Appendix A

Fluvial Geomorphological Assessment for the Vickery Coal Project

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For

Whitehaven Coal Limited

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FLUVIAL SYSTEMS

GEOMORPHOLOGY • CATCHMENT HYDROLOGY
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Fluvial geomorphological assessment for Vickery Coal Project

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Table of Contents

List of Figures

1 Introduction

1.1 Purpose of this document

Whitehaven Coal Limited (Whitehaven) is seeking to recommence mining operations at the Vickery Coal Mine (herein referred to as the Vickery Coal Project [the Project]). The Project is located within the Gunnedah Basin, in the New South Wales Gunnedah Coalfield, with the planned open cut being situated approximately 25 kilometres (km) north of Gunnedah.

This report is the fluvial geomorphology component of the Surface Water Assessment report (Evans & Peck, 2012) for inclusion in an Environmental Impact Statement (EIS) for the proposed mining activities.

This report details the investigations and analysis undertaken to define existing fluvial geomorphological conditions in the rivers and creeks both within, and in the vicinity of, the area covered by the Project. This assessment provides baseline information for the purposes of determining the fluvial geomorphology-related risks arising from the proposed mining activities.

1.2 Background

Mining commenced at the Vickery Coal Mine (then known as Namoi Valley Coal Project) in 1986 with a small underground operation which continued until 1991. From 1991 to 1998 approximately 4 million tonnes of coal was extracted using open cut mining methods. Mining operations at the Vickery Coal Mine ceased in 1998.

Since mining ceased in the late 1990s, rehabilitation activities have been completed and the site is currently in care and maintenance.

Whitehaven acquired 100% of Coal Lease 316 and Authorisation (AUTH) 406 from Rio Tinto Limited in January 2010.

1.3 Project overview

The main activities associated with the development of the Project would include:

- development and operation of an open cut mine within Coal Lease 316, Authorisation 406, Mining Lease 1471, Mining Lease Application (MLA) 1, MLA 2 and MLA 3;
- use of conventional mining equipment, haul trucks and excavators to remove up to 4.5 million tonnes per annum of ROM coal and approximately 48 million bank cubic metres of waste rock per annum from the planned open cut;
- placement of waste rock (i.e. overburden and interburden/partings) within external emplacements to the west and east of the planned open cut (i.e. Western Emplacement and Eastern Emplacement) and within mined-out voids;
- construction and use of on-site coal crushing, screening and handling facilities to produce sized ROM coal;
- transport of ROM coal by haulage trucks to the Whitehaven Coal Handling and Processing Plant (CHPP) on the outskirts of Gunnedah (approximately 20 km to the south of the Project open cut);
- use of an on-site mobile crusher for coal crushing and screening of up to 150,000 tonnes of domestic specification coal per annum for direct collection by customers at the Project site;

- use an on-site mobile crusher to produce up to approximately 90,000 cubic metres (m^3) of gravel materials per annum for direct collection by customers at the Project site;
- construction and use of water supply bores and a surface water extraction point on the bank of the Namoi River and associated pump and pipeline systems;
- construction and use of new dams, sediment basins, channels, dewatering bores and other water management infrastructure required to operate the mine;
- construction and use of new soil stockpile areas, laydown areas and gravel/borrow areas;
- construction of a 66 kilovolt (kV)/11 kV electricity substation and 11 kV electricity transmission line;
- transport of coarse rejects generated at the Whitehaven CHPP via truck to the Project for emplacement within an in-pit emplacement area;
- transport of tailings (i.e. fine rejects) generated within the Whitehaven CHPP via truck to the Project for emplacement within co-disposal storage areas in the open cut and/or disposal in existing off-site licensed facilities (e.g. the Brickworks Pit);
- realignment of sections of Blue Vale Road, Shannon Harbour Road and Hoad Lane to the east and south of the open cut;
- realignment of the southern extent of Braymont Road to the south of the open cut;
- construction of an approximately 1 km long section of private haul road (including an overpass over the Kamilaroi Highway) between Blue Vale Road and the Whitehaven CHPP;
- ongoing exploration, monitoring and rehabilitation activities; and
- construction and use of other associated infrastructure, equipment and mine service facilities.

The proposed life of the Project is 30 years.

1.4 Director-General's Requirements

The Director-General's Requirements for the Project were issued on 19 January 2012 under Section 78A of the *Environmental Planning and Assessment Act, 1979*. They specify that the EIS must include an assessment of the impact of the Project on watercourses and associated riparian vegetation and provide the following:

> *Geomorphic assessment of Driggle Draggle Creek, the unnamed southern watercourse and associated tributaries within the mining area, including details of stream order (using the Strahler System), river style and energy regimes both in channel and on any adjacent floodplains*.

1.5 Scope of this report

This fluvial geomorphological assessment addresses the relevant Director-General's Requirements by providing:

- a description of the existing environment, using sufficient baseline data;
- an assessment of the potential impacts of the Project; and
- a description of the measures that would be implemented to avoid, minimise, and if necessary, offset the potential impacts of the project, including detailed contingency plans for managing any significant risks to the environment.

2 Methodology

2.1 General approach

In the absence of specific guidelines, policies, plans and statuary provisions to guide the geomorphic characterisation of the streams in the study area, the geomorphic characterisation was designed to provide information that would support an interpretation of the physical environment.

In this context, stream geomorphology can be measured at two main scales:

1. Geomorphic stream type (lengths of stream at the reach-scale, usually thousands and hundreds of metres, consistent in terms of connectivity with the surrounding valley, bed material, and channel form).
2. Geomorphic feature (characteristic physical features of streams at the cross-section- and reach-scale, usually hundreds and tens of metres).

Thus, a methodology was devised to classify streams of the study area according to geomorphic type, and to measure the geomorphic features of the streams at the cross-section and reach-scale.

The geomorphic characterisation was based on a combination of field survey and desktop analysis of existing data. The field survey was undertaken by Dr Christopher Gippel of Fluvial Systems Pty Ltd over the period 13 to 15 March 2012.

2.2 Definition of the study area

The study area was interpreted as the area within the proposed disturbance footprint and extending beyond this boundary north to Driggle Draggle Creek, into the headwaters of some stream lines located in Vickery State Forest to the ease, and south to an unnamed tributary (locally referred to as Stratford Creek) that drains to the Namoi River. Thus, the study area contained six main drainage lines, with streams lacking mapped or local names given names for use in this report. Some streams were given a notation for use in mapping (Figure 1):

- Stratford Creek south of the disturbance footprint, which drains to the Namoi River.
- South Creek, which drains to Stratford Creek.
- Driggle Draggle Creek, which drains to Barbers Lagoon, which is connected to the Namoi River.
- Northern Drainage Line, which drains to Driggle Draggle Creek.
- North-west Drainage Line, which drains to Driggle Draggle Creek.
- Western Drainage Line, which drains to North-west Drainage Line.

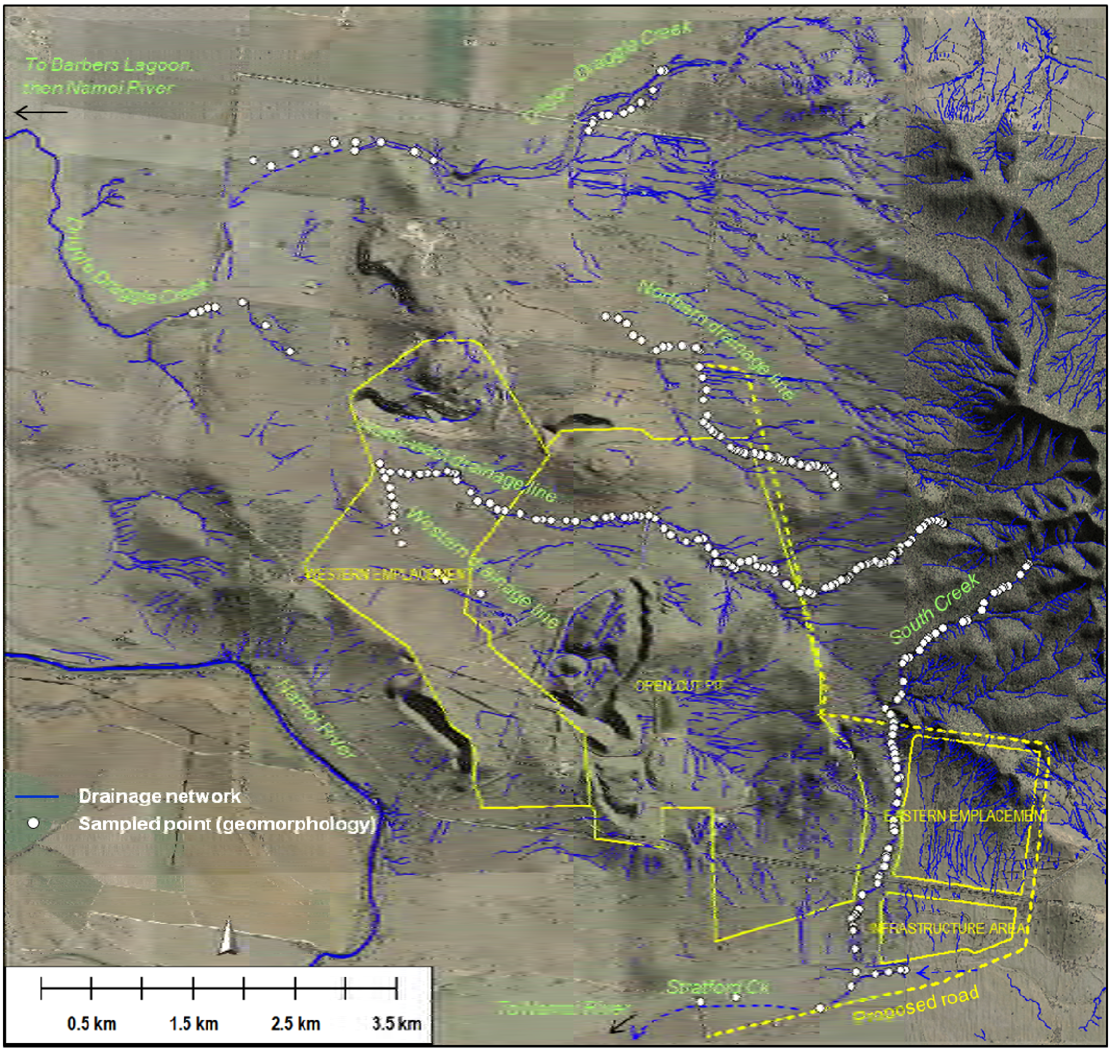

Figure 1. All mapped streamlines within the vicinity of the study area, showing their relationship to the main drainage lines. The general drainage direction is east to west.

The field investigation and desktop analysis considered some areas outside of the disturbance footprint because:

i. an understanding of the fluvial geomorphology of a stream requires a catchment perspective; and

ii. surface water management under conditions of the Project could alter the pattern of runoff in streams outside of the disturbance footprint.

Any impact of the Project on the fluvial geomorphological character of the streams would be effected through hydrological changes. While South Creek passes through the disturbance footprint, its hydrology would be little affected by the Project, hence the hydrology of Stratford Creek would be insignificantly impacted. Similarly, while the hydrology of Driggle Draggle Creek could be impacted through the combined hydrological changes to the Northern, North-west and Western drainage lines, the scale of the change would be so small that no significant hydrological (and thus geomorphological) impact could be determined for Barbers Lagoon or the Namoi River.

2.3 Stream field survey

The objective of the field survey was to obtain sufficient information to enable characterisation of stream type, and stream geomorphic features. Stream type classification relies partly on variables that can only be measured in the field, and partly on variables that can be measured from maps and a digital elevation model (DEM). Geomorphic features of the streamlines in the Project area are too small to be viewed on aerial photographs or other remotely sensed imagery, so they have to be measured in the field.

Due to the large number of streamlines in the study area, it was impractical to cover every metre of stream on foot. As the main objective of the work was to characterise the streams of the area, rather than to map in detail the specific characteristics of all individual lengths of stream, a sampling approach was appropriate.

The approach was to walk the entire length of the main channel of South Creek, Driggle Draggle Creek, Northern Drainage Line, North-west Drainage Line and the Western Drainage Line, making regular observations. The streamlines not covered by the field survey were small headwater tributaries and small drainage lines that mostly lacked a distinct channel (Figure 1). These streams were assumed to be geomorphologically similar to surveyed streams that were located in similar situations in the study area.

The approach to field survey was to walk along the streamline until a noteworthy feature was encountered. In most instances this constituted a knickpoint or a change in stream form or bed material. In the absence of noteworthy features, basic observations of channel dimensions, bed material and large woody debris were made at random points about 20 to 150 metres (m) apart (depending on stream size and heterogeneity). The exception was the expanses of relatively featureless swampy meadow, which lacked measureable attributes. In this case, the drainage line was simply noted as being featureless. As well as measuring and recording data on a standard field sheet, geo-referenced photographs were taken at each observation site. In total, data were collected at 284 sites (Figure 1).

2.4 Digital data

An aerial photograph was available for the years 1956, 1975, 1991, 2001 and 2011. These photographs were georeferenced and had undergone rectification. However, the photographs contained varying degrees of distortion and shadowing, which limited the scale at which stream features could be compared between photographs.

Digital elevation data were supplied as a 20 m x 20 m grid of aerial-survey derived spot elevations reported to 0.01 m accuracy (but the survey accuracy would be less than this). These data were converted to an elevation grid (DEM) using Global Mapper™ software. The software automatically selects the optimum grid size.

The field survey revealed that the supplied digital streamline layer was, in most places, a reasonable representation of actual streams. In most instances where stream channels were indicated by the digital layer, a channel or depression was found in the field. The supplied digital streamline layer was mapped at much higher level of detail than on the printed 1:25,000 map sheets (Boggabri 8936-4-S, Gulligal 8936-3-N, Willuri 8936-1-S and Kelvin 8936-2-N mapsheets). The cartography of the mapsheets was based on 1981 aerial photographic data (prior to commencement of mining in the area), while the digital streamline layer was based on existing conditions.

2.5 Stream order

Stream order was assigned according to the Strahler system, whereby a headwater stream is order 1, and the order increases by 1 when a stream of a given order meets one of the same order. Note that stream order is sensitive to the level of detail in the stream network definition. The stream order used here is with respect to the network depicted on the 1:25,000 maps. The drainage of the study area is typified by discontinuous stream channels. The Strahler system does not include rules for handling stream discontinuity. Here, stream order was applied to general lines of drainage, which did not have to be well defined channels, and it was assumed that stream order was retained across discontinuities.

2.6 Stream dimensions

Global Mapper™ software was used to generate from the DEM data concerning the distribution of topography of the catchment (elevation and slope) and gradient of stream lines. Stream gradient was derived by sampling ~1000 points along the channel ~250 m upstream and downstream of the point of interest and taking the slope of a linear regression between elevation and distance. Stream dimensions (bankfull width and depth) were measured in the field survey, but in broad, low gradient valley situations the channel was not easily distinguished (vegetation cover was extensive at the time of the survey). In these cases, channel dimensions were measured from the DEM.

2.7 Geomorphic type

2.7.1 Section- and reach-scale geomorphic features

Section and reach-scale geomorphic features were the fundamental unit of field observation and measurement. When a feature was observed, its location was recorded using hand-held GPS. The dimensions of the feature were measured, and at the same time, the density of large woody debris, bed material size, valley and floodplain setting, and basic channel dimensions were recorded. The following stream features were observed in the study area:

- Continuous defined channel (bed and banks present).
- Indistinct channel (flow path but no clear bed and banks).
- Incision (channel deeper than expected for an unimpaired stream).
- Pool (could be wet or dry).
- Cascade/waterfall (length of steeply-sloping rock or boulder in headwaters).
- Knickpoint (vertical drop in channel bed, can be in headwaters in rock or boulder, or in fine grained sediments in lower valley setting).
- Head of creek (upstream extent of a headwater channel or channel in valley fill).
- Channel junction (where two streams meet).
- Artificial drainage features (dam or drain).

The dimensions of some features were measured using a tape measure or range finder. For knickpoints, their height was measured. For pools, their length, maximum width and maximum depth were measured. These dimensions were with respect to their potential full level, as defined by the elevation of the downstream hydraulic control, so did not necessarily relate to the level of water in the pool on the day of the survey.

Basic channel dimensions of width and depth were measured relative to the bankfull morphological surface. Bankfull level was defined on the basis of channel form, vegetation and lichen limits. In incised streams, two sets of width and depth measurements were made, one that characterised the inset bankfull channel, and one that characterised the entire incised channel form.

Large woody debris loading was counted over a 20 m stream length, centred on the observation point. Here large woody debris was defined as dead wood within the bankfull channel longer than 1.0 m and thicker than 0.1 m. The count of large woody debris was converted to a wood density per 100 m of stream length.

Bed material size was placed within one of six classes:

- Exposed bedrock.
- Boulder (> 256 millimetres [mm]).
- Cobble (64 - 256 mm).
- Gravel (2 – 64 mm).
- Sand (0.06 – 2 mm).
- Mud (mostly silt and clay).

The primary observation for bed material was the dominant size class. However, in some locations the bed material was evenly mixed across a number of size classes, or was multi-modal. In these instances, up to four bed material sizes were noted as present, in descending order of dominance.

2.7.2 Stream type classification

The geomorphic stream type classification used here borrowed from, and is consistent with, the River Styles® framework (Brierley and Fryirs, 2000; Brierley and Fryirs, 2005; Brierley and Fryirs, 2006; Fryirs and Brierley, 2006; Brierley et al., 2011). The River Styles® classification is based on valley setting, level of floodplain development, bed materials and geomorphic units. The River Styles® framework was designed to cover all Australian stream types, and can be applied at a large scale, where a range of different styles would be expected. Most of the styles apply to partly confined and unconfined (i.e. alluvial/lowland) valley settings where streams are relatively large and feature many distinctive units such as levees, pools and riffles, bars, islands, benches, cutoff channels, backswamps, wetlands and floodplains. The streams in the study area are relatively small-scale and generally lack these features.

The River Styles® framework recognises four stream types in the study area. These were previously mapped by Lampert and Short (2004) as:

- *Low sinuosity gravel* – the Namoi River.
- *Low sinuosity fine grained* - lower Driggle Draggle Creek.
- Alternating *Floodout* and *Valley fill* - Driggle Draggle Creek.

The mapping of Lampert and Short (2004) was at the scale of the entire Namoi River basin, so in the study area they did not map streams other than the Namoi River and Driggle Draggle Creek. Thus it was necessary to include an additional stream type – *Headwater* streams.

2.8 Stream energy regime

Two important variables used in connection with quantitative channel stability assessment are boundary (or bed) shear stress and stream power, which are linked through the variables discharge, slope, channel dimensions and velocity.

A commonly used indicator of stream power is cross-sectional stream power (Ω), which is the power per unit length of a reach. Cross-sectional stream power (watts per metre [W/m]) is defined as:

$$\Omega = \rho g Q S \qquad (1)$$

where,

ρ = the density of the water (usually assumed to be 1,000 kilograms per metre cubed [kg/m^3])

g = the acceleration due to gravity (9.8 metres per second squared [m/s^2])

Q = water discharge (cubic metres per second [m^3/s])

S = the energy slope of the stream (usually approximated by either the water slope or the channel bed slope) measured as metre fall per metre length

The product of ρ and g is the unit weight of water (γ), and is often assumed to be equal to 9,800 Newtons per metre cubed (N/m^3). Bagnold (1966) used Ω in the estimation of sediment transport rates and in the prediction of stream capacity. Phillips (1989) also found that Ω provided a physically-based measure of sediment transport capacity.

Perhaps the most commonly used measure of energy expenditure in stream channels is specific stream power (ω). In essence, specific stream power is the rate of energy expenditure per unit area of the channel bed. Specific stream power per unit bed area (watts per metre squared [W/m^2]) is defined as:

$$\omega = \rho g R S V \qquad (2)$$

where,

R = hydraulic radius of the channel (m), equal to A/P where A is the cross-sectional area of the flow, and P is the length of the wetted perimeter

V = mean depth-averaged flow velocity (metres per second [m/s]).

Specific stream power is equivalent to Ω/W where W is channel width.

Mean boundary shear stress (Newtons per metre squared [N/m^2]) (τ) is:

$$\tau = \rho g R S \qquad (3)$$

It can be seen that specific stream power is related to mean boundary shear stress multiplied by velocity (V).

Bed shear stress is a measure of a stream's capacity to transport sediment. Nanson and Croke (1992) suggested that the related quantity, stream power, is useful as the primary basis for organizing floodplains into classes. With slope and discharge, cross-sectional stream power can be calculated, and width data allows estimation of specific stream power. Specific stream power is measured for bankfull flow conditions. Bankfull represents a fairly frequent discharge with an average recurrence interval (ARI) of 1 – 2 years (Wohl and Merritt, 2005). Thus, in estimating the catchment-wide distribution of stream power, Stacey and Rutherfurd (2007) used the 1.5 year ARI event and Jain et al. (2006), Worthy (2005) and Reinfelds et al. (2004) used the 2 year ARI event. In this study, bankfull was estimated by the 2 year ARI event.

Daily runoff was modelled for 112 years at a number of nodes in the study area (for a description of the hydrological modelling see the Surface Water Assessment [Appendix B of the EIS]). These data were used to predict the 2 year ARI event magnitude (Q_2) by fitting a LPIII distribution. These mean daily flow data are not representative of daily peak instantaneous flow rates. Ronald DeRose (CSIRO, pers. comm., 16th August 2005) indicated that for a small sample of sites from the upper Goulburn River and Ovens River, Victoria, the peak instantaneous (15 minute) discharge was commonly 1.5 to 2 times the daily average for single storm events. He also indicated that for other streams, a colleague, Barry Croke, obtained a similar range of ratios, and there was a suggestion that the ratio decreased with increasing catchment area. Other experience of the author suggests that in small headwater environments the daily peak instantaneous flow rate can be 3 times (or more) the mean daily flow. For the study area, the modelled mean daily flow rates were factored by 3 to achieve a more realistic estimate of daily peak instantaneous flow rate. Driggle Draggle Creek had a significantly higher catchment area (200 square kilometers [km^2]) compared to the other modelled nodes (all less than 20 km^2), so those flows were factored by 2.

Nanson and Croke (1992) defined three main classes of floodplain on the basis of stream power (energy):

- High energy, non-cohesive (>300 W/m^2)
- Medium energy, non-cohesive (10 – 300 W/m^2)
- Low energy, cohesive (<10 W/m^2)

Stream power has been demonstrated to show a distinctive downstream pattern, peaking in the mid-catchment zone, with explainable discontinuities also possible (Knighton, 1999; Lawler, 1992; Lawler, 1995; Lecce, 1997; McEwan, 1994; Fonstad, 2003; Reinfelds et al., 2004; Jain et al., 2006). The upper-mid catchment zone of higher stream power would logically correspond with Schumm's (1977) sediment transport zone. In general, greater sediment storage occurs in the headwaters and lower valleys where stream power is low, whereas little sediment is stored in mid-basin reaches where stream power is high (Lecce, 1997).

3 Characterisation of Existing Conditions

3.1 Comparison of historical aerial photographs

Within the limitations imposed by distortion and image quality, there were no distinguishable changes to the plan form of any of the channels in the study area from 1956 to 2011, except for those channels directly disturbed by previous mining in the 1980s and 1990s. Thus, the channel form is relatively stable.

3.2 Stream order

Based on printed 1:25,000 topographic sheets, measured at the downstream end of each drainage line, South Creek is 4th order, Western drainage line is 3rd order, North-west drainage line is 4th order, Northern drainage line is 3rd order, Driggle Draggle Creek is 4th order where it meets North-west drainage line, and downstream of that to where it meets Barbers Lagoon it is 5th order.

3.3 Stream power (energy regime)

Stream power estimated for the peak discharge of the 2 year ARI event (Q_2) was generally less than 10 W/m^2, except for South Creek where it was between 10 and 20 W/m^2 (Figure 2). Thus, most streams in the study area fall into the low energy - cohesive class of Nanson and Croke (1992), with South Creek in the medium energy - non-cohesive class.

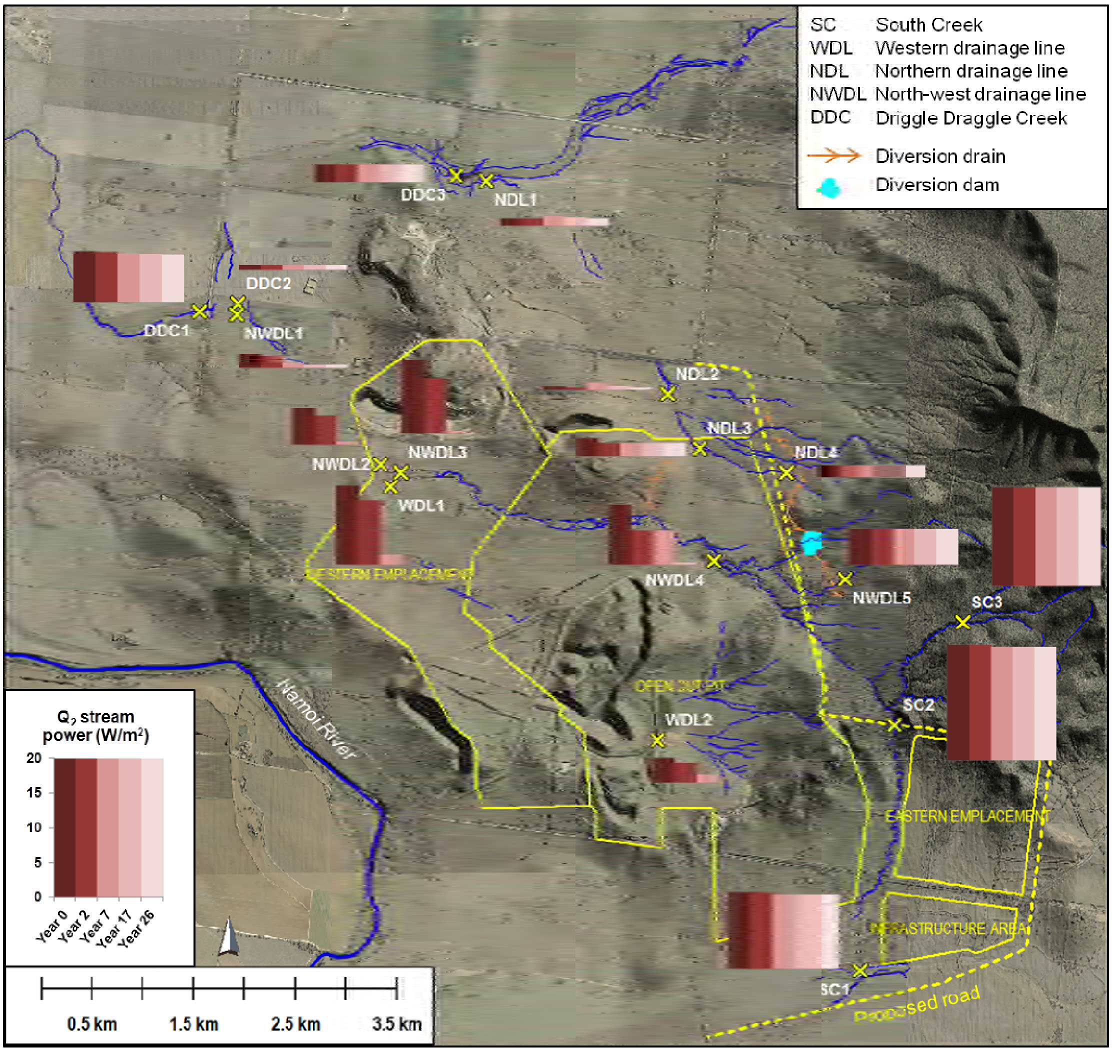

Figure 2. Distribution of stream power at modelled nodes throughout the study area, estimated for existing conditions, and Years 2, 7, 17 and 26 of the proposed study area.

3.4 Stream type

Stream type classification was based on that of Lampert and Short (2004), with the addition of Headwater, and Drainage on reformed land (rehabilitated mine site) types (Figure 3). The Floodout type indicated by Lampert and Short (2004) as typical of parts of Driggle Draggle Creek was not included here, because the creek was observed to be relatively uniform along its length. The greatest length of streams in the study area, and within the proposed emplacement and open cut areas, is Valley fill type (Figure 3, Figure 4). These streams typically had a small, ill-defined, discontinuous or non-existent channel, and were situated within low-gradient broad valley slopes.

In the upstream drainage areas of the Valley fill stream types, a distinct channel was present, which distinguished them as Headwater type. Field observations indicated that the change from distinct Headwater type to indistinct Valley fill type corresponded roughly to the 300 m contour, so this was used as the criterion to classify the stream network (Figure 3, Figure 4). South Creek had a short section of transition between Headwater and Valley fill type, where the valley walls were gently sloping, and the headwater catchment supplied cobble and gravel bed material (Figure 4).

Driggle Draggle Creek downstream of the junction of North-west drainage line developed a distinct channel and belonged to the Low sinuosity fine grained type (Figure 3, Figure 4). The Namoi River is of the Low sinuosity gravel type (Lampert and Short, 2004) (Figure 3, Figure 4).

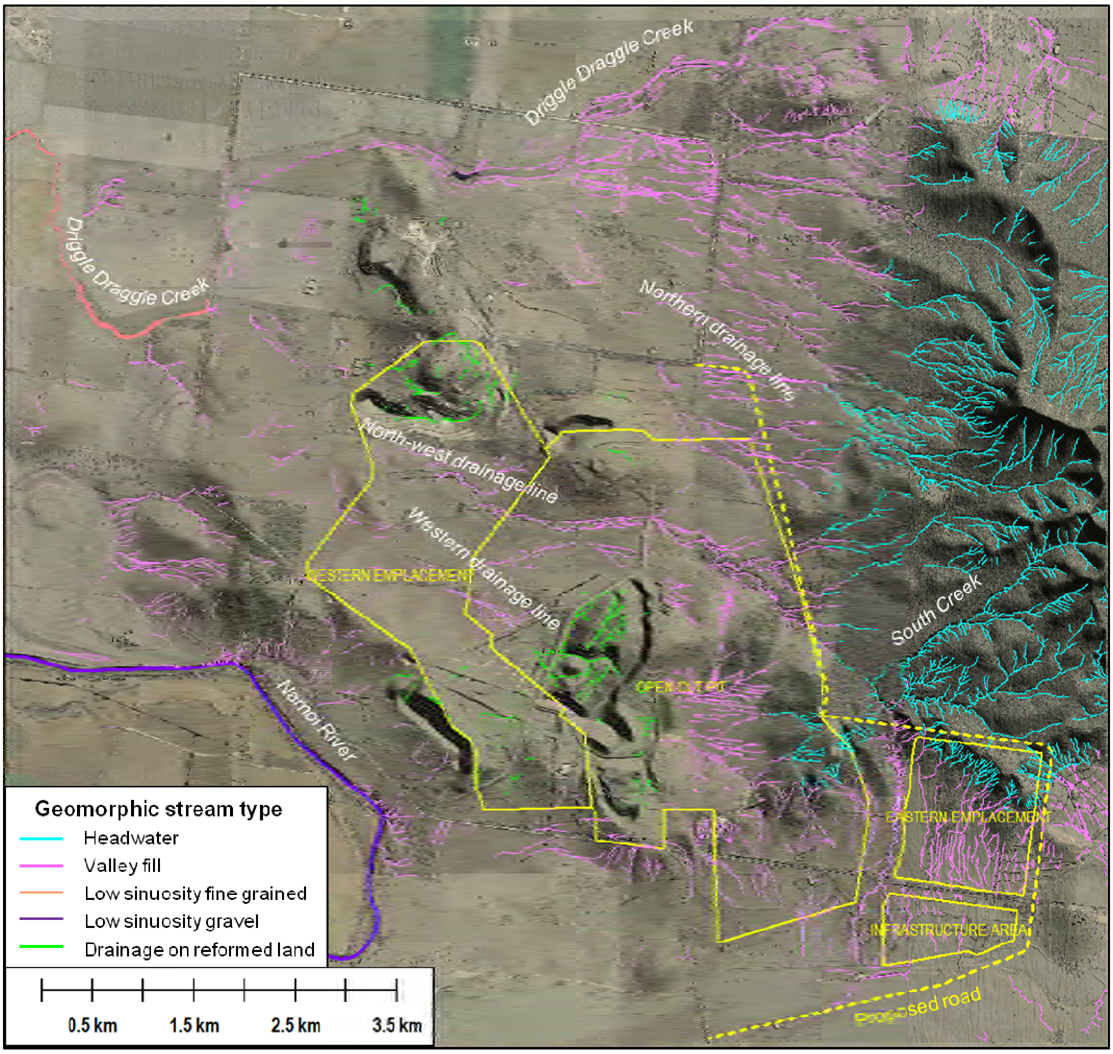

Figure 3. Distribution of geomorphic stream types throughout the study area.

Figure 4. Photographs of the stream types within the study area. D and E are headwater type, H is Low sinuosity gravel type, J is Low sinuosity fine grained type and the rest are Valley fill type (F is a transition between Headwater and Valley fill types). All photographs except C are looking downstream.