by the relative cohesiveness of the floodplain and channel bank sediments. Sand and gravel sediments are treated as non-cohesive, and slit and clay as cohesive. Three floodplain classes are identified: Class A – high-energy non-cohesive; Class B – medium energy non-cohesive; and Class C – low energy cohesive. Within each class are a number of orders that can be identified on the basis of sediment loads, stream power, processes, landforms, and channel planform. Changes in environmental variables such as sediment supply and stream power may result in predictable shifts of floodplain behaviour, which can form a basis for management.

The channel environments of Sandy Creek and its tributaries are (not surprisingly) often sandy, and thus would fall in Class A or Class B (non-cohesive), although the anastomosing channels of Rocky and Little Sandy Creeks suggest these environments have cohesive sediments and would be Class C floodplains.

2.7 Stream power

When considering the geomorphic environment of alluvial river channels a useful concept is that of *stream power.* This is the rate of energy expenditure in flowing water, and is a measure of the energy available to do geomorphic work along the channel. In fluvial geomorphology it is usually referred to as *specific stream power,* which is the amount of energy expended per unit area of the bed and is written:

$$\omega\ (w/m^2) = \gamma Qs\ /\ W$$

Where ω = specific stream power in watts per square metre; γ = specific weight of water; Q = discharge; s = water surface slope, and w = water surface width.

It can be calculated for any discharge, but in geomorphic studies is usually determined for the bankfull event.

For engineered channels in alluvial materials stream power at bankfull stage of ≤35 w/m^2 should ensure the channel does not fail due to erosion (Brookes, 1990). In natural alluvial channels stream powers can exceed these values, depending on the type of system. Actively meandering channels can have bankfull stream power in the range of 20 – 100 W/m^2, while braided rivers can have stream powers in the range of 100 W/m^2 to >1000 W/m^2. These higher values for natural systems are in part due to the larger accommodation space within a floodplain where a channel can shift its position in response to the effects of channel forming discharge events.

The Queensland Department of Natural Resources and Water has published guidelines for water course diversions for use in the Central Queensland Mining Industry (2008), and these are shown in Table 2-1. These have been used in the Bowen Basin of Central Queensland as general indicators of the potential success of a river diversion, and are considered appropriate for use in the Galilee Basin.

Table 2-1 River Diversion Hydraulic Guidelines

ARI (years)	Stream Power (W/m^2)
2 (unvegetated channel)	< 35
2 (vegetated channel	< 60
50	< 220

These guidelines are appropriate for channels formed in alluvial materials, but where a diversion is located within competent bedrock or highly cohesive material not subject to normal fluvial erosion it was deemed unnecessary to meet these guidelines.

2.8 Reaches

Erskine *et al* (2005) define river reaches as:

> *Homogenous lengths of stream within which hydrological, geological, and adjacent catchment surface conditions are sufficiently constant so that a uniform river morphology […] is produced.*

This concept provides a useful way of separating reaches along the river of similar character, and this in turn will allow for simplified assessment and identification of mitigation measures.

In the present study, data on stream slope, channel morphological characteristics, floodplain elevation and discharge have been used to inform reach identification.

2.9 Stream typology

Erskine *et al* (2005) provide a classification of Australian tropical river types based on data obtained from fluvial systems in a broad arc across northern Australia between the Fitzroy River in the Kimberley and another Fitzroy River Central Queensland. This includes the Burdekin/Belyando catchment where Sandy Creek is located. While the classification was developed to be relevant to issues of fish community ecology, it is strongly based on geomorphic principles so is useful here.

Of their nine river types, several are potentially relevant to the Sandy Creek and its tributaries: bedrock confined (Middle Creek and parts of Well Creek), meandering (Lagoon Creek), anabranching (Sandy Creek), and anastomosing (Rocky and Little Sandy Creeks).

2.10 ACARP reports

This watercourse geomorphic assessment has been informed by several Australian Coal Association Research Program (ACARP) reports as follows.

ID&A, 2000 *Maintenance of geomorphic processes in Bowen Basin river diversions.* Stage 1. ACARP Project C8030.

ID&A, 2001 *Monitoring and evaluation program for Bowen Basin river diversions.* Stage 2 ACARP Project C9068.

Fisher Stewart, 2002 *Bowen Basin river diversions design and rehabilitation criteria.* Stage 3 ACARP Project C9068.

Waddington and Associates, 2001 *Impacts of mine subsidence on the strat and hydrology of river valleys and development management guidelines for undermining cliffs, gorges and river systems.* ACARP Project C8005.

Waddington and Associates, 2002 *Impacts of mine subsidence on the strat and hydrology of river valleys and development management guidelines for undermining cliffs, gorges and river systems.* ACARP Project C9067.

Potential Fluvial Geomorphic Effects of Mine Proposal

This section describes those aspects of the Kevin's Creek Project that have the potential to affect the fluvial geomorphic environment and in particular the characteristics and functioning of watercourses in the MLA.

The mine proposal includes surface opencast pits and associated infrastructure, and underground longwall mining. To enable these activities streams will need to be diverted, and levees built to protect mine operations from floodwaters. In addition, the longwall mining will result in subsidence at the ground surface of between 0.5 and 3 m, and this has the potential to change surface runoff patterns. All of these activities will have potential geomorphic effects.

3.1 Longwall Mining

In longwall mining coal is extracted in panels that are typically about 300 m wide by 1 – 3.5 km long and 2 to 5 m thick. When coal is extracted using this method, the roof above the seam is allowed to collapse into the void that is left as the face retreats. As the roof collapses the fracturing settlement of the rock progresses through the overlying strata and results in sagging and bending of the near surface and subsidence of the ground above.

Generally, subsidence occurs over the centre of the longwall panel and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of the coal extracted underground.

Where several panels are mined in a series and chain pillars are left between the panels. The chain pillars crush and distort as the coal is removed from both sides of them, but usually they do not totally collapse and, hence the pillar provides a considerable amount of support to the strata above them.

The subsidence at the surface develops progressively as the coal is extracted within the area of influence of the extracted panel. As further adjacent panels are extracted, additional subsidence is experienced, above the previously mined panel or panels. The subsidence effect at the surface occurs in the form of a wave.

3.1.1 Location of Longwall Mining

The underground mining will take place on the western side of the MLA and will affect about 181 km^2 of low hills, floodplains, and watercourses in the catchments of Well, Middle, Rocky and Little Sandy, and Greentree Creeks. The longwall panels will be oriented north-south, will be ~300 m wide and 1.5 km to 8 km long. Three longwall areas are proposed: North, Central and South.

The North area consists of 35 panels in 25 rows, 1.5 km to 5.5 km long, covering 66 km^2 in the catchments of Well Creek and the downstream parts of Middle Creek.

The Central area consists of 19 panels, 3.5 km to 8 km long, covering 57 km^2 in the catchments of Middle Creek (upper), and the north side of the Rocky Creek catchment.

The South area consists of 23 panels 3 km to 5.5 km long, covering 58 km^2 in the upper catchments of Rocky and Little Sandy Creeks. A small part of Greentree Creek catchment will also be affected.

The location of the longwall panels in the mining area is likely to affect the watercourses as follows:

– Well Creek from ch 20936 to ch 4200 (16.7 km), 21 panels.

– Middle Creek from ch 19345 to ch 0 (19.3 km), 25 panels.

– Rocky Creek from ch 13589 to ch 2297 (11.2 km), 17 panels.

– Little Sandy Creek from ch 31075 to ch 15600 (15.5 km), 16 panels.

– Greentree Creek from ch 14715 to ch 12906, and from ch 11536 to ch 10521 (2.8 km), 5 panels.

3.2 Open cut pits

Two open put pits are proposed. The main pit will cover ~20 km^2 and will remove some 7.2 km of the Little Sandy Creek watercourse and floodplain between ch 12000 and ch 4800. This pit will also extend onto the Sandy Creek floodplain between channel chainages 14000 and 8000 (6 km).

A second pit area will be located between Well Creek and Sandy Creek in the northern part of the MLA. This will cover ~4 km^2, about half of which will be on floodplain landforms.

Levees will be constructed around these pits in order to exclude floodwaters from entering the mine workings.

3.3 Stream diversion

The size and preferred location of mine pits usually requires stream diversions to direct watercourses around or away from these large mine features. One diversion is proposed at Kevin's Corner to divert Little Sandy and Rocky Creeks away from the main (southern) mine pit. The arrangement of the stream network means that a relatively simple diversion of about 5.7 km will carry Little Sandy Creek and Rocky Creek north to join the natural channel of Middle Creek. Thus the diversion will take flow away from the originating watercourses and not return it. This is different to many stream diversions where water is taken back to the original channel.

The upstream 2.7 km of the diversion will be across the floodplains of the two creeks, it will then be cut for 1.9 km through the 15.5 m high ridge between Rocky and Middle Creek valleys, before a finishing reach of 1.4 m along the Middle Creek valley. The top width of the diversion will be up to 360 m, and the floodplain width will be ~200 m. The low flow channel will have a top width of 20 m and be ~2 m below the floodplain.

The diversion will pick up Little Sandy Creek flows at model ch 18340, flows north for 2.1 km to pick up Rocky Creek flows at model ch 3960, and then flows a further ~2.5 km to deliver them to Middle Creek at ch 7300 with the natural channel of Middle Creek resumed at ch 5900. Where the diversion joins Middle Creek flood flows there will be increased 2.5 to 2.75 times. Downstream where Middle Creek joins Well Creek flood flows will be increased 1.2 times.

The diversion has been designed with a very slight meander pattern with a wavelength of about 1 km. The purpose of this is to ensure the diversion follows within the subsidence footprint of a single longwall panel.

3.4 Potential Effects of Mining on Geomorphic Environment

3.4.1 Longwall subsidence effects

Due to underground mining, channels and floodplains situated directly over longwalls will drop by approximately 0.5 to 3 m. Potential watercourse and drainage system impacts include:

- Loss of surface water flow through surface cracking; and
- Change to stream bed profiles between longwall panels.

Hillslopes will be affected with a new surface topography potentially re-arranging surface runoff patterns.

Surface Cracking

Surface cracking may occur between the longwall panels, and this will affect a zone up to 60 m wide. The cracking could create voids in which surface waters may potentially be lost to shallow groundwater. In addition, the cracking may weaken the bank sediments leading to enhanced potential for gullying and delivery of increased sediment to the channel.

Changes to Streambed Profiles

The underground longwall panels are oriented generally perpendicular to the flow of the surface watercourses. Subsidence beneath stream channels will therefore introduce a 300 m long by up to 3 m high wave-like pattern along the channels. This may result in the formation of pools along the watercourses.

Impacts on Flood Inundation Levels

It is likely that subsidence will reduce the flood capacity and create more frequent inundation of floodplain.

3.4.2 Open pit and levee effects

The open pits will remove about 15 km^2 of the existing fluvial landscape of watercourses and floodplains associated with Little Sandy Creek, Well Creek and Sandy Creek. The levee banks will constrict floodplain width along the true left side of the Sandy Creek floodplain, and along both side of the Well Creek floodplain. The restricted floodplain conveyance space may increase stream power across the floodplain and in the channels leading to increased erosion and destabilisation of these landforms.

3.4.3 Diversion effects

The potential adverse impacts of poorly designed stream diversions have been documented in the ACARP reports listed Section 2.10. These can include effects within the diversion including excessive erosion or deposition in the channel or on the floodplain, unstable meanders, and loss of riparian vegetation; and effects downstream such as increased erosion or deposition, and adverse water quality effects.

Effects within the diversion

Diversion design will not attempt the replicate the natural anastomosing channel pattern of Rocky and Little Sandy Creeks, thus potential effects will be associated with the stability of the diversion, rather than its ability to recreate the existing environment. The low flow channel will need to adequately convey the bankfull discharge initially of Little Sandy Creek, and then Rocky Creek when it joins the diversion. The floodplain to either side will need to be wide enough to convey all floods without resulting in elevated stream power values in the channel or on the floodplain that could trigger adverse erosion of these landforms.

3 Potential Fluvial Geomorphic Effects of Mine Proposal

The banks of the diversion where it passes through the ridge between Rocky and Middle Creeks will be up to 15 m high and may be subject to surface erosion. In addition, two small natural gullies flow from the east towards the true right bank of the diversion along the Middle Creek section. Flows from these will need to be managed as the drop down into the diversion.

Effects downstream of the diversion

The channels of Middle Creek and then Well Creek will be required to carry the extra Rocky Creek and Little Sandy Creek diverted discharge. As noted above, flood flows will increase in Middle Creek by a factor of 2.5 to 2.75.

Under these increased stream energy conditions the Middle Creek channel could develop towards different equilibrium conditions including a wider channel and increased bedload transport capacity. Bank erosion could deliver more sediment to the channel.

Downstream the increase in Middle Creek discharge as it joins Well Creek will be less obvious as the flow increase there will only be 1.2 times the flow from Well Creek upstream. However, if flood flows in Well and Middle Creeks are not synchronous, there may be a temporary buildup of extra Middle Creek sediment at the junction. The extra flow in Well Creek will slightly increase the frequency of floodplain inundation events along Well Creek.

Landscape Setting

The proposed Kevin's Creek coal mine is about 400 km west of Rockhampton in central Queensland. The landscape setting provides an important context from which to understand the geomorphology of the Sandy Creek and tributary stream environments.

4.1 Central Queensland Landscapes

Three main landscape features dominate the eastern margin of the Australian continent: a Coastal Plain with Residual Hills rising above it that is backed by the Great Escarpment; and the Eastern Uplands that include the Great Dividing Range. The highest relief is associated with the residual hills and Great Escarpment near the coast where mountains can rise to over 1000 m. Once the Great Escarpment is crossed the landscape of the Eastern Uplands actually falls away in height to the west inland from the coast and relief is much lower with generally less than 200 m separating the highest and lowest parts of the landscape. Emerald which is ~250 km west of Rockhampton is only 180 m above sea level on the floodplain of the Nogoa River. However to the west the landscape rises again towards the Great Dividing Range, which despite its name is not particularly 'great' as relative relief here is typically less than 200 m, and gentle tablelands often occur.

Occasional features of the Eastern Uplands are areas of Tertiary age basalt volcanism that forms scattered lava flows and low domes. An area of basalt occurs just east of the Kevin's Creek MLA. The Uplands have been worn down by fluvial (river erosion) processes over many tens of millions of years to the low relief surfaces seen today, and the bedrock deeply weathered to form deep weathering profiles and associated ferricrete and silcrete duricrusts. The remnants of former fluvial environments have been preserved in consolidated Tertiary fluvial sandstones and conglomerates. These elements are all seen in the Kevin's Creek MLA.

As the Sandy Creek catchment is located on the eastern flanks of the Great Dividing Range. The landscape slopes to the east and north before Sandy Creek joins the Belyando River (20 km downstream of the MLA) that then carries the water north for 300 km to the Burdekin River and thence a further 165 km to the Coral Sea.

4.2 Landscapes of the Sandy Creek Catchment

The Sandy Creek catchment covers 3,187 km^2 and is in the southwest part of the 35,378 km^2 Belyando Catchment, which in turn is part of the 125,368 km^2 Burdekin Catchment. Although the catchment is generally referred to at this large scale as the Sandy Creek Catchment, nearly half of it is made up the Lagoon Creek catchment (1,296 km^2), and a further 436 km^2 is in Greentree Creek. At the point where Sandy Creek enters the MLA, it has an upstream catchment area of 1,732 km^2, and at the northern MLA boundary the catchment area is 2,737 km^2. The watercourse network in the MLA is shown in Figure 4-1.

4 Landscape Setting

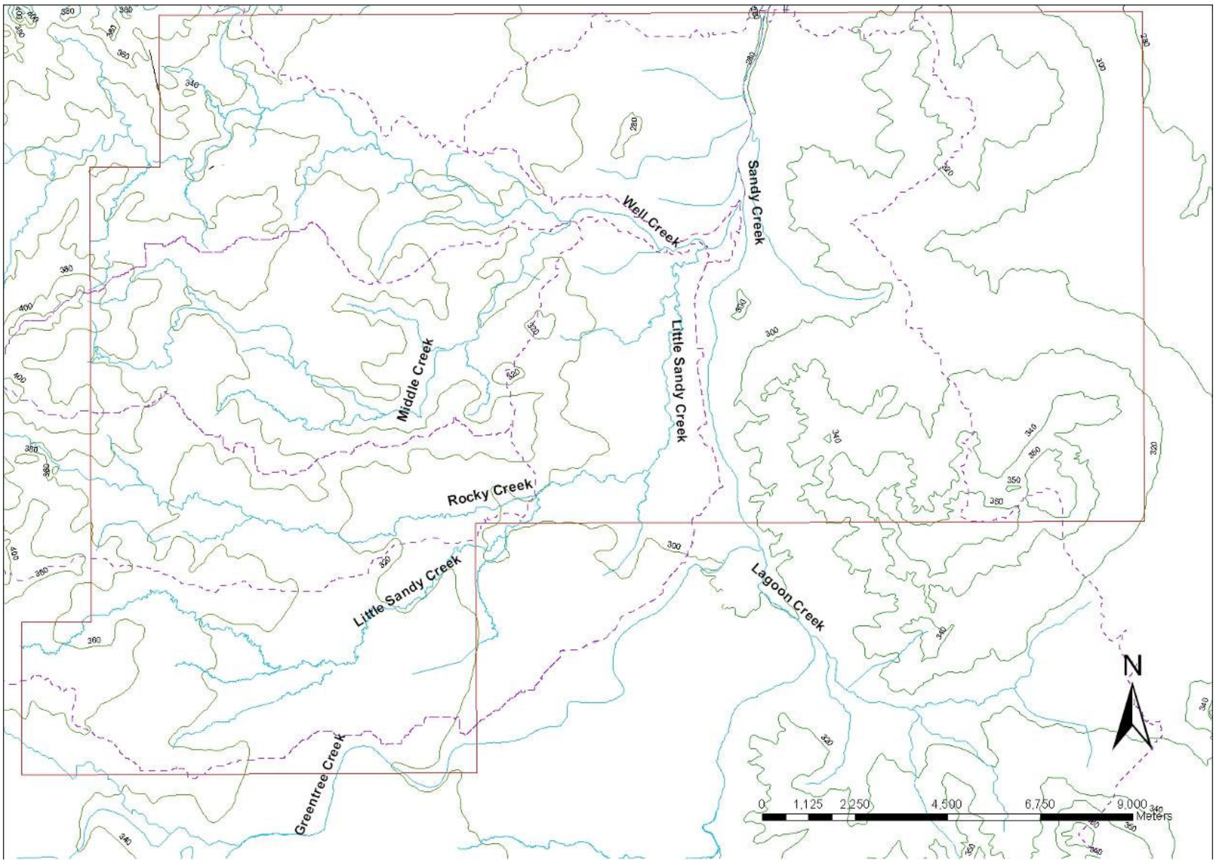

Figure 4-1 Watercourses of the Kevin's Corner MLA

Although the catchment is at the ‘top’ of the landscape adjacent to the Great Dividing Range, much of it has quite gentle slopes with total relief of less than 50 m. More rugged hills occur in the far southwest near Alpha, and to the west and southwest of the Kevin’s Corner MLA. Here there is 100 – 200 m of relief. To the east, lower hills 50 – 100 m high separate Sandy Creek from Native Companion Creek.

4.2.1 Landscapes in and around the MLA

There are several distinctive landscape types in and around the MLA.

Tablelands. The top of the Great Dividing Range (GDR) to the west of the MLA paradoxically contains some of the flattest parts of the landscape. At the headwaters of Well Creek and Greentree Creek the GDR is in fact a tableland at about 460 – 420 m above sea level (asl). This is underlain by Tertiary alluvium.

Dissected hills and escarpments. The edge of the tableland gives way to rugged dissected hills with steep escarpment slopes. There can be up to 100 m of relief here as the hills drop rapidly into the upper valleys of Well Creek and Greentree Creek. This rugged hill country lies just to the west of the MLA, and it is here that the coal measures can be seen outcropping at the surface.

Low hills and gentle slopes. Much of the topography of the MLA comprises low hills and gentle slopes. These are blanketed in Tertiary and Quaternary alluvium from which the landscape derives its generally soft texture.

4 Landscape Setting

Floodplains. Sandy Creek and its tributaries have cut valleys into the low hills and gentle slopes and formed floodplains across the valley floors as shown in Figure 4-2. The extent of the floodplains shown is based on the extent of the 100-yr ARI TUFLOW flood model output. These are the areas that will be the main focus of this report.

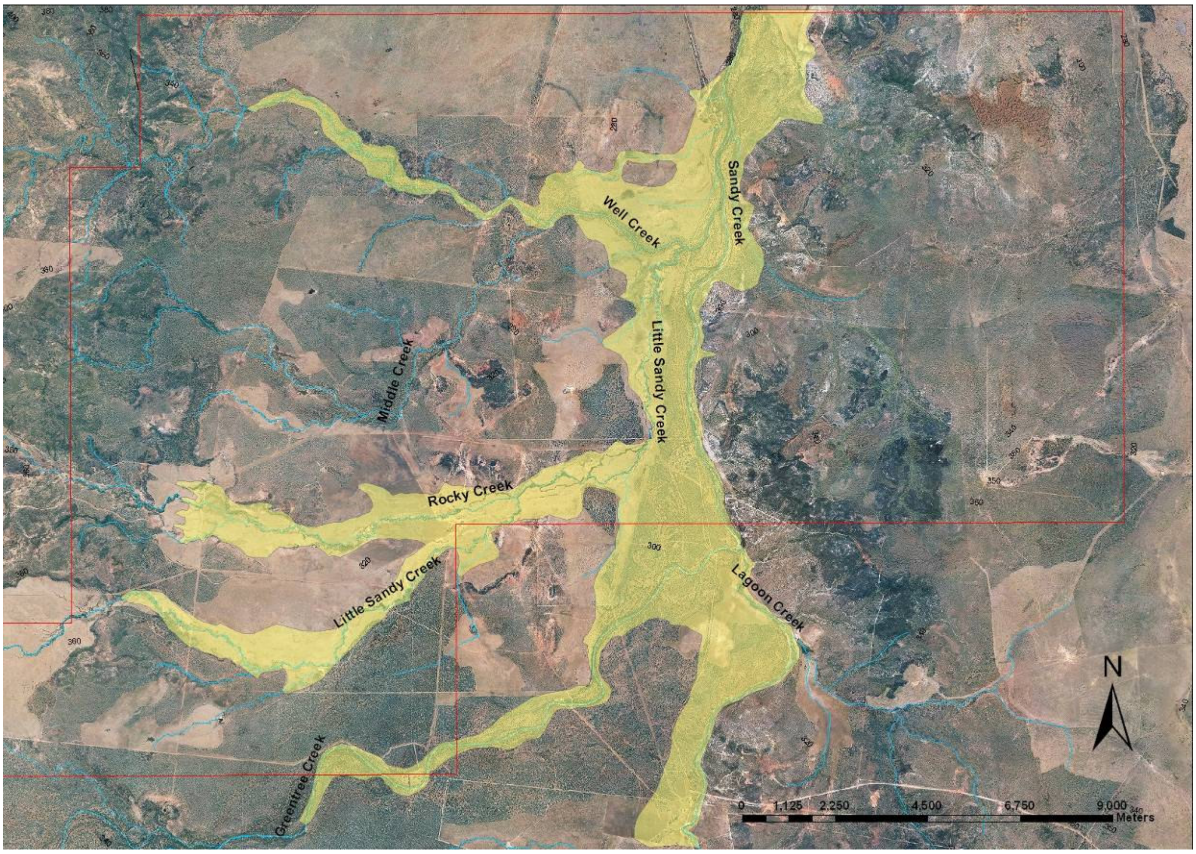

Figure 4-2 Floodplains of the Kevin's Corner MLA (Floodplains shaded in yellow. The remaining landscape area within the MLA and west of Sandy Creek is low hills. East of Sandy Creek the hills are higher.)

4.2.2 Sandy Creek valley

The Sandy Creek valley floor is up to 2 km across. The stream channel is at about 296 m asl as it enters the MLA and the floodplain here is at ~300 m elevation. Downstream as it leaves the MLA the channel has dropped to 278 m asl, and the floodplain is at ~ 283 m asl.

The floodplain covers about 23 km^2, and along the eastern side merges with the floodplain of Little Sandy Creek.

The valley is asymmetric with steeper eastern hills rising some 50 m to 345 m elevation in just 2 km from Sandy Creek. To the west the hills are lower rising 30 m to 325 m elevation more than 4 km from Sandy Creek.

4.2.3 Eastern hills

East of Sandy Creek is a 120 km^2 area of hills separating Sandy Creek from Native Companion Creek which is more than 15 km away and beyond the eastern side of the MLA. Half of this area drains west in short <5 km long streams to Sandy Creek, while the eastern half drains to Native Companion Creek. The hills rise to about 345 m elevation, some 50 m above the Sandy Creek valley floor.

4.2.4 Western Sandy Creek Tributaries

The western 250 km^2 of the MLA, to the west of Sandy Creek, is the area that will be most affected by the Kevin's Corner Project. Little Sandy, Rocky, and Middle Creeks flow east from this area before joining Well Creek and thence Sandy Creek some 4 km south of the northern boundary of the MLA.

Greentree Creek

Greentree Creek is a large tributary catchment covering 436 km^2 and with a main stem about 50 km long. It drains southeast from the GDR tableland through dissected hills and into the low hill country to the south of the MLA. Only about 3.4 km of the watercourse enters the south edge of the MLA, comprising just 9.3 km^2 of catchment area.

Little Sandy Creek

This moderately large east-draining catchment covers 149 km^2 and some 73 km^2 (~50%) of it is in the MLA. It is very similar to Middle and Rocky Creeks in its upper reaches (see below). The 37 km watercourse drains low hills east of the GDR and is joined by Rocky Creek before issuing onto the western side of the Sandy Creek floodplain and flowing north to join Well Creek ~2 km upstream of the latter's junction with Sandy Creek.

The highest point is at 400 m asl, and it meets Well Creek at 285 m. The surrounding hills are generally less than 10 m above the valley floor, and topographic data shows that 73% of the catchment has slopes less than 1^o, and just 2% is steeper than 3^o. These low gradients mean there is generally low potential energy in this system and it is a low energy watercourse.

Rocky Creek

Rocky Creek is a small 53 km^2 catchment in the low hills of the western MLA, and the watercourse runs for 19 km to join Little Sandy Creek. It rises in dissected hills to the east of the GDR, and 33 km^2 (62%) is in the MLA. The highest point is 460 m asl, and it joins Little Sandy Creek at 300 m asl. The surrounding hills rise 20 – 30 m above the valley floor. Although adjacent to Little Sandy Creek it is a little more hilly with 58% of the catchment slopes at <1^o and 5% is steeper than 3^o.

Middle Creek

This small (53 km^2) catchment flows for 20 km from low hills east of GDR. It is a tributary of Well Creek and 91% of it is within the MLA. The highest point is 400 m als, and it joins Well Creek at 292 m als. The surrounding hills rise 20 – 30 m above the valley floor. Just under half the catchment slopes are <1^o and 5% slopes at >3^o.

Well Creek

Well Creek is a large 252 km^2 catchment and the watercourse flows for more than 50 km from the GDR tableland through dissected hills to the low hills of the MLA to join Sandy Creek. Only 17% of the catchment area is within the MLA. However, Well Creek and its tributaries Middle Creek and Little Sandy and Rocky Creeks cover 196 km^2, which is 78% of the area west of Little Sandy Creek that will be most affected by the Kevin's Corner Project. The highest point is at 480 m asl, and it joins Sandy Creek at 283 m als. The surrounding hills rise to more than 40 m above the valley floor. This higher relief is reflected in the slope data such that 13% slopes at >3^{o}, the largest proportion of any of the MLA catchments.

4.3 Geology

The nature of the geological materials at or near the surface strongly influences fluvial geomorphology processes and landforms. The surface geology of the MLA is predominantly alluvium of various ages, while the coal measures that will be the target of mining activities only occur at the surface in the far west.

4.3.1 Permo-Triassic coal measures

The Permian-Triassic age sedimentary rocks that contain coal seams consist of a wide variety of lithologies including sandstone, siltstone, mudstone, conglomerates, and limestone. However, they only cover about 17 km^2 in the upper Well and Middle Creek catchments and in the hills to the east of Sandy Creek.

4.3.2 Tertiary non-marine sediments

Consolidated Tertiary non-marine sediments occur widely particularly across the western part of the MLA area, covering about 42 % of the catchment area. These are predominantly river alluvium and were formed in a landscape not dissimilar to the present. They mostly occur on low hills flanking the dissected hills east of the Great Dividing Range. They have been subjected to deep weathering leading to the formation of cemented duricrusts and clay rich mottled zones. Where the duricrusts intersect stream beds they result in knick points in the long profile and small waterfalls.

4.3.3 Basalt

Basalt does not occur within the MLA but does outcrop just to the east on Surbiton Station.

4.3.4 Quaternary Alluvium

A significant proportion (32%) of the MLA is underlain by relatively young Quaternary age alluvium identified as floodplain landforms. This is subdivided into an older set of now in-active floodplains (55 km^2 or 15% of the MLA area), and a younger set (65 km^2 or 17% of the MLA) that are still actively forming, although parts of these areas may only be inundated once in a few hundred years. These are mapped in Figure 4-2.

4.4 Vegetation

Details of the MLA vegetation characteristics are described in the Ecology Technical report that accompanies the EIS. This section briefly addresses vegetation cover and its potential influence on runoff and sediment delivery to the stream network. The area is mostly *Eucalypt* low woodland with tall shrubs and a grass understory. Some areas of brigalow (acacia) woodland may also occur. Denser tree cover occurs along stream riparian margins.

It is well established that landuse practices that reduce the percentage ground cover of vegetation leads to increased surface runoff and increased sediment loads in rivers. These issues have been well documented for the Burdekin Basin in which Sandy Creek occurs. The *Burdekin Water Quality Improvement Plan Catchment Atlas* (2009) identifies that the Sandy Creek catchment as a whole is in slightly better condition that the rest of the Belyando and Burdekin catchments. The estimated rate of soil erosion is ~240 kg/ha/yr compared to ~330 kg/ha/yr for the Belyando Basin, and ~560 kg/ha/yr for the whole Burdekin Basin

4.4.1 Recent vegetation cover changes

A major driver of soil erosion has been tree clearing to improve pasture for cattle grazing. The land use history of the area is probably very similar to that described for the Bowen Basin just to the east (ID&A, 2000). European settlement of the area developed in the 1860s with sheep grazing of the native pastures along stream floodplains. However, it was not until the 1960s that Queensland Government incentives lead to the widespread tree clearing with heavy machinery. This extended into the Sandy Creek area and can be seen in the historical aerial photo coverage.

The 1952 photographs cover the southern part of the MLA (Little Sandy Creek, Rocky Creek, and Greentree Creek). Tree cover is largely intact and there is no evidence for any tree clearing. The 1969 aerial photographs cover the whole MLA and similarly show no evidence for clearing although the Hobartville Road is now quite obvious running adjacent to Sandy Creek. The 1980 photographs only show a small area in the centre of the MLA showing parts of Little Sandy, Rocky, and Middle Creeks. Some 3.4 km^2 has been cleared around and airstrip that had been formed during the 1970s phase of mining exploration. This suggests that tree clearing had begun sometime in the 1970s, but was not then well advanced.

The 1991 aerial photographs show tree clearing was well underway in the MLA, particularly in the area west of Sandy Creek. Measurements of the area covered by woodland, dense tree cover, and tree clearance are shown in Table 4-1. The figures for 1952/1969 are estimated. Woodland is largely undisturbed cover of low woodland trees. Dense tree cover includes a variety of patches of what appear to be closed canopy forest on hill country or riparian/floodplain forest associated with streams.

Table 4-1 Kevin's Corner MLA Land Cover 1952 – 2008

Area	1952/1969	1991	2008
Woodland	344 km^2	30 8 km^2	260 km^2
Dense tree cover	30 km^2	24 km^2	15 km^2
Trees cleared	0 km^2	41 km^2	99 km^2
Total area	*374* km^2	*374* km^2	*374* km^2
Percent of MLA			
Woodland	92%	83%	69%
Dense tree cover	8%	6%	4%
Trees cleared	0%	11%	26%

All of the land cleared of trees is on the gentler slopes and floodplains to the west of Sandy Creek, in the area that will be most affected by the proposed mining operations. This area covers about 251 km^2, and therefore some 39% of this area has been cleared of trees.

The tree clearance had occurred in different proportions in the catchments as shown in Table 4-2.

Table 4-2 Area cleared of trees in Sandy Creek tributary catchments

Catchment	Area cleared	% cleared of catchment in MLA
Well Creek (excl Middle and Little Sandy Creeks)	9.2 km^2	19.9%
Middle Creek	7.1 km^2	14.7%
Rocky Creek	17.8 km^2	53.5%
Little Sandy Creek (excl Rocky Creek	28.3 km^2	63.0%
Sandy Creek northern tributaries	20.5 km^2	80.7%

Catchments with more relief and steeper slopes such as Middle and Rocky Creek have been less cleared than those with gentler slopes (Little Sandy and Rocky Creeks). The Sandy Creek minor northern tributaries have the largest proportion of cleared land, reflecting their very gentle slopes.

4.4.2 Land degradation

The term land degradation refers to a range of land surface effects that result in loss of soil and vegetation cover. Of particular concern are the processes of soil erosion and gullying that result in loss of productive land and delivery of sediment to watercourses. The *Burdekin Water Quality Improvement Plan Catchment Atlas* (2009) mentioned above summarises land degradation effects in the Burdekin Basin, of which Sandy Creek and the Kevin’s Corner MLA are a part. While some level of land degradation is a natural process in this environment, accelerated rates often follow in the decades after land is cleared of trees. These processes were observed in the MLA area.

Figure 4-1 shows an example of both natural and accelerated land degradation in the upper reach of Little Sandy Creek. A bend of the creek is naturally eroding the base of a 3 – 4 m high bank. Tree clearing on the floodplain (foreground) has allowed surface and sub-surface runoff to occur, which has resulted in deep gullies eating away the top of the stream bank. Large volumes of sediment are being delivered to the watercourse.

The significance of this land degradation is that it is a response to the previous decades of tree clearing that is only now becoming evident in the landscape. The sediment that is being delivered to the stream channels has yet to make its way fully down the system, and as it moves downvalley channel aggradation is likely to occur. Future management of watercourses in the MLA needs to take into account the potential for increased sediment loads that are unrelated to mine activities, but which may result in reduced capacity of the channels to convey flood flows.

Figure 4-3 Natural and accelerated land degradation, upper reach of Little Sandy Creek

4.5 Hydrological setting

All of the streams in the MLA are ephemeral or intermittent streams, flowing only for a few weeks after heavy rainfall. Flow is comprised entirely of stormflow. There is no groundwater-derived baseflow to sustain river discharge through the dry spells between floods. Channel-forming discharge events will be irregular and highly flashy in nature. Further upstream in Lagoon Creek the groundwater table is apparently higher as semi-permanent pools remain here in this watercourse.

The general hydrological environment is described in detail in *Kevin's Corner EIS: Flood Hydrology Study.*

4.5.1 Flood Hydrology of Sandy Creek

Flood magnitude, frequency and duration are important for fluvial geomorphology as it flood events that drive channel and floodplain change. Assessment following ACARP Guidelines is related to 2 year and 50 year average return interval floods (2-yr ARI and 50-yr ARI). The 2-yr ARI event is close to the 'mean annual flood' which is statistically that flood which occurs on average once every 2.33 years. As discussed above in Section 2 the bankfull flood is most important for channel development, and this can occur through a wide range of frequencies from once every two to twenty years. The floodplains adjacent to the channels may only be fully inundated in 50-yr ARI events. Thus, the 2-yr to 50-yr ARI floods are most relevant to this discussion.

Table 4-3 shows the magnitude and frequency of various floods at different points along Sandy Creek and its tributary channels. Data has been derived from outputs of the HEC-RAS hydrological model that shows how water is distributed through the watercourse during floods. For the larger events, water also flows across wide floodplains and thus may pass to different catchments from those through which they had entered the MLA. Thus the flows shown in this table may not be the same as the total flows identified in the *Kevin's Corner EIS: Flood Hydrology Study.* These flows are however likely to be the most relevant for stream geomorphology as they are in the channels where most geomorphic change occurs.

Table 4-3 Magnitude of flood events in Sandy Creek and its tributary watercourses (m^3/s)

Flood frequency (ARI)	2 yr	5 yr	10 yr	20 yr	50 yr
Sandy Creek and upstream tributaries					
Lagoon Creek upstream of Greentree Creek junction	10	55	100	175	330
Greentree Creek at Lagoon Creek Junction	25	95	190	340	640
Sandy Creek at upstream (sth) MLA boundary	35	145	290	515	970
Sandy Creek at downstream (nth) MLA boundary	40	160	330	590	1100
Tributaries of Sandy Creek within MLA					
Little Sandy Creek at Well Creek junction	10	50	130	280	415
Rocky Creek at Little Sandy Creek junction	5	15	30	50	90
Middle Creek at Well Creek junction	5	15	30	55	130
Well Creek at Sandy Creek junction	15	55	115	200	560

Much larger magnitude floods are also described *Flood Hydrology Study* report. These are very relevant for mine safety, but are less relevant to geomorphology as they are very rare and thus unlikely to be primary drivers of landform change.

Baseline Assessment of Fluvial Geomorphic Environment

Sandy Creek is the master stream of the Kevin's Corner MLA, and is formed by the joining of Lagoon Creek and Greentree Creek. These latter are significant watercourses in the adjacent Alpha Project MLA, and have an important influence on Sandy Creek. Thus, they are an important aspect of the fluvial geomorphology of the Kevin's Corner MLA, and are described briefly below before a fuller treatment of Sandy Creek and its tributaries in the Kevin's Corner MLA.

5.1 Greentree Creek

Greentree Creek[†] is a large left bank tributary of Lagoon Creek, and where these two join 775 m south of the Kevin's Corner MLA they become Sandy Creek. Although Sandy Creek is a continuation of the Lagoon Creek main stem, it is Greentree Creek that gives Sandy Creek its distinctive characteristics. The creek is located to the south and west of the Kevin's Corner area but in two short sections enters the MLA at its southern edge where meander bends sweep north. These incursions occur between ch 14919 and ch 12781 (2.14 km), and ch 11536 and ch 10337 (1.2 km). These are between 10 and 15 km upstream of where Greentree joins with Lagoon Creek.

Greentree Creek has not been studied in detail for this report, or in the *Kevin's Corner EIS: Hydraulics Technical Report* but is described in the Alpha Coal Project Geomorphology Technical Report (Parsons Brinckerhoff, 2010). preliminary HEC-RAS model was prepared and outputs from this have been used to inform this discussion. However, the outputs should only be regarded as giving a broad indication of this environment as the model has not been fully developed.

Greentree Creek rises at the Great Dividing Range with four major tributaries contributing water from rugged hill country and escarpments along some 40 km of the range. These tributaries flow southeast, then east and northeast for 20 -30 km and have combined to form the main Greentree Creek about 19 km upstream of the junction with Lagoon Creek. It is this lower main section that has been modelled and will be briefly described here.

The main section of Greentree Creek flows northeast just to the south of the MLA between slopes rising less than 10 m above the valley floor. In the upstream part of this reach the valley itself is mostly less than 500 m wide except on two meander bends that swing into the MLA where it is up to 1 km across. In the lower 3.5 km the valley widens as the floodplain merges with the Lagoon/Sandy Creek floodplains.

The long profile of the modelled main stem of Greentree Creek is shown in Figure 5-1, and the overall slope is a uniform 0.19%. The valley length is about 14.6 km, giving a sinuosity index of 1.26 which is in the sinuous class (between straight and meandering). The channel planform is of broad irregular meanders with a wavelength of 2 – 3 km.

The channel comprises a uniform sand sheet 25 – 35 m across widening to 40 – 50 m downstream. Banks are sloping and well vegetated indicating no recent history of stream bed incision. In fact, the channel appears to be aggrading with sand beginning to engulf the lower trunks of trees (see Figure 5-2 below). Channel type is mostly single thread, although there are a few short anabranching reaches. At bankfull discharge the channel would be running at 2 – 3 m deep, and this appears to occur at floods of magnitude a little greater than 10 yr ARI. Floodplains extend a few hundred metres away from the channel, and palaeochannels are common in the upper part of this reach.

[†] In the Alpha Coal Project Geomorphology Technical report this 19 km reach is called Sandy Creek.

5 Baseline Assessment of Fluvial Geomorphic Environment

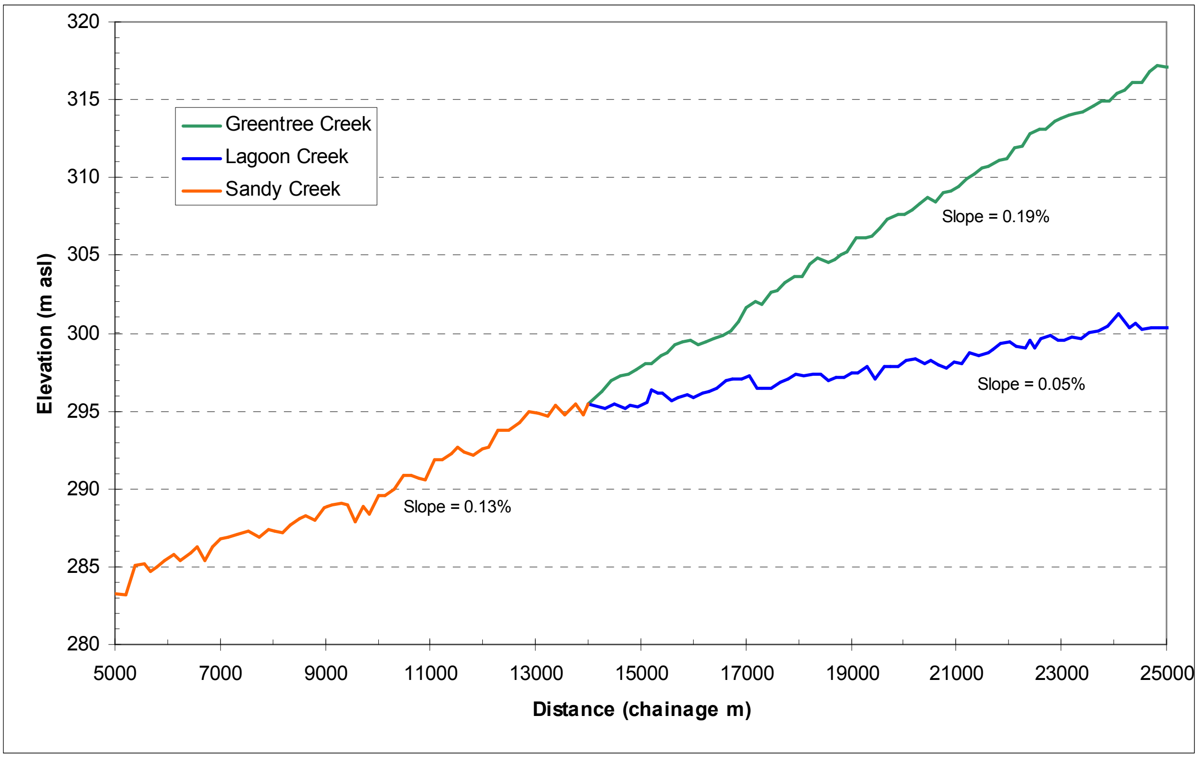

Figure 5-1 Bed profiles of Lagoon, Greentree and Sandy Creeks

Greentree Creek would only be slightly affected by the Kevin's Corner Project. However, the adjacent Alpha Coal Project will have a much more significant effect as that proposal entails a 14 km diversion that would take all of the flow away from the lower 11.8 km of the creek.

5.1.1 Greentree Creek in the Kevin's Creek MLA

As noted above, Greentree Creek enters the Kevin's Corner MLA in two short sections. The upstream section (ch 14919 – ch 12781) is confined between low hills that gives the creek between 0.5 to 1 km in which to form its channel and floodplain. The channel is mainly single thread with some ridge anabranching reaches. The sandy bed is typically 20 – 25 m wide. Bankfull discharge depth is about 3 m, and a ~0.5 m high levee occurs along the true right bank in some places but in-channel benches do not appear to be present. The lower part of the floodplain is inundated at >10 yr ARI flood events, and there is a 150 m wide palaeochannel incised about 2 m into this landform. The floodplain is initially on the true right side of the valley, and then switches to the true left downstream. There is a 1 – 2 m high terrace rising up to a second floodplain level that appears to be inundated by the 50 yr ARI flood. This part of Greentree Creek will be affected by subsidence associated with 3 or 4 underground longwall mining panels.

The downstream section (ch 11536 – ch 10337) is in a 400 – 800 m wide valley. The channel is single thread apart from one island anabranching section of about 150 m length. The sandy bed is 25 – 30 m wide. Bankfull discharge depth is 2 – 3 m and there are occasional low levee banks and in-channel benches. The two stage floodplain of the upper reach is not well developed here, although the palaeochannel is present and the 20-yr ARI flood would cause most parts of this landform to be inundated.

Figure 5-2 Greentree Creek at ch 11500

Figure 5-2 shows Greentree Creek where it enters the southern edge of the MLA. The ~30 m wide channel has two anabranches with a narrow vegetated ridge between. The sandy bed is aggrading.

This part of Greentree Creek will be affected by subsidence associated with one of the Kevin's Corner underground longwall mining panels. However, a more significant effect will arise from the adjacent Alpha Coal Project as it is proposed to divert the entire flow of Greentree Creek away from this and all downstream reaches.

5.2 Lagoon Creek

Lagoon Creek drains a very large catchment area upstream of the Kevin's Corner MLA, and is the main stream draining through the Alpha Coal Project area. No part of it enters the Kevin's Corner MLA, but as the main upstream tributary of Sandy Creek, it represents an important input or upstream boundary condition for the Kevin's Corner MLA stream geomorphic system.

Lagoon Creek has not been studied in detail for this report or in the *Kevin's Corner EIS: Hydraulics Technical Report* but is described in the Alpha Coal Project Geomorphology Technical report (Parsons Brinckerhoff, 2010). The *Hydraulics Technical Report* HEC-RAS model covers the lower 12.5 km of Lagoon Creek, and the digital terrain model and aerial photography also covers that area. These data have been used to compile the following brief description.

Lagoon Creek rises in the Great Dividing Range some 70 km south of the Kevin's Corner MLA. It receives most of its water from left bank tributaries, while those on the right bank are short. The relatively rugged hills to the east rise to 380 – 400 m asl and these slope steeply down to the valley floor at 300 – 320 m asl in a distance of about 6 km. To the west, the Great Dividing Range is some 30 km distant and rises to over 450 m asl. Close to the range the hills are steeper and contain steep escarpments, but to the east towards the main valley of Lagoon Creek slopes are much gentler.

The lower 12.5 km of Lagoon Creek have been included in the HEC-RAS model and are briefly described here. This is the reach immediately upstream of the Kevin’s Corner MLA, and the watercourse occupies a 1 – 2 km wide valley confined between the eastern hills that extend close to the true right bank of the Creek, and the low western slopes.

The long profile of this reach is shown in Figure 5-1, and while the bed level is irregular in detail, it has a uniform overall slope of just 0.05%. Valley length is about 9.3 km, giving a sinuosity index of 1.3 which is in the sinuous class. The channel planform is irregular, dominated by a large meander bend with a 3 km wavelength. However, upstream beyond the area described here the channel pattern is more sinuous with numerous tight short wave length meander bends.

The channel is predominantly single thread, although there are some sections with 2 to 3 anabranches. Presumably lagoons were a feature of the channel when it was originally named, but only a few occur in this lower 12.5 km reach today. The longest is 1.2 km long upstream of the Degulla Road bridge, and two smaller ones have been artificially formed behind low weirs. Their presence indicates the regional water table here is likely close to the surface for much of the year. A floodplain landform is not consistently developed along Lagoon Creek. Floodplain sections between ch 17000 and ch 20000 are poorly developed and do not become inundated until floods of about 50 yr ARI magnitude and greater. Upstream of here they do not occur at all. Downstream from ch 17000 there are small floodplains that are active in 2 yr ARI to 10 yr ARI floods, and downstream of about ch 15000 the floodplain merges with that of Greentree Creek and would be >1 km wide when inundated in >50 yr ARI floods.

PB (2010) describes the channel as being over-supplied with sand bedload, and suggest the channel will be aggrading in the long term. Our limited observations of the creek at the Degulla Road crossing and just upstream of the Greentree Creek confluence did not indicate either significant sand bedload or noticeable aggradation, particularly when compared to the large sand bedload being carried by Greentree and Sandy Creeks in the Kevin’s Corner MLA.

Figure 5-3 shows Lagoon Creek just upstream of the Greentree Creek confluence. It is a tree-lined lagoon reach with overbank deposits of fine sand and silt from recent floods. This low energy watercourse environment is in marked contrast to the coarse sand bed of Sandy Creek less than 200 m downstream. From this it is interpreted that that Lagoon Creek is unlikely to be a major source of bedload for Sandy Creek, and this is consistent with its low gradient and lack of floodplain development.

This lower section of Lagoon Creek will not be directly affected by the Alpha Coal Project apart from a levee bank along the true left floodplain that would constrain floodplain width in very large floods.

5.3 Significance of Greentree and Lagoon Creeks

Lagoon Creek has a much larger catchment area than Greentree Creek, and it is the upstream continuation of Sandy Creek which is the master stream of the Kevin’s Corner MLA. Yet this stream delivers only about one third of the flood flow to Sandy Creek (see Table 5-1 for flood flows estimated from HEC-RAS model outputs). Greentree Creek is also the major source of sand bedload for Sandy Creek as it flows through the MLA.

5 Baseline Assessment of Fluvial Geomorphic Environment

Table 5-1 Estimated flood flows in Lagoon, Greentree and Sandy Creeks

ARI	Greentree Creek	Lagoon Creek	Sandy Creek
2-Year	25 m^3/s	10 m^3/s	35 m^3/s
5-Year	95 m^3/s	45 m^3/s	140 m^3/s
10-Year	195 m^3/s	95 m^3/s	290 m^3/s
20-Year	340 m^3/s	175 m^3/s	515 m^3/s
50-Year	635 m^3/s	335 m^3/s	970 m^3/s

Figure 5-3 Lagoon Creek upstream of the Greentree Creek junction at ch 14200

Thus, although little of the Greentree Creek channel is within the Kevin’s Corner MLA this stream will be of considerable significance through the life of the mine and beyond. This arises from the very significant bedload that this stream carries and delivers to Sandy Creek in the Kevin’s Corner MLA. It is likely that the creek naturally carried a high sand bedload, but as noted above field observations suggest it is now aggrading its bed. The effects of this aggradation have not yet reached downstream to Sandy Creek, but will probably start to arrive within a decade or so. Sandy Creek in the MLA will therefore be required to carry an increased sediment load and may respond by aggrading its bed thus changing its hydraulic characteristics.

5.4 Sandy Creek

Sandy Creek is the master stream of the Kevin's Corner MLA. It flows 13.2 km from south to north through the MLA and is joined by only one significant tributary, Well Creek that joins from the west at ch 5000. There is some diversity of channel form along the watercourse, but there is more uniformity so it is treated as a single stream reach.

Despite being the most important stream system of the MLA its channel and floodplain environments cover only about 23 km^2, which is less than 10% of the area that will be impacted by the proposed mine. The general landscape setting is described above in Section 4.2.2.

Figure 5-4 shows the bed profile of Sandy Creek through the MLA. The overall slope is 0.13%, although in detail the upper third is lightly steeper (0.17%), while the downstream section from ch 9750 slopes at 0.11%. The upstream sub-reach slope is steeper than Lagoon Creek (0.05%), but similar to that of Greentree Creek (0.19%) with which it shares similarities.

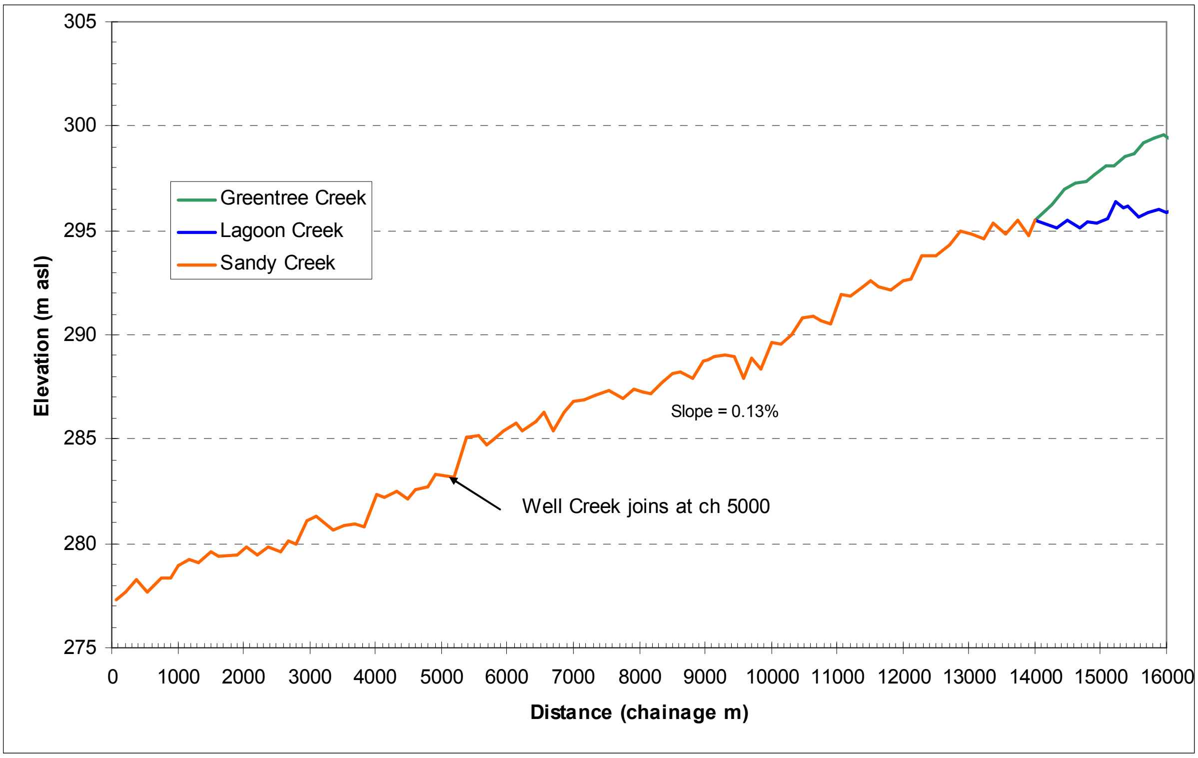

Figure 5-4 Bed profile of Sandy Creek

In planform the channel shows some very gentle bends, but overall sinuosity is very low at SI = 1.05 placing it is the straight channel class. It is a multithread watercourse with 2 – 5 individual channels showing characteristics of a ridge anabranching system. The anabranching channels occupy up to 150 m of the valley floor, and are separated by well vegetated ridges up to 20 m across. There is a short 1.6 km section that is island anabranching between ch 10500 and ch 8800 where the channels occur across a 350 m wide valley floor and the well vegetated islands are >100 m across.

Morphological characteristics of the channels are shown in Table 5-3. The mean values given are geometric means. These are considered representative of overall channel conditions as the calculation is less affected by occasional large or small outliers[‡]. Channel width is the total top width at 2-yr ARI when the channels will be fully covered with water. Individual anabranch channels are typically around 20 m wide.

Table 5-2 Sandy Creek channel characteristics

	Sandy Creek
Channel length in MLA	13.2 km
Sinuosity	1.05
Mean channel slope	0.13% (0.17% and 0.11%)
Mean channel width	78 m
Mean channel depth below floodplain	3.1 m

HEC-RAS model outputs relevant to channel morphological characteristics are summarised in Table 5-3.

Table 5-3 Sandy Creek HEC-RAS model outputs

	ARI	
Mean flow depth (m)	2-yr	1.5
	5-yr	2.4
	10-yr	3.1
	20-yr	3.8
	50-yr	4.5
Mean top width (m)	2-yr	78
	5-yr	130
	10-yr	190
	20-yr	291
	50-yr	621
Mean channel specific stream power (W/m^2)	2-yr	4.9
	5-yr	13.8
	10-yr	22.7
	20-yr	35.0
	50-yr	56.1
Mean total specific stream power (W/m^2)	2-yr	4.9
	5-yr	13.0
	10-yr	18.2
	20-yr	21.3
	50-yr	19.2

[‡] In this report all HEC-RAS summary data is presented as geometric means. The HEC-RAS output data contains a few very large values amongst the more common lower values. Close inspection of the model shows these spikes occur where channel slope increases sharply over a short distance. In some cases these will occur naturally where duricrusts or bedrock outcrop across the channel. Examination of the aerial photographs and digital terrain model did not locate any distinctive channel features that could account for such spikes. Therefore they are likely to be an artefact of the software that was used to create the cross section data. By calculating a geometric mean these spikes are included as part of the analysis, but do not force the overall mean to be inflated unrealistically.

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Bankfull conditions are estimated to be at around the 10-yr ARI event when most anabranch ridges and islands would be inundated. Flow depth increases quickly up to the 10-yr ARI event, then more slowly thereafter indicating the floods are increasingly spreading out onto the floodplain. Channel top width increases rapidly above the 10-yr ARI flood as more and more of the floodplain is inundated. Channel stream power increases with increasing flood magnitude to be around 20 – 25 W/m^2 in the bankfull event, and 56.1 W/m^2 in the 50-yr ARI flood. The HEC-RAS software is not able to model anabranching channels accurately as it defines only one main channel. Channel stream power is concentrated in the one channel, when it should be spread amongst the other anabranches. Total stream power, which is averaged across the whole channel and floodplain, will therefore give a more realistic indication of stream power. Table 5-2 shows this stream power is much less than channel stream power for the 1:10 AEP and greater floods when significant out-of-main-channel flow is occurring.

Downstream of the Well Creek junction there are several long pools in the channel. These are over 500 m long and appear to last into the dry season.

The bed of the Sandy Creek comprised of medium to coarse sand, and overbank deposits adjacent to the channels are fine sand and silt. A few gravel lags with particles up to ~ 2 cm diameter also occur. There is no evidence that the channel is actively aggrading, however there is a significant volume of bedload passing through the reach. This is supplied mostly by Greentree Creek, with some also supplied by Well Creek.

The floodplain rises to more than 5 m above the channel bed and becomes very wide at 100-yr ARI floods and greater. In these conditions the floodplain is more than 2.5 km wide, and merges with those of Little Sandy Creek and Well Creek. There are few distinctive landforms on the floodplain apart from some shallow palaeochannels.

Figure 5-5 shows Sandy Creek just downstream of the Greentree/Lagoon Creeks confluence. Greentree Creek is entering from the left, and Lagoon Creek continues behind the trees to the right.

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Figure 5-5 Sandy Creek at the Lagoon/Greentree confluence

The wide sandy channel is in marked contrast to the Lagoon Creek reach shown in Figure 5.4 that is directly behind this view. Lagoon Creek flows downstream for a few hundred metres in its own channel to the right. The bed of Sandy Creek is up to 1 m above Lagoon Creek.

Figure 5-6 shows Sandy Creek about mid way along the MLA reach at ch 7925. This looks upstream and shows the ridge anabranching channel form. The grassed bank on the right is an in-channel bench.

Figure 5-6 Anabranching channel in Sandy Creek at ch 7925

5.5 Well Creek

Well Creek is the only significant tributary to join Sandy Creek in the MLA, and its general catchment setting is described above in Section 4.2.4. It is divided into two reaches: the upper extends 15.3 km to the junction with Middle Creek; the lower reach extends 5.6 km to Sandy Creek, and includes the junction with Little Sandy Creek.

Figure 5-7 shows the bed profile of the creek which while irregular shows a typical concave overall profile. The steeper upper reach with overall gradients of 0.28% to 0.22% contrasts with the more gently sloping lower reach where the gradient is 0.17%.

Table 5-4 Well Creek channel characteristics

	Upper Reach	*Lower Reach*
Channel length in MLA	15.3 km	5.6 km
Sinuosity	1.4	1.1
Mean channel slope	0.28% - 0.22%	0.17%
Mean channel width	16 m	21 m
Mean channel depth below floodplain	3.0 m	2.8 m

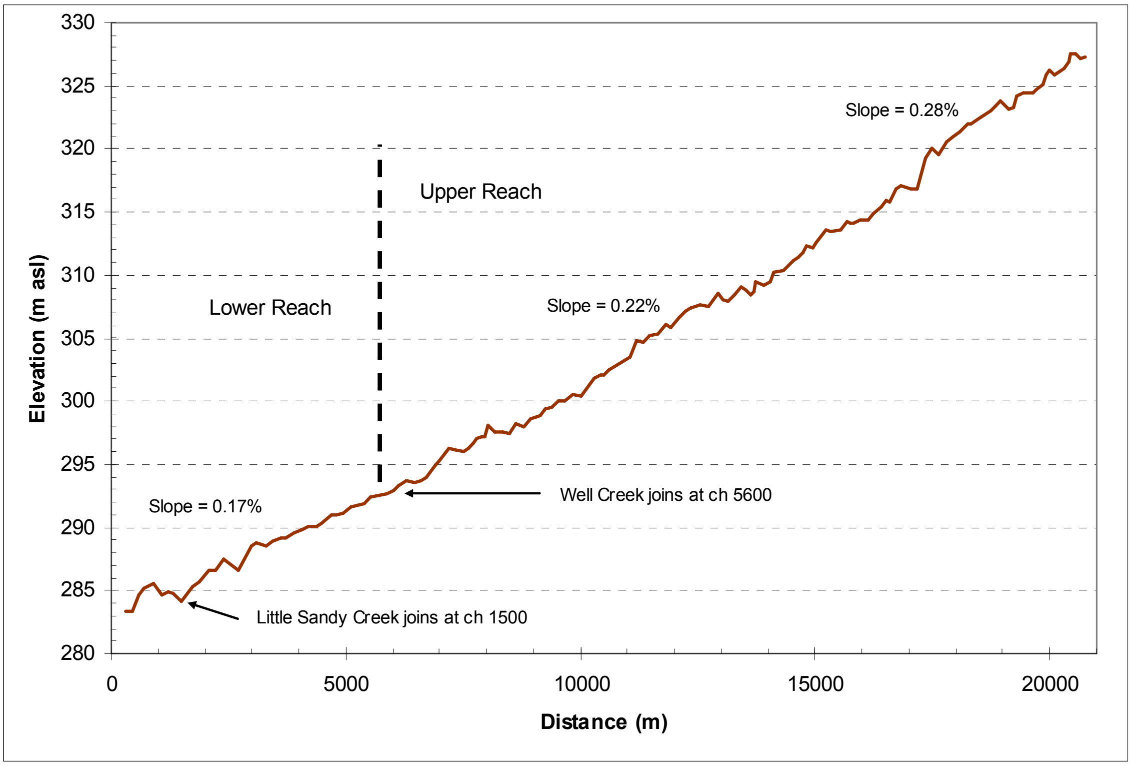

Figure 5-7 Bed profile of Well Creek

5.5.1 Upper Well Creek

In the upper reach the channel is often confined between low hills, and there are some shallow gorge-like sections and knick points where duricrusts outcrop in the channel. The single thread channel has irregular meander bends with an overall sinuosity SI = 1.4. The bed varies between 10 m and 20 m width, and where a floodplain landform is present the bed is ~3 m below.

The bed comprises a uniform sand sheet of coarse sand with occasional gravel lags. Figure 5-8 shows part of the upper reach near ch 15550. This view upstream shows a ~10 m wide channel incised ~2 m below a floodplain. The uniform sand sheet bed appears to be aggrading over the lower trunks of the riparian trees.

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Figure 5-8 Upper Reach of Well Creek at ch 15500

Table 5-5 Well Creek HEC-RAS model outputs (geometric means)

	ARI	Upper Reach	Lower Reach
Mean flow depth (m)	2-yr	1.1	1.3
	5-yr	2.0	2.2
	10-yr	2.6	2.8
	20-yr	3.1	3.2
	50-yr	3.6	3.6
Mean top width (m)	2-yr	16	21
	5-yr	34	50
	10-yr	76	92
	20-yr	155	228
	50-yr	247	830
Mean channel specific stream power (W/m^2)	2-yr	11.3	7.7
	5-yr	30.3	21.7
	10-yr	49.2	32.9
	20-yr	69.2	31.2
	50-yr	99.6	39.7

HEC-RAS model outputs for the upper reach (Table 5-5) show the generally confined nature of the upper reach, and the resulting high stream power that develops in the channels during larger floods. The bankfull stage flood event conditions occur between the 10-yr and 20-yr ARI events.

5.5.2 Lower Well Creek

Downstream from the junction of Middle Creek, Well Creek has a gentler bed long profile (0.17%), and while still predominantly a single thread channel there are some anabranching reaches. There are broad irregularly spaced bends but sinuosity is low at SI = 1.1.

The channel bed averages 21 m across and is incised on average 2.8 m below the floodplain. The valley floor widens and the floodplain merges downstream with that of Sandy Creek. As can be seen from Table 5-5 the gentler slope and wider channel results in lower mean channel stream power conditions.

Figure 5-9 shows a view downstream of the lower Well Creek channel at ch 5600 just downstream of the Middle Creek junction.

Figure 5-9 Lower Reach of Well Creek at ch 5600, just downstream of the Middle Creek junction

The 15 m wide bed comprises medium sand with a small point bar on the true left, and there is a small in-channel bench on the true right. The channel is incised ~3 m below the floodplain which is affected by floods between 10-yr and 20-yr ARI. Both Middle Creek and the Upper Well Creek reach are actively contributing sand to the lower reach.

Downstream at ch 1500 Little Sandy Creek joins the lower reach of Well Creek. Sandy Creek at this point is not carrying any significant bedload, and the sand bed of Well Creek is 0.5 m to 1 m higher than, and extends a tongue of sediment ~15 into channel of Little Sandy Creek.

Figure 5-10 is a view upstream in Well Creek just upstream of where it joins with Sandy Creek. The bed is 20 m across and consists of medium sand with a thin surface mud drape. The channel is ~2 m below the floodplain and there is a small in-channel bench on the true left. Riparian vegetation is dense, but the lower trunks are exposed indicating bed aggradation has not yet occurred here.

However, the well developed sand bars show the system is actively transporting sediment to Sandy Creek.

Figure 5-10 View looking upstream in Well Creek at the junction with Little Sandy Creek

5.6 Middle Creek

Middle Creek is a tributary of Well Creek, it flows between low hills in a confined valley with limited or no floodplain development, and is described above in Section 4.2.4. Figure 5-11 shows the bed profile which is relatively uniform and slightly concave in shape. As the creek is confined along its whole length it has been described in a single reach.

Middle Creek is the steepest of the MLA watercourses with an upstream slope of 0.52% declining to 0.27% near Well Creek. In planform there are some irregular wavelength bends, and in the upper part the channel sinuosity is SI = 1.4, declining downstream to SI = 1.2. The channel is single thread throughout its length.

Table 5-6 Middle Creek channel characteristics

	Sandy Creek
Channel length in MLA	19.5 km
Sinuosity	1.4 to 1.2
Mean channel slope	0.52% declining to 0.27%
Mean channel width	9 m
Channel depth	1 – 2 m

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HEC-RAS model outputs relevant to channel morphological characteristics are summarised in Table 5-7. As above, the data are geometric means calculated to reduce the effect of large and small outliers on the results. The channel is narrow, the average width of 12 m showing a range from <5 m upstream increasing downstream to ~15 m near the Well Creek junction. The confined valley has not allowed

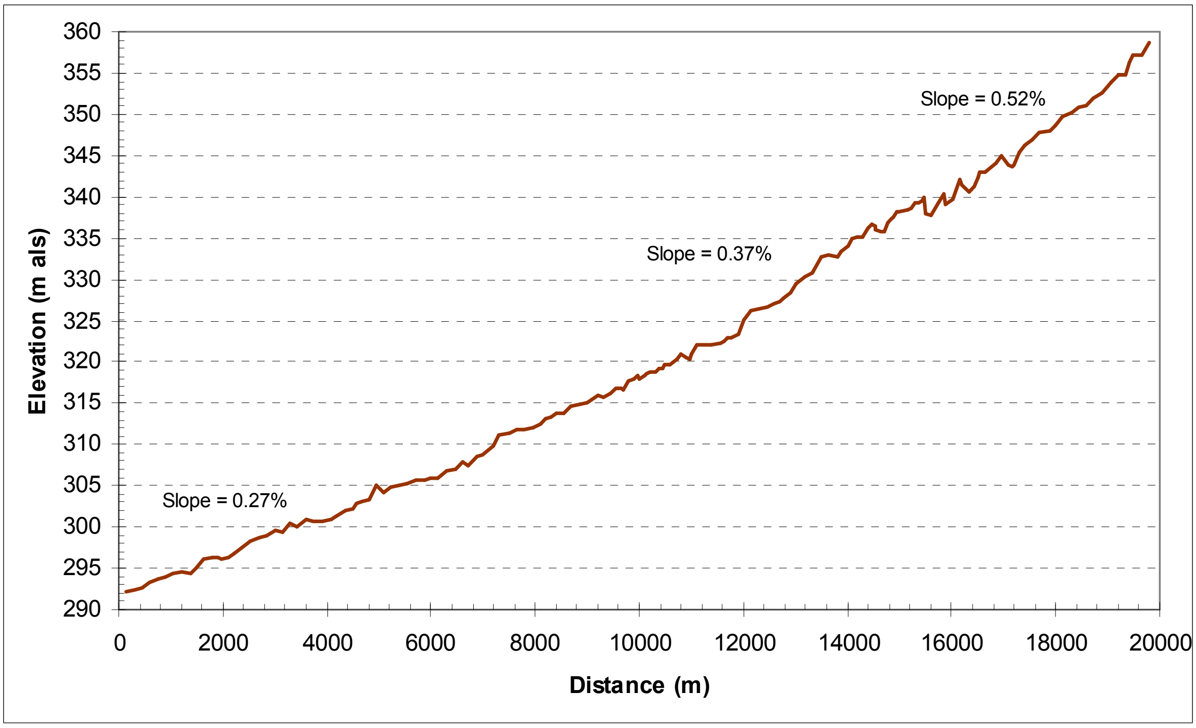

Figure 5-11 Bed profile of Middle Creek

development of a proper floodplain, although there are some floodplain-like occurrences in wider parts of the valley. The valley has similarities to Erskine *et al's* (2005) *bedrock confined* stream type where the confining material is Tertiary age alluvium partly cemented by deep weathering effects. As a result the valley is probably less confined than would be the case in a bedrock setting and some deposition of alluvium has occurred. These valleys are typically unstable in the long term as the relatively thin deposits of alluvial fill adjacent to the channel can be stripped by large infrequent floods, and then re-formed during smaller events.

The proposed Little Sandy/Rocky Creek diversion will discharge into Middle Creek at about ch 7200. At this point the east flowing Middle Creek turns to flow generally north to eventually join Well Creek. Table 5-7 also shows the overall characteristics of this part of the watercourse. Through most of this reach the channel is a 2 – 3 m deep slot, 30 – 50 m wide at the top with a ~10 m wide channel bed. There are discontinuous in-channel benches, and the 50-yr ARI event flow is confined to a width of <70 m. A short section between ch 5700 and ch 4500 has a ~200 m wide floodplain inundated at 50-yr ARI floods.

Table 5-7 Middle Creek HEC-RAS model outputs

	ARI	Middle Creek	Lower 7 km
Mean flow depth (m)	2-yr	0.6	1.0
	5-yr	1.0	1.7
	10-yr	1.3	2.1
	20-yr	1.6	2.5
	50-yr	2.0	3.0
Mean top width (m)	2-yr	12.1	9.7
	5-yr	19.7	18.5
	10-yr	28.6	33.4
	20-yr	40.9	65.8
	50-yr	64.5	122.0
Mean channel specific stream power (W/m^2)	2-yr	4.4	7.8
	5-yr	11.0	18.9
	10-yr	19.0	31.4
	20-yr	29.3	45.6
	50-yr	45.5	66.1

Figure 5-12 shows the upper part of Middle Creek at about ch 14500. The narrow low energy channel is still carrying flow after recent heavy rainfall.

Figure 5-12 Middle Creek at about ch 14500

Figure 5-13 shows part of the lower Middle Creek at ch 5100. This is in the sub-reach where a floodplain has formed. The bed is a uniform medium – coarse sand sheet with a thin gravel lag derived from a duricrust exposure just upstream. The HEC-RAS modelling indicated floodplain flow would occur in floods a little larger than the 10-yr ARI event. The creek here is carrying a significant bedload, and is possibly starting to slowly aggrade its bed.

Figure 5-13 Middle Creek at about ch 5100

5.7 Rocky Creek

Rocky Creek is a tributary of Little Sandy Creek, and it flows from low hills in the southwest part of the MLA. Much of its course is through a wide valley floor with extensive floodplain development. The landscape setting is described above in Section 4.2.4. Figure 5-14 shows the bed profile which is a uniform 0.29%. An upper single thread confined reach of 3 km can be separated from the lower 11.5 km unconfined anastomosing reach; however, as can be seen in Table 5-8 the morphological characteristics of the channels are very similar apart from the increased width in the lower reach.

Table 5-8 Rocky Creek channel characteristics

	Upper Reach	*Lower Reach*
Channel length in MLA	3 km	11.5 km
Sinuosity	1.3	1.3
Mean channel slope	0.29%	0.29%
Mean channel width	8 m	13 m
Mean channel depth below floodplain	1.7 m	1.7 m

The planform of the lower reach is distinctively anastomosing. The pattern of dividing and rejoining sinuous channels is best developed in the lower two kilometres where 2-3 channels carry water in 2-yr and 5-yr ARI floods. Upstream the anastomosing pattern is still present, but the individual channels are only active during much larger >50-yr ARI floods.

Each of the anastomosing channels forms a simple 2 – 3 m deep by 10 – 15 m wide slot incised below the floodplain surface. They follow a moderately tortuous path swinging up to 200 m away from each other and rejoining 1 km and more downvalley.

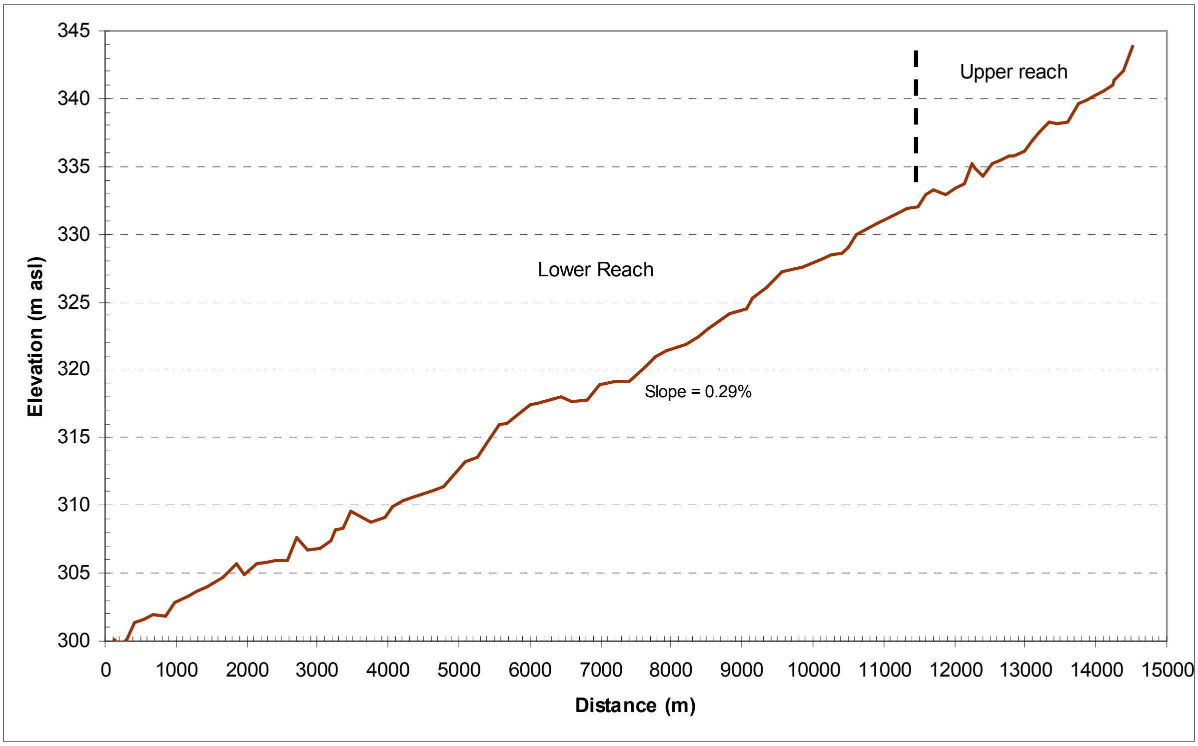

Figure 5-14 Bed profile of Rocky Creek

The HEC-RAS data in table 5-9 shows the confined character of the upper reach with bankfull conditions occurring at floods greater than 20-yr ARI. Channel stream power values are moderate to low. The small stream character continues downstream into the lower reach, but here the Bankfull discharge stage occurs with flood between 10-yr and 20-yr ARI magnitude, and in 50-yr ARI floods many hundreds of metres of floodplain is inundated. Stream power is lower through this reach, even in the single main channel that the HEC-RAS software models. However, in floods of magnitude 5-yr ARI and greater multiple channel threads are flowing and stream power across these will be greatly reduced. This can be seen in the total stream power values in Table 5-9 that decline with the larger floods as more water is carried across the floodplain.

Table 5-9 Rocky Creek HEC-RAS model outputs

	ARI	Upper Reach	Lower Reach
Mean flow depth (m)	2-yr	0.7	0.8
	5-yr	1.3	1.4
	10-yr	1.7	1.7
	20-yr	2.0	1.9
	50-yr	2.5	2.1
Mean top width (m)	2-yr	7.7	12.9
	5-yr	12.6	35.9
	10-yr	16.9	75.9
	20-yr	29.1	164.6
	50-yr	49.4	281.5
Mean channel specific stream power (W/m^2)	2-yr	8.0	3.7
	5-yr	19.6	13.7
	10-yr	32.0	23.2
	20-yr	45.7	30.1
	50-yr	61.7	46.2
Mean total specific stream power (W/m^2)	2-yr	7.8	6.5
	5-yr	19.0	9.7
	10-yr	29.4	9.7
	20-yr	30.0	8.1
	50-yr	33.1	9.4

Figure 5-15 is a view upstream at the meeting of two anastomosing channels incised ~2 m below the floodplain. The channel on the right is less active and constrained by a duricrust bluff. The channel on the left is more active and carrying medium-coarse sand bedload. The overbank sediment in the foreground is fine sand. Some minor migration of the channel is evident as it meanders around and undercuts the roots of an in-channel tree.

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Figure 5-15 Rocky Creek anastomosing channels at ch 7000

Figure 5-16 shows the lower reach of Rocky Creek at ch 2150 looking upstream, and showing the simple trapezoidal channel cut ~2 m below the floodplain. Large woody debris is common in the channels of the lower reach. The bed is a uniform sand sheet of medium – coarse sand with a fine gravel lag. At this location and throughout this lower reach the channel banks comprise cohesive fine sand and silt. This difference between the floodplain and channel sediments suggests there is an imbalance between the current stream sediment load and the channel form as anastomosing streams do not usually have sandy beds. It is likely that the sand bedload has already arrived due to increased land degradation arising from the clearance of trees in the catchment of Rocky Creek. Several gully erosion sites occur up-valley that are directly contributing sediment to the creek.

Figure 5-16 Lower reach of Rocky Creek at ch 2150

Rocky Creek will be diverted at about model chainage 3365 and the flow carried north to Middle Creek. The lower 3.4 km of the channel including the well developed anastomosing system will be lost.

5.8 Little Sandy Creek

Little Sandy Creek is the longest watercourse in the MLA, flowing east for 32.7 km from dissected hills near the GDR through a broad valley floor between low hills, before issuing onto the western side of the Sandy Creek floodplain and flowing a further 9 km north to join Well Creek. The landscape setting is described above in Section 4.2.4. Figure 5-17 shows the bed profile which has a typical concave form with a steep upper reach (slope 0.67%) declining downstream to a very gentle 0.07% near Well Creek. Four reaches are identified: a single thread upper reach of 4.3 km in a confined valley; an upper-middle single thread reach of 11.1 km in a wide valley floor; a lower-middle multi thread 16.4 km long anastomosing reach in a wide valley floor; and a 3 km long lower single thread reach. Overall some 63% of this catchment area within the MLA has been cleared of tree cover.

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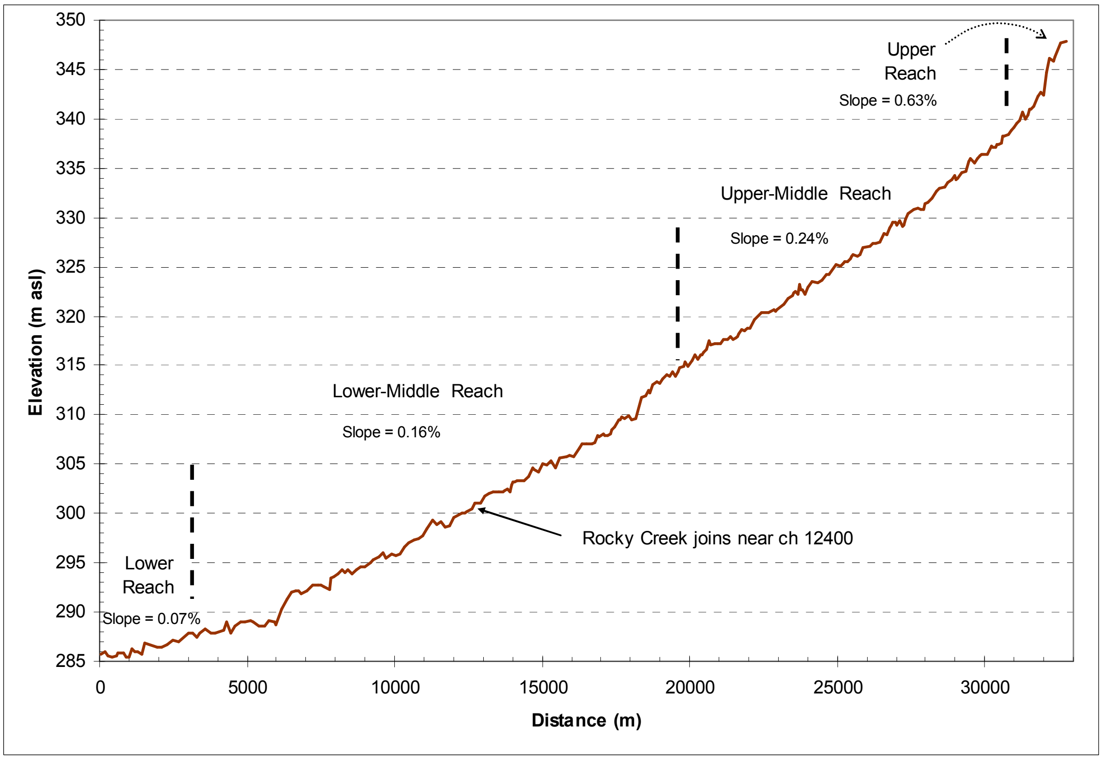

Figure 5-17 Bed profile of Little Sandy Creek

Table 5-10 shows the downstream variations in channel morphological characteristics. As the bed slope declines the channel becomes wider and deeper. This watercourse is also the most sinuous in the MLA, with the upper-middle and lower reaches having SI values >1.5 in the meandering class.

Table 5-10 Little Sandy Creek channel characteristics

	Upper Reach	*Upper-Middle Reach*	*Lower-Middle Reach*	*Lower Reach*
Channel length in MLA	4.3 km	11.1 km	16.4 km	3 km
Sinuosity	1.2	1.6	1.4	1.7
Mean channel slope	0.63%	0.2%	0.16%	0.07%
Mean channel width	8 m	16 m	17 m	25 m
Mean channel depth below floodplain	1.9 m	1.5 m	2.2 m	2.7 m

The upper two reaches are single thread watercourses. The steep gradient and narrow channel of the upper reach results in relatively high stream power values (Table 5-11). Figure 5-18 shows the channel at ch 31650. The narrow shallow channel here is incised less than 1 m into a floodplain, and is clogged with coarse sand bedload. Through the upper-middle reach the watercourse meanders across a wide floodplain. Meander wavelength is 200 – 300 m, and the bankfull discharge stage is typically a flood >10-yr ARI. Stream power is lower here as bed slope declines. The channel banks are actively eroding on the outside of bends, and small gullies are delivering sediment to the channel.

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Figure 5-18 Upper reach of Little Sandy Creek at ch 31650

The lower-middle reach is a multi-thread anastomosing channel system, and the similarly anastomosing Rocky Creek joins in the upper part of this reach. In the upper and middle parts this reach has 2 – 3 active meandering channels that split and re-join at 1 – 1.5 km intervals and can be more than 500 m apart. The channels are ~2 m below the floodplain and bankfull discharge stage is at around the magnitude of the 10-yr ARI flood. From Table 5-11 the stream power is a little higher than in the upstream reach despite the lower gradient here. This arises in part from the extra discharge contributed by Rocky Creek, but also is likely due to HEC-RAS modelling the bulk of the flow with a single main channel. Total stream power here is much reduced and this is likely to be a better representation of flow energy through this reach.

Figure 5-19 shows an upstream part of this lower middle reach at ch 10950. The bed is about 5 m across and incised about 1.5 m below the floodplain. Bedload is medium-coarse sand with some gravel lag, arranged in waves with an amplitude of about 1 m. Large woody debris is present and the cohesive steep banks are being eroded.

Further down reach at ch 7390 the sand bedload is not present, although fine sand overbank deposits do occur (see Figure 5-20). The simple channel is form incised 1 – 2 m below the floodplain, and there is an accumulation of large woody debris. Two anastomosing channels are meeting, and the banks of cohesive silt typical of this channel type are evident. The sand bedload described from upstream parts of the watercourse has apparently not reached downstream to this point yet.

In the lower 8.5 km of Little Sandy Creek the watercourse flows northwards along the western margin of the floodplain of Sandy Creek. The two channel systems are about 1 km apart, and in large floods (ARI 100-yr) their floodplain merge together.

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Figure 5-19 Lower-middle reach of Little Sandy Creek at ch 10950

Figure 5-20 Lower- middle reach of Little Sandy Creek at ch 7450

The lower Little Sandy Creek reach is a short (3 km) single thread channel that takes the creek to its junction with Well Creek. Bed slope is very low and the channel is wide and deep. Stream power drops to very low levels (see Table 5-11), and bankfull discharge occurs relatively frequently at floods of magnitude 5-yr to 10-yr ARI.

Figure 5-21 Lower reach of Little Sandy Creek at ch 50, just upstream of the Well Creek confluence

Figure 5-21 shows Little Sandy Creek just upstream of its confluence with Well Creek (see Figure 5-10). The 25 m wide low energy channel is incised 2 – 3 m below the floodplain and is dominated by silt and mud sediments. The sand bedload of the upper reaches has not yet made its way to this point.

The Well Creek – Little Sandy Creek confluence is about 800 m from the Sandy Creek channel. Floods of 50-yr ARI magnitude result in the floodplains of all three systems merging.

Table 5-11 Little Sandy Creek HEC-RAS model outputs

	ARI	Upper Reach	Upper-Middle Reach	Lower-Middle Reach	Lower Reach
Mean flow depth	2-yr	0.6	0.7	1.1	1.4
(m)	5-yr	1.0	1.1	1.8	2.3
	10-yr	1.3	1.3	2.1	3.0
	20-yr	1.5	1.5	2.3	3.5
	50-yr	1.9	1.8	2.7	4.1
Mean top width	2-yr	8	16	17	45
(m)	5-yr	17	40	69	162
	10-yr	25	86	174	343

	ARI	Upper Reach	Upper-Middle Reach	Lower-Middle Reach	Lower Reach
	20-yr	32	178	269	482
	50-yr	57	316	427	632
Mean channel specific stream Power (W/m^2)	2-yr	6.1	2.8	3.9	0.8
	5-yr	14.8	6.8	10.1	2.4
	10-yr	21.8	9.2	14.5	4.0
	20-yr	31.1	11.9	20.0	4.0
	50-yr	40.6	18.3	27.1	12.0
Mean total specific stream power (W/m^2)	2-yr	6.1	2.3	3.6	0.4
	5-yr	12.1	4.2	3.9	0.7
	10-yr	15.6	3.9	3.0	0.8
	20-yr	20.9	3.2	3.4	0.7
	50-yr	20.1	3.7	4.1	2.1

5.9 Significance of baseline geomorphic features to inform design of the Kevin’s Corner Project stream changes

All of the watercourses described above will to some extent be affected by the Kevin’s Corner Project such that their geomorphic systems will be partly changed. Potential effects range from complete removal of parts of the Rocky and Little Sandy Creek channels, greatly reduced flow in other parts of Rocky and Little Sand Creeks, increased flow in downstream reaches of Middle and Well Creeks, and diversion of flow from Little Sandy and Rocky Creeks into Middle Creek. In addition, the floodplain width of Sandy Creek will be reduced in size, and most channels, floodplains and hillsides in the western part of the MLA will be affected by ground surface elevation changes due to underground mining subsidence. For sustainable design of the proposed Project stream interventions the following issues need to be considered.

1. The Sandy Creek anabranching channel system requires a combination of moderate channel stream power and good vegetation cover to maintain stability. The floodplain is a low stream power environment covered during 50 yr to 100 yr ARI floods. Increased flows in this environment could lead to stripping of floodplain sediments. The constriction of the Sandy Creek floodplain will increase flow depths and velocities on the floodplain and in the channels, and stream power will also increase across both environments. These effects will need to be managed through the life of the mine and beyond.
2. Diversion of the small Little Sandy and Rocky Creek flows into Middle Creek Sandy Creek and Spring Creek will take flow from an anastomosing channel environment with multiple channels and a wide floodplain. Design will need to ensure all channels and floodplain flows will be directed into the diversion. The diversion will reduce a multiple thread channel to a single channel.
3. The Little Sandy/Rocky Creeks diversion will deliver increased flow to Middle Creek. This confined stream will experience increased magnitude and frequency of channel-forming flows, and a new equilibrium channel environment could need to be allowed to develop.
4. The increased flow in Middle Creek will increase flow in Well Creek in the reach between the junctions of Middle Creek and the former Little Sandy Creek. Again, a new equilibrium system may develop here as the channel and floodplain environments adjust to the changed flow regime.

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5. Subsidence will affect all of the MLA catchment, channel and floodplain areas of Rocky Creek, Little Sandy Creek, and Middle Creek. It will also affect parts of the catchment, channel and floodplains of Well Creek. Sandy Creek will not be affected by subsidence.

   New surface water flow paths will form on hillslopes and these could cause accelerated soil loss and land degradation, which in turn would deliver more sediment to the channels. New irregularities will be imposed on channel bed profiles and pooling of flow may result. Surface depressions on floodplains will cause ponding and changed surface water flow paths that may result in loss of floodplain sediments. These factors will all need to be managed to avoid adverse effects on fluvial geomorphic systems.
6. It has been demonstrated that the present watercourses of Well Creek, Middle Creek, Little Sandy Creek, and Rocky Creek are beginning to carry more bedload sediment and this is being deposited in the upper channel reaches causing aggradation and channel shallowing. This in turn will increase the frequency of bankfull discharge events. It is expected that this sediment will continue to make its way downstream reaching Sandy Creek within a decade or two. This main stream is already carrying an appreciable sand bedload. Increased sediment loads will also arise from underground mining subsidence. Therefore, all watercourses and diversions will need to be designed and/or managed for these increased sediment loads throughout the mine life and beyond. Issues may arise in relation to the effects of sand deposition in main channels and tributary junctions, and the potential for reduced channel conveyance.

Fluvial Geomorphic Effects of Kevin’s Corner Project

Potential fluvial geomorphic effects of the Kevin’s Corner coal mine project have been outlined above in Section 3 and 5.9. This section addresses these in more detail. The mine project will have many inter-related effects, but this section only deals with those directly related to the geomorphology of the fluvial system, in particular:

- Potential effects on hillslope surface runoff and soil erosion processes arising from longwall subsidence;
- Potential effects of subsidence on watercourse and floodplain geomorphology;
- Potential effects on channel geomorphology within the diversion channel;
- Potential effects on the natural channels of Middle Creek and Well Creek downstream of the diversion; and
- Potential effects of levees along Sandy Creek and Well Creek on floodplain and watercourse geomorphology.

By far the largest spatial effect will be from subsidence which will affect some 181 km^2 of the MLA as described in Section 3. While large in area, the effects will be diffuse and not readily identified. The diversion and levees will affect a much smaller area, but the potential effects, if they occur, would be more noticeable in the watercourses and floodplains.

6.1 Longwall subsidence effects

Due to underground mining, hillslopes, channels and floodplains situated directly over longwalls will drop by approximately 0.5 to 3 m.

6.1.1 Subsidence effects on hillslopes

Subsidence of the underground longwall mining panels will introduce a regular 300 m spaced waveform oriented north-south across the landscape.

In the 66 km^2 North Hancock mining area covered by Well Creek and lower Middle Creek the amplitude of the subsidence will mostly be 1.5 m to 2 m, declining in the far west to less than 1.5 m. There will be 25 sets of subsidence surface wave forms. Surface relief here is 10 m to 30 m from valley floor to the tops of the low hills. The subsidence will be variously oriented with respect to the slopes, in places sub/parallel to slope and in other places across the slopes. Slope angles here are generally low (85% – 95% are ≤3^{o}), and the amplitude of the subsidence will be mostly less than 10% of the total hillslope relief. Thus it is likely that surface runoff patterns will only change slightly and should not lead to increased soil erosion as long as good ground cover is maintained.

In the 57 km^2 Central Hancock mining area covered by upper Middle Creek and the north part of Rocky Creek the amplitude of the subsidence will be greater at 3 m over the whole area. There will be 19 sets of subsidence surface wave forms. Surface relief here is 15 m to 20 m from valley floor to the tops of the low hills. Subsidence will be generally oriented up/down slope. Slope angles here are low (95% are ≤3^{o}), and the amplitude of the subsidence will be up to ~20% of the hillslope surface relief. It possible that downslope surface runoff could be enhanced, leading to the formation of erosion gullies. Good ground cover should be maintained, and sediment/runoff check dams may need to be placed if gullies start to form.

In the 58 km^2 South Hancock mining area covered by Rocky and Little Sandy Creeks and a small part of Greentree Creek the amplitude of the subsidence will be 3 m over the whole area. There will be 23 sets of subsidence surface wave forms. Surface relief here is 10 m to 15 m from valley floor to the tops of the low hills. Subsidence will be generally oriented up/down slope. Slope angles here are low (>95% are ≤3^{o}), and the amplitude of the subsidence will be up to ~30% of the hillslope surface relief. Downslope surface runoff could be enhanced, leading to the formation of erosion gullies. Good ground cover should be maintained, and sediment/runoff check dams may need to be placed if gullies start to form.

6.1.2 Subsidence effects in watercourses

Potential watercourse geomorphic impacts could arise from:

- Loss of surface water flow through surface cracking; and
- Change to stream bed profiles between longwall panels.

Loss of watercourse flow

Subsidence causes surface cracking in the areas between the panels. This may occur in a zone up to 60 m wide. Channel flow could percolate into the cracks and voids and discharge lost from the channel. This effect is not likely to have geomorphic significance. The Tertiary and Quaternary age alluvium that underlies the surface is not likely to suffer the same extent of cracking as intact bedrock. In addition, the percolation would need to be very rapid to significantly reduce the flood flows that are most responsible for geomorphic change in the channel.

Changes to streambed profiles

The underground longwall panels are oriented generally perpendicular to the flow of the surface watercourses. Subsidence beneath stream channels will therefore introduce a 300 m long by up to 3 m high wave-like pattern along the channel bed. This will initially create pools along the watercourses, but subsequently sediment movement along the channel will fill in the pools and recreate the former bed profile. Experience in the Bowen Basin has shown these pools can be re-filled within the space of one or two floods, but such rapid in-filling probably requires the watercourse was carrying a significant volume of bedload sediment.

Impacts on bank stability

The surface cracking described above could weaken the channel bank sediments leading to enhanced potential for erosion on the outside of meander bends, or the development of preferential flow paths for subsurface pipeflow particularly if the sediments are highly dispersive. Such pipeflow often results in the development of tunnel gully erosion features.

Impacts on Flood Inundation Levels

It is likely that subsidence will lead to a local reduction in flood capacity and create more frequent inundation of floodplain. Initially the subsidence will drop the surface of both the floodplains and adjacent channels by the same amount. However, re-filling of the channel subsidence with bedload sediment will raise the bed level, but not affect the subsided floodplain level. Thus, once bed recovery has occurred, floodplain inundation oriented along the longwall panels will occur as noted below.

6.1.3 Subsidence effects on floodplains

Subsidence effects on the floodplains of Rocky, Little Sandy, and Well Creeks are documented in the *Hydraulics Technical Report*. The effects will be most obvious on the wider floodplains of Rocky and Little Sandy Creeks. It is apparent that the total area of floodplain inundation could decrease with the pillars (between the subsided panels) standing above deeper water in the subsided parts.

The main potential geomorphic effect of the subsidence will be related to return flow from the floodplains back to the watercourses as the flood level declines. The subsided panels will create preferential flow paths for return flow. If ponding has occurred and the return flow reaches the channel as water levels there have declined, the flow would drop over the channel back and gully erosion will develop at these points.

6.2 Watercourse changes

Figure 6-1 shows the changes that will occur to the watercourses within the MLA. A new watercourse (diversion) will be formed, others will loose some or all their flow but remain as landforms, others will have increased flow, and still others will be lost altogether.

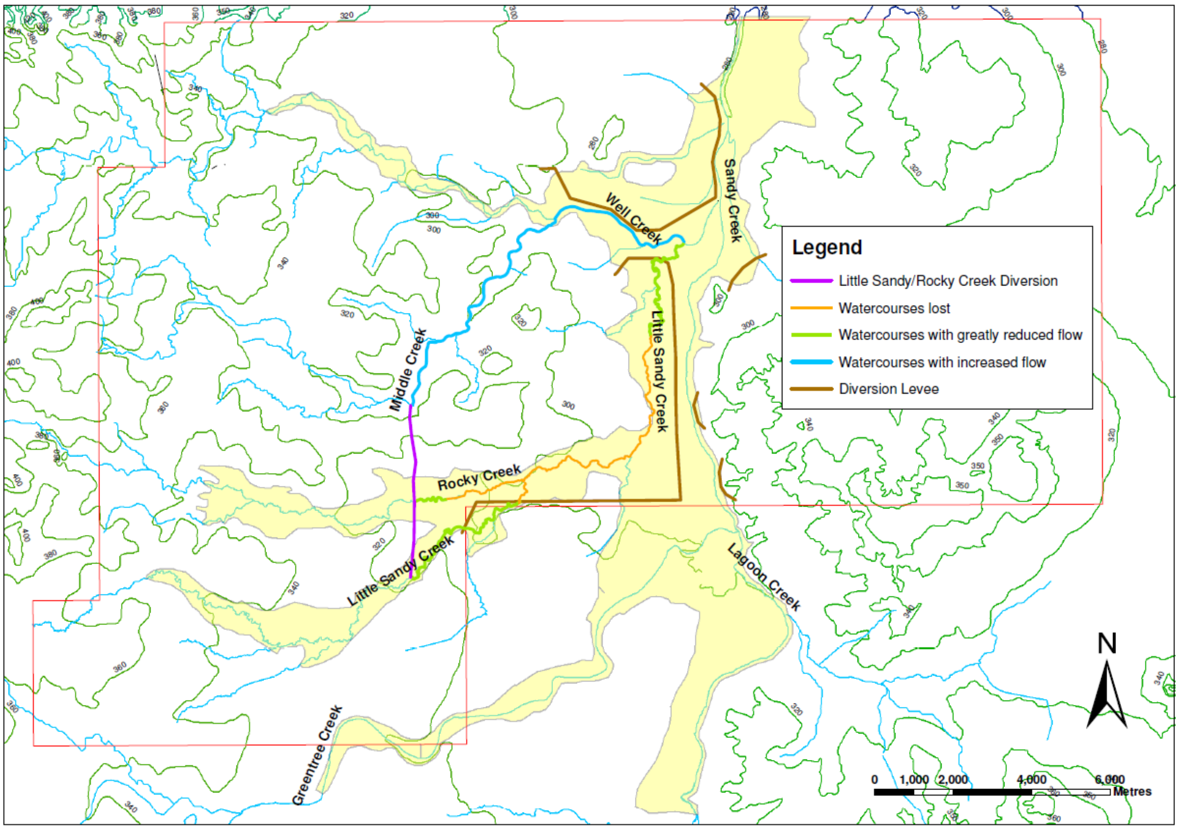

Figure 6-1 Watercourse changes due to the Kevin's Corner coal mine project

Little Sandy and Rocky Creek will be diverted north to join Middle Creek. The diversion structure will be 5.6 km long. Downstream of this diversion the natural channels of these creeks will remain but carry little or no flow in the 3.8 km (Rocky Creek watercourse), and 5.3 km (Little Sandy Creek watercourse) of channel that will be between the diversion and the west side of the pit area.

An 8.6 km section of the Little Sandy Creek watercourse will be lost under the main mine pit area. Downstream of the northern edge of the pit the Little Sandy Creek channel will remain but will carry greatly reduced flow comprising runoff derived from the small area of low hills to the west.

A 1.1 km reach of Middle Creek will be re-formed into the downstream end of the diversion, and the 5.1 km of watercourse from here downstream to Well Creek will carry increased flow. Well Creek will also carry increased flow for 4 km to its (former) confluence with Little Sandy Creek.

Levees will constrain the floodplain of Sandy Creek for 11.1 km north from the southern boundary of the MLA. Levees will constraint the floodplain of the lower 4.5 km of Well Creek.

6.3 Diversion effects

The proposed diversion of Little Sandy and Rocky Creek to flow into Middle Creek is described above in Section 3.3 and in detail in the *Hydraulics Technical Report* where the proposed design is assessed against the ACARP stream diversions guidelines.

The 5.7 km long diversion will cross the existing floodplains of Little Sandy and Rocky Creeks for ~ 3 km, then be cut through the low ridge separating Rocky Creek and Middle Creek watercourses. In the ~2.1 km Little Sandy Creek section it will be required to carry flows of 3 m^3/s to 90 m^3/s, and from Rocky Creek onwards the flows will be from 5 m^3/s to 145 m^3/s. These are the geomorphologically significant flows up to 50-yr ARI event. The 100-yr ARI and larger floods are discussed in the *Hydraulics Technical Report*. Upon entering the Middle Creek watercourse the diversion flows will increase Middle Creek flows by 2.5 to 2.75 times.

Geomorphic effects within the diversion

The main geomorphic effects within the diversion are discussed in the *Hydraulics Technical Report* and will not be repeated here. Diversion design will not attempt the replicate the natural anastomosing channel pattern of Rocky and Little Sandy Creeks, thus potential effects will be associated with the stability of the diversion, rather than its ability to recreate the existing environment. The diversion has been designed with a slight meander pattern with a wavelength of about 1 km. The purpose of this is to ensure the diversion follows within the subsidence footprint of a single longwall panel. Wider meanders would result in complex interactions between the watercourse and the un-subsided ridges between longwall panels.

The low flow channel will need to adequately convey the bankfull discharge and bed sediment loads of Little Sandy Creek and Rocky Creek. In the section across the existing floodplains the substrate will be alluvial and the channel will be able to evolve towards a natural planform. If adverse sedimentation occurs in this low energy environment, a second or third channel could be provided to replicate the multi-thread pattern and locally increase stream power.

The banks of the diversion where it passes through the ridge between Rocky and Middle Creeks will be up to 15 m high and may be subject to surface erosion. In addition, two small natural gullies flow from the east towards the true right bank of the diversion along the Middle Creek section. Flows from these will need to be managed as they drop down into the diversion.

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Effects downstream of the diversion

The channels of Middle Creek and then Well Creek will be required to carry the extra Rocky Creek and Little Sandy Creek diverted discharge. Table 6-1 shows HEC-RAS model outputs for the pre and post diversion cases for the short (~1 km) section of Middle Creek that will be reformed at the downstream end of the diversion, and the remainder of the natural channel to its junction with Well Creek 6.2 km downstream.

The diversion affected reach will have increased flow depth and width, but as the bed gradient will be reduced, the overall flow velocity and stream power will be reduced. This may reduce bedload sediment transport capacity although the values are still within ACARP guidelines.

Downstream of the diversion flood discharges will increase in the Middle Creek natural channel by a factor of 2.5 to 2.75. As can be seen in Table 6-1 flow depth, flow width, and velocity all increase and as a result stream power values also increase. The increases for the 2-yr and 5-yr ARI events are minor, but beyond these flood magnitudes the increases are more substantial.

Middle Creek is the highest energy system of all the MLA watercourses, and this is to be expected given its steeper gradient, and valley confined character. These types of streams are naturally subject to low frequency high magnitude floods that can cause very extensive geomorphic changes such as stripping out small in-channel benches and floodplain fragments that may have developed in the narrow valley floor. Thus there is a semi-cyclic longer-term pattern of erosion/deposition that re-sets these fluvial environments. The 2-yr to 50-yr ARI floods modelled here are too small to be these geomorphic re-setting events. The 105 W/m^2 stream power value for the diverted case still leaves Middle Creek well below the ACARP 220 W/m^2 upper limit for natural water courses.

It is therefore unlikely that Middle Creek will experience significant changes as a result of the increased discharge arising from the diversion of Little Sandy and Rocky Creeks. There may be some trend towards a wider channel and increased bedload sediment transport capacity. However, given the watercourse already has a natural riparian vegetation cover these changes should be readily absorbed.

Table 6-1 HEC-RAS model outputs of Middle Creek changes due to the diversion

	ARI (yr)	**Diversion reach baseline**	**Diversion reach diverted**	**Downstream of diversion baseline**	**Downstream of diversion diverted**
Flow depth (m)	2	0.8	1.3	1.0	1.3
	5	1.4	2.3	1.7	2.1
	10	1.8	2.8	2.1	2.6
	20	2.2	3.2	2.6	3.0
	50	2.7	3.7	3.0	3.5
Top width (m)	2	8	13	10	12
	5	14	81	19	32
	10	22	173	33	63
	20	39	216	61	114
	50	69	231	119	194
Channel velocity (m/s)	2	0.8	0.6	0.7	0.9
	5	1.1	0.9	1.0	1.2

6 Fluvial Geomorphic Effects of Kevin's Corner Project

	ARI (yr)	**Diversion reach baseline**	**Diversion reach diverted**	**Downstream of diversion baseline**	**Downstream of diversion diverted**
	10	1.3	1.0	1.3	1.5
	20	1.6	1.1	1.5	1.8
	50	1.9	1.2	1.7	2.1
Channel mean stream power (W/m^2)	2	10.9	3.2	7.3	11.4
	5	23.8	10.1	17.5	28.6
	10	37.8	12.8	30.0	48.8
	20	57.7	14.1	43.6	73.5
	50	95.6	20.3	61.6	105.1

Downstream of the Middle Creek confluence Well Creek will experience increased flood flow. The increased discharge will be ~1.2 times above the natural flows. Table 6-2 shows HEC-RAS model outputs of changes for the reach ch 5600 to ch 3000. Downstream of here the watercourse enters the Sandy Creek valley and effects there are assessed below in Section 6.4. The increased discharge results in a small increase in flow depth, width, and velocity. There is an increase in stream power for the 20-yr and 50-yr ARI events. However, the diverted case values are still well below ACARP guidelines and are unlikely to have a significant geomorphic effect.

Table 6-2 HEC-RAS model outputs of Well Creek changes due to increased discharge conditions

	ARI (yr)	**Baseline conditions**	**Increased discharge conditions**
Flow depth (m)	2	1.1	1.1
	5	2.0	2.1
	10	2.5	2.6
	20	2.9	3.1
	50	3.3	3.5
Top width (m)	2	21	22
	5	55	61
	10	114	146
	20	298	275
	50	679	526
Channel velocity (m/s)	2	0.7	0.8
	5	1.2	1.2
	10	1.5	1.5
	20	1.5	1.8
	50	1.6	2.1
Channel mean stream power (W/m^2)	2	7.3	8.7
	5	22.1	24.9
	10	41.8	41.4
	20	43.4	66.0
	50	50.0	96.9

A possible minor geomorphic effect could arise if flood flows are not synchronous in the two watercourses. Bedload sediment in Middle Creek could be deposited at the junction with Well Creek awaiting a flood of sufficient magnitude to carry it further downstream. This may result in localised flooding or small-scale re-alignment of the channels, but these will be temporary effects lasting until the next flood of sufficient magnitude clears the deposit away.

6.4 Open pit and levee effects

The open mine pits will remove about 17 km^2 of the existing watercourses and floodplains associated with Little Sandy Creek, Well Creek and Sandy Creek.

The five levees are shown in Figure 6-1, with two long ones on the western side of Sandy Creek and in the lower Well Creek valley, and three small ones on the east side of Sandy Creek. They will have a total length of 27 km. The longest will be 15 km running around the southern and eastern sides of the main pit, and then west into the lower valley of Well Creek. The levee on the north side of Well Creek runs for 8.9 km and swings out into the lower Sandy Creek valley. These two levees will keep water out of the two main mine pits. The short levees (0.7 km – 1.6 km long) on the eastern valley side will protect smaller mine infrastructure.

The main Sandy Creek levee will constrict the true left side of the floodplain along 6 km of the valley, reducing the >1.7 km wide floodplain here to around 500 m width. North of Well Creek the reduced floodplain width will be similar, and the restriction would end about 2 km from the northern boundary of the MLA. Table 6-3 shows HEC-RAS data for baseline and levee-restricted cases.

It can be seen that for flood up to 50-yr ARI the HEC-RAS modelling predicts there will be effectively no change to channel and floodplain conditions. This is due to these floods not being large enough to be restricted by the levees. TUFLOW modelling reported in the *Hydraulics Technical Report* shows the 100-yr ARI event will be restricted by the levees, and the effects of this are discussed in that report. Given the extra flow will predominantly be in the low velocity environment of the floodplain it is considered unlikely that significant geomorphic effects would arise from the 100-yr ARI and larger events. Rather, geomorphic effects along Sandy Creek will be concentrated in the more active watercourse environment that is affected by the much smaller channel-forming events up to the magnitude of the 50-yr ARI event.

Table 6-3 HEC-RAS model outputs of Sandy Creek changes due to floodplain levee restriction

	ARI (yr)	**Baseline conditions**	**Levee-restricted floodplain**
Flow depth (m)	2	1.5	1.5
	5	2.5	2.5
	10	3.2	3.2
	20	3.8	3.9
	50	4.5	4.5
Top width (m)	2	77	78
	5	129	130
	10	193	194
	20	294	272
	50	622	648

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	ARI (yr)	**Baseline conditions**	**Levee-restricted floodplain**
Channel velocity (m/s)	2	0.7	0.7
	5	1.0	1.0
	10	1.2	1.2
	20	1.5	1.4
	50	1.7	1.7
Channel mean stream power (W/m^2)	2	5.0	4.9
	5	14.2	14.1
	10	23.5	23.1
	20	35.7	35.5
	50	56.9	56.6

Effects of levee restriction of the lower Well Creek floodplain are shown in the HEC-RAS model outputs in Table 6-4. This compares model outputs for the lower 4.5 km of Well Creek where the floodplain will be most restricted by levees. Again, there is little change from baseline conditions in the 2-yr to 50-yr ARI floods. However, the 50-yr ARI flood will be restricted by the levees, and velocity and stream power increase as a result. However, these are still within ACARP guidelines for natural streams and thus no significant geomorphic effects are likely.

Table 6-4 HEC-RAS model outputs of Lower Well Creek changes due to floodplain levee restriction

	ARI (yr)	**Baseline conditions**	**Levee-restricted floodplain**
Flow depth (m)	2	1.4	1.3
	5	2.3	2.3
	10	2.8	2.8
	20	3.2	3.3
	50	3.5	3.6
Top width (m)	2	21	25
	5	53	68
	10	98	146
	20	265	317
	50	961	618
Channel velocity (m/s)	2	0.8	0.7
	5	1.2	1.0
	10	1.4	1.3
	20	1.4	1.5
	50	1.5	1.7
Channel mean stream power (W/m^2)	2	7.7	7.2
	5	22.2	15.1
	10	34.5	26.5
	20	32.8	38.5
	50	36.0	56.2

Proposed Monitoring and Mitigation

This report has identified a variety of potential geomorphic effects that could arise in the watercourses, floodplains and hillslopes of Sandy Creek and its tributaries as a result of the Kevin's Corner Project. These effects are mostly directly related to hydraulic issues covered in detail in the *Hydraulics Technical Report*. Design mitigation concepts have been proposed in that report, and no further geomorphic-specific design is required.

Fluvial geomorphic process regimes in a semi-arid environment such as the Kevin's Corner area are episodic, occurring during heavy rainfall events and their subsequent floods. Many months or even years may pass between such events. Geomorphic change may also not occur or only occur in small amounts during an initial series of storms and flood events as the environment may be able to effectively absorb such events without significant effects. However, a subsequent (culminating) event may trigger change once a threshold has been passed. In this way there can be time in which to identity the on-set of change before it occurs and respond accordingly to the specific circumstances that are presented. In this regard, reactive environmental management can be effective, and responses can be tailored to specific issues as they emerge. This is considered an appropriate approach to take in relation to geomorphic processes.

Crucial to this approach is adequate monitoring which can identify the small changes that are likely to lead on to more significant effects. The following outline of a monitoring program is proposed in order to establish baseline pre-mining geomorphic conditions, and to then detect and subsequently mitigate potential adverse geomorphic effects arising from the Kevin's Corner Project during the mine life.

A detailed monitoring program should be developed from this outline. Monitoring needs to be broad enough to detect landscape-scale changes (for example that that are likely to occur due to subsidence), but also detailed enough to anticipate particular problem sites such as in and around the diversion.

Baseline geomorphic description.

A detailed survey of the MLA geomorphology should be undertaken prior to mining activities. This should be supported by:

- Airborne LIDAR survey (accuracy ± 0.1 m)
- Dry season vertical aerial photography (Additional wet season photography would also be useful)
- Helicopter-acquired high definition digital video of all major streamlines

Various landform, slope, watercourse and other mapping classifications should be developed for inclusion in a GIS database. The watercourse classification should identify knick points and other areas where high stream power conditions are likely to occur

Particular attention should be placed on areas likely to be most affected including the diversion, Middle Creek and Well Creek below the diversion, and Sandy Creek.

Reference watercourse and floodplain reaches of at least 300 m should be documented upstream, within, and downstream of the potentially affected areas. Data gathered should include ground surveyed cross sections, bed sediment samples, floodplain sediment dispersivity, large woody debris, bedforms (pools/riffles/runs/sand sheets/bedrock controls).

Land degradation types and distribution should be mapped across the MLA.

7 Proposed Monitoring and Mitigation

This material should be compiled into a descriptive and interpretive reference geomorphological report supported by relevant GIS databases

Monitoring throughout the mine life

The above data gathering should be repeated at 5 yearly intervals throughout the mine life.

Reporting should assess the nature and extent of geomorphic changes that have occurred since the previous survey, and recommend remedial actions to address any mine-related adverse effects on the geomorphic environment. This assessment should cover channel, floodplain, and diversion changes, the extent and effects of subsidence across the landscape, and changes in the nature and extent of land degradation processes.

An important part of these on-going assessments will be appropriate documentation of rainfall, storms, floods and other landforming processes that may have influenced geomorphic processes in the preceding years. It will be necessary to differentiate clearly between those processes that are natural and those that are due to mining or other human activities.

Between each five-yearly survey, annual rapid geomorphic assessments should be carried out to identify occurrences of accelerated erosion or sedimentation. This could include stream bend erosion, gullying, tunnel gullying, aggradation at stream confluences, bank weakening due to subsidence etc. Appropriate recommendations for site remediation should be included in the reporting of these rapid assessments.

Event-based full scale monitoring should also occur within 6 months after 10-yr ARI or greater floods. This should then be repeated within 2 years to document recovery, and the 5-yearly surveys continued after that.

End of mine survey

A full survey of the geomorphic environment should be undertaken at the end of the mine life prior to relinquishment of the miming licence. The reporting should comprehensively review all previous monitoring and recommend any mitigation that may be appropriate to ensure a stable geomorphic system is able to continue to evolve into the future.

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Limitations

URS New Zealand Limited (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of URS Australia and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 16th June 2010.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 10th October 2010 June and 15th April 2011 and is based on the information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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