LEIGH CREEK MINE SITE - SURFACE WATER DRAINAGE REVIEW

Prepared for Flinders Power Partnership - Leigh Creek

February 2017

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Flinders Power Partnership - Leigh Creek

Leigh Creek Mine Site - Surface Water Drainage Review

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1 Introduction

The Leigh Creek Mine ceased operation in November 2015, and the site is currently being prepared for closure. One of the key risks to successful mine closure is the longer-term surface water management to mitigate potential on-site and off-site impacts in accordance with stakeholder expectations.

MWH has been engaged by Flinders Power Partnership (FPP) to undertake a review of preliminary surface water drainage designs for closure conditions at the Leigh Creek mine site. This review focusses on the drainage designs within and surrounding the Main Pit.

This technical note summarises the approach and findings from the review of drainage designs provided by FPP in September 2016 and design notes and concept designs provided in January 2017.

2 Data and information provided for review

2.1 September 2016 data

The following information was provided to MWH for review:

- two Adobe Acrobat files showing drainage design layouts;
    - drainage design “D6_M13M14_SW.PDF”
    - drainage design “D6_M10M11_SW.PDF”
- initial AutoCAD drawing showing details of the drains and bunds;
    - AutoCAD drawing “mt15_mt21_surface_water.dxf”
- additional AutoCAD drawings showing the crest bunds and profiled slopes along the southern waste rock dump.
    - AutoCAD drawing “sea_sick_avenue_profiled_slopes.dxf”
    - AutoCAD drawing “sea_sick_avenue_crest_bunds.dxf”

2.2 January 2017 data

The following information was provided to MWH for review:

- design notes (Adobe Acrobat files):
    - “LCK_Map17_1.0 Notes Draft.PDF”
    - “LCK_Map18_1.0 Draft Notes.PDF”
    - “LCK_Map19_1.0 Notes Draft.PDF”

- AutoCAD drawings:
  - "lck_subcatchment_poly.dxf" – sub-catchments for Map 17, 18 and 19 areas
  - "lck_design_master.dxf" – bunds, drains, drop structure details
  - "map17_18_19.dxf" – contours and drainage designs combined into a single digital elevation model
  - "160503_retdam_dn_el219.dxf" – drain along the western extent of the site.
- Report:
  - Leigh Creek Coalfields Retention Dam Options Analysis (Alinta Energy, November 2015).

No additional information was reviewed for this study.

3 Drainage designs

3.1 Drainage features

An overview of the Map 17 to Map 19 areas and sub-catchments included in this review is shown in **Figure 3-1**. The Map 17 to Map 19 area covers the Main Series pit and surrounding low and high walls. The proposed drainage designs are shown in **Figure 3-2**. The drainage designs comprise a number of drains, bunds, drain/bund combinations, evaporation ponds and drop structures. The drawing files (provided in dxf format) were imported into ArcGIS in order to display the underlying digital elevation model (DEM) and drainage infrastructure alignments.

The drainage design approach (as per the Map 17 to Map 19 Design Notes, CLD Mining 2017) was to minimise surface water inflow to the pit voids as far as possible by intercepting surface water runoff and directing runoff to evaporation areas. Runoff directed towards pit voids will enter the voids mainly via a number of drop structures. The Design Notes provide details of typical cross sections for conceptual bunds and drains; these may be refined following the review outcomes.

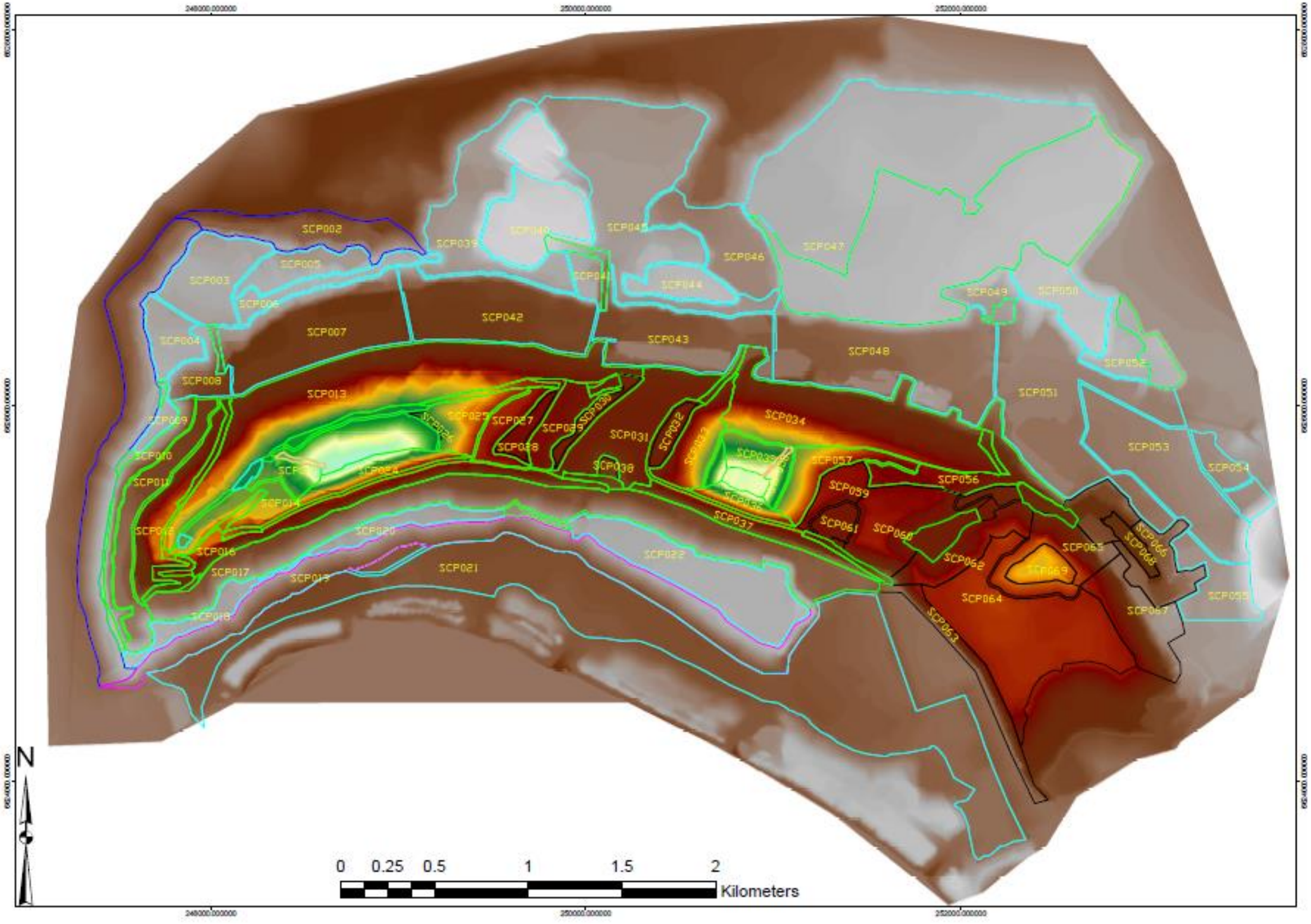

Figure 3-1: Map 17 to 19 areas sub-catchments (CLD Mining January 2017)

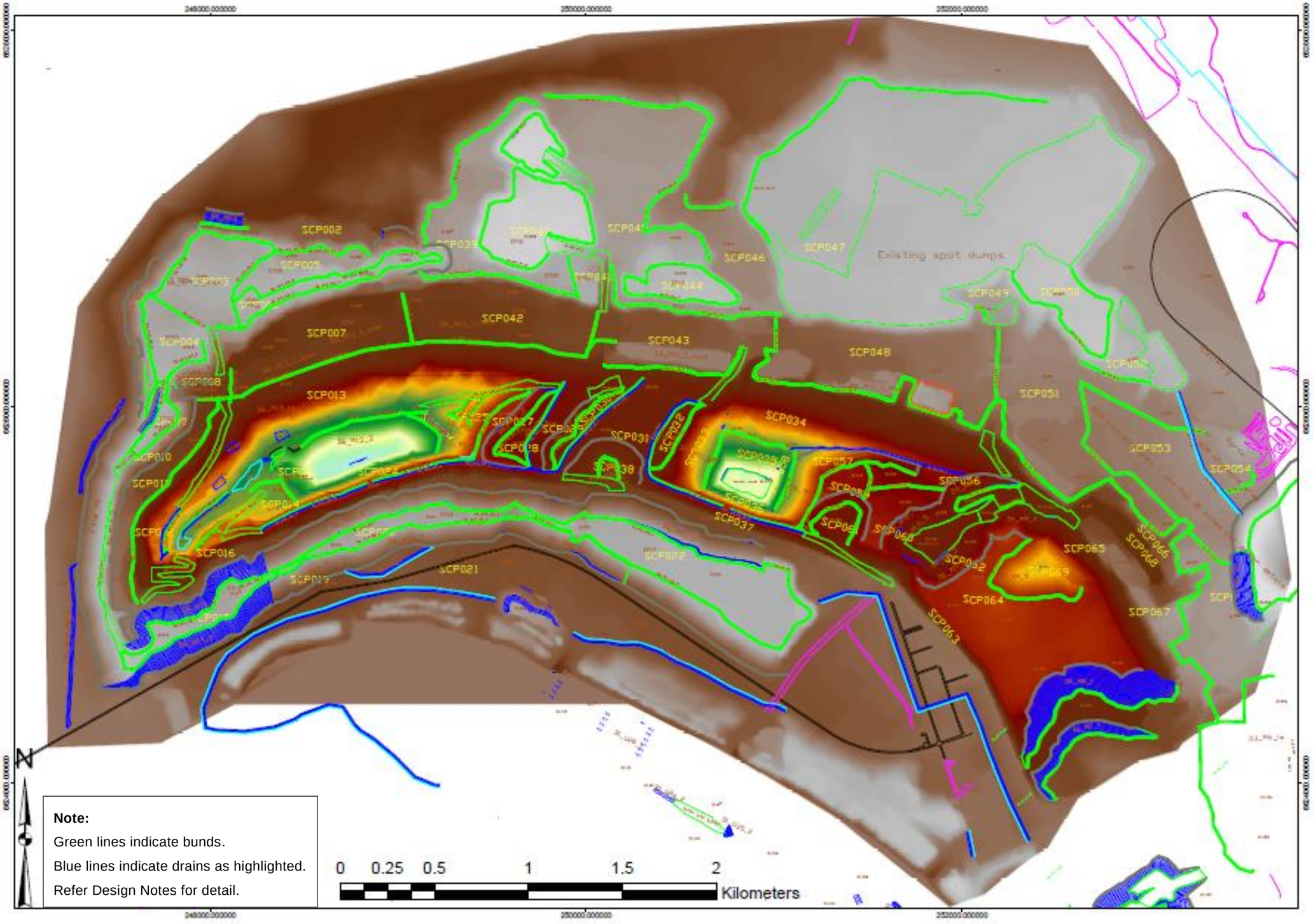

Figure 3-2: Drainage Design Layout (CLD Mining January 2017)

4 Review comments

4.1 Design criteria

The following design criteria were used:

- Drainage channels and drop structures: 1% AEP design peak flows, with a check for the 10% AEP peak flows;
- Evaporation pond: 1% AEP rainfall for a number of durations, ranging from 10 minutes to 72 hours.

4.2 Design hydrology

No hydrologic data or design flood peak discharge rates were provided for review. Based on a 20 January 2017 teleconference between Flinders Power, MWH and Coffey Consultants, it was agreed that the 1% AEP design flood peak would be used for the review, and the 10% AEP design peak discharge rates used for a low-flow check. MWH calculated design hydrology to inform the review process.

Design peak discharge rates (10% and 1% AEP) were estimated for the sub-catchments draining towards pit voids. Peak flows were not estimated for sub-catchments designed to function as evaporation ponds.

The following approach was used to estimate peak flows:

- sub-catchment areas were extracted from the provided sub-catchment layer;
- ARC-Hydro and ARC-RORB software was used to calculate the longest water course and equal area slope for each sub-catchment;
- design rainfall extracted from the Bureau of Meteorology (BoM) and used in the Leigh Creek Closure Surface Water Assessment (MWH, 2016) was used;
- the Rational Method was used to estimate peak flows, based on all sub-catchments being less than 1 km² in size.

Table 4-1: Design peak flows (m³/s)

Sub-catchment	Design peak flow (m³/s)	
	10% AEP	1% AEP
SC_010	1.41	2.47
SC_011	0.99	1.78
SC_012	2.17	3.81
SC_013	8.83	15.55
SC_014	1.20	2.12
SC_015	0.73	1.27
SC_016	2.62	4.60
SC_017	0.74	1.32

Sub-catchment	Design peak flow (m³/s)	
	10% AEP	1% AEP
SC_018	0.96	1.71
SC_019	3.02	5.43
SC_023	1.38	2.46
SC_024	1.41	2.48
SC_027	0.39	0.70
SC_029	0.78	1.38
SC_031	1.82	3.24
SC_033	5.56	9.76
SC_034	4.35	7.75
SC_035	0.83	1.46
SC_036	0.76	1.33
SC_037	0.93	1.66
SC_056	1.7	3.00
SC_057	1.34	2.36
SC_058	0.43	0.75

The closure option for the retention dam, located to the south of the upper series pit, involves a spillway with a crest elevation of 219 mAHD and a peak design discharge rate of 220 m³/s for the 1% AEP design flow event (based on the current closure plan). A flood mitigation bund is proposed to direct any spills from the retention dam to the west of the secondary storage area to a diversion drain downstream of the access road. The drain is designed to direct water from the retention dam overflow and natural watercourse to the west around the Leigh Creek mine into Leigh Creek.

The western catchments are small (less than 20 km²). Critical durations for these catchments will be shorter than the retention dam 0.1% AEP event critical duration (around 9 hours), reducing the risk of coincidental peaks at the diversion drain. Stormwater runoff from the western catchments may result in some ponding in the drain, potentially reducing the drain capacity to some extent. The 220 m³/s peak discharge rate from the closure plan was therefore used to assess the hydraulic capacity of the diversion drain.

4.3 Evaporation pond storage assessment

A number of evaporation ponds are proposed, with the key aim to intercept runoff and reduce surface water inflow to the pit voids. The following approach was used to assess evaporation pond capacities:

- Arc-Hydro and 3D Analyst (ArcGIS add-ons) software was used to estimate available storage for each of the evaporation sub-catchments. A cut-fill type approach is used, where the lowest spill point in a sub-catchment is identified from the proposed designs and terrain data to estimate the available storage capacity estimated.

- 1% AEP design volumes were calculated from the intensity-frequency-duration (IFD) curves (Leigh Creek Closure Surface Water Assessment (MWH, 2016)) for 10 minutes, 1hour, 24 hour and 72 hour durations.
- Infiltration losses of 2 mm/hr were assumed.
- Available storage was then compared with the calculated rainfall volumes to identify sub-catchments with surplus or deficit storage capacity.

Results of the evaporation pond assessment are summarised in **Table 4-2**. Ponds with deficit storage, i.e., where insufficient storage is available and spills potentially expected, are highlighted in **Table 4-2**.and shown in **Figure 4-1**. Note that **Figure 4-1** shows storage areas for all sub-catchments, including sub-catchments draining to the pit voids; the focus is on the evaporation pond catchments listed in **Table 4-2**.

Table 4-2: Evaporation ponds

Sub-catchment / Evaporation Pond	Catchment Area (km²)	Estimated storage capacity (m³)	1% AEP Surplus / Deficit for duration			
			10 minutes	1 hour	24 hours	72 hours
SC_003	0.172	7,300	3,110	-2,292	-8,777	2,217
SC_004	0.082	32,610	30,607	28,024	24,923	30,180
SC_005	0.093	17,320	15,056	12,138	8,635	14,574
SC_006	0.064	11,650	10,104	8,110	5,717	9,774
SC_007	0.365	189,200	180,311	168,852	155,095	178,416
SC_008	0.068	4,200	2,542	405	-2,161	2,189
SC_009	0.024	5,912	5,330	4,581	3,681	5,206
SC_020	0.073	24,820	23,047	20,762	18,018	22,669
SC_021	0.603	469,193	454,530	435,628	412,934	451,404
SC_022	0.293	37,232	30,101	20,910	9,874	28,581
SC_025	0.082	2,294	297	-2,277	-5,367	-128
SC_026	0.005	6,416	6,296	6,142	5,956	6,271
SC_028	0.032	40,948	40,163	39,151	37,935	39,995
SC_030	0.028	12,366	11,680	10,796	9,734	11,534
SC_032	0.032	17,518	16,748	15,755	14,563	16,584
SC_038	0.008	0	3,636	3,373	3,058	3,593
SC_039	0.284	85354	78,452	69,555	58,873	76,981
SC_040	0.184	13,591	9,104	3,319	-3,625	8,147
SC_041	0.036	0	23,374	22,236	20,870	23,185
SC_042	0.334	96,210	88,088	77,618	65,048	86,357
SC_043	0.272	399,323	392,709	384,183	373,946	391,299
SC_044	0.074	61,769	59,966	57,641	54,850	59,581
SC_045	0.561	37,257	23,603	6,003	-15,129	20,693
SC_046	0.191	177,084	172,428	166,426	159,220	171,436
SC_047 / EP23	0.899	57,770	35,904	7,718	-26,124	31,243
SC_048 / EP22	0.492	43,907	31,938	16,508	-2,016	29,386
SC_049 / EP30	0.054	229	-1,096	-2,803	-4,853	-1,378
SC_050 / EP24	0.136	20,100	16,802	12,551	7,447	16,099
SC_051 / EP26	0.506	248,075	235,755	219,873	200,805	233,129
SC_052 / EP25	0.066	8,500	6,902	4,843	2,370	6,562
SC_053 / EP27	0.323	102,500	94,637	84,502	72,333	92,961

Sub-catchment / Evaporation Pond	Catchment Area (km²)	Estimated storage capacity (m³)	1% AEP Surplus / Deficit for duration			
			10 minutes	1 hour	24 hours	72 hours
SC_054 / EP28	0.049	7,986	6,795	5,259	3,416	6,541
SC_055 /	0.124	5,262	2,251	-1,629	-6,288	1,610
SC_059 / EP30	0.054	2,000	690	-999	-3,027	410
SC_060 / EP32	0.179	209,214	204,851	199,227	192,475	203,921
SC_061 / EP31	0.035	0	8,401	7,312	6,006	8,221
SC_062 -SC_064, SC_067 / EP35	1.213	6,638,925	6,609,416	6,571,379	6,525,709	6,603,127
SC_065, SC_069 / EP34						
SC_066, SC_068 / EP36						

The following are noted based on the concept designs provided and capacity comparisons (refer to Figure 4-1 to reference locations). Screen shots of individual catchments discussed below are included in Appendix A.

- A number of sub-catchments / evaporation ponds have insufficient capacity to capture and contain rainfall for one or more of the 1% AEP storm durations assessed.
- SC_003 – contains an elevated area in the centre of the basin, reducing pond storage capacity. Surface ponding will occur mainly along the northern and southern bunds.
- SC_008 – No connection between western bund / spoil dump at north-western extent (in the DEM), allowing surface water to spill. Connection should result in sufficient storage capacity.
- SC_025 – Embankment / bund along the western edge / extent is low compared to the pond elevations, limiting ponding capacity.
- SC_040 – Elevated areas in the south resulting in runoff to the north, where the bund is low compared to the higher ground, limiting ponding capacity.
- SC_045 – No connection between bunds at the north-west corner, allowing surface water to spill. Connection and some reshaping of the internal area will result in sufficient storage capacity.
- SC_047 – Elevated areas in the south resulting in runoff to the north. Low bund along north-west edge limiting ponding capacity.
- SC_048 – Elevated areas to the north, resulting in runoff to the south. Low bund along the southern edge limiting capacity.
- SC_049 – No bund along the southern extent from about the middle of the sub-catchment boundary to the eastern boundary, allowing surface water to spill south towards the pit void.
- SC_055 – Full sub-catchment boundary not provided. To be reviewed, full sub-catchment area should potential provide sufficient ponding capacity.
- SC_059 – Elevated areas in the centre, resulting in runoff to the western bund. Excavation from the elevated areas may be an option to increase capacity.
- SC_060 – This sub-catchment spills into SC_064 when it fills up to an elevation of 147.5 mAHD.
- SC_062 to SC_069 – These sub-catchments can interact at various elevations between evaporation ponds EP34, EP35 and EP36. The total storage available within these evaporation

ponds is significantly larger than the potential rainfall runoff for all durations considered. Note that individual sub-catchments within this area may have insufficient capacity for some storm durations; however, total storage exceeds potential excess rainfall by some margin.

- Spoil dumps are used in a number of locations as bunds, forming part of the proposed drainage measures.
- All proposed bunds are based on Type A Bund dimensions, with a 3 m height and 4 m top width. Proposed side slopes angles were not provided; side slopes should be added to the design notes and sketches. Slopes of 1H:2.5V (extracted from the design surface) were assumed, giving a 6.8-m bottom width. The bund height may reflect some potential overdesign, particularly in catchments with surplus storage capacity. This may also apply to some areas of sub-catchments with insufficient capacity. In areas where a 1-m height is adequate for containing design flows, the smaller Type B bunds may be more appropriate.
- Minor additional earth works may be required to provide sufficient capacity to contain the modelled rainfall events. This may include excavation of higher lying areas within the affected sub-catchments, minor raising of bunds where overflows are likely to occur, or a combination of the above.
- For closure designs the materials should ideally be selected in order to provide as self-sustaining a structure as possible in the long term with minimal or no maintenance. The bunds should be constructed with select fill material that contains minimal gravels and cobbles and should be compacted for stability and seepage resistance. Sections of the bunds will act as drainage structures to convey runoff to ponding areas; with limited rock armouring material available on site additional fill material comprising gravels and cobbles could be placed in critical locations as a buttress against the side slopes for erosion resistance. For relatively high bunds, a key trench and/or scarified foundation preparation may be warranted to minimise piping over the long term.
- Stormwater management for the intercepted sub-catchments will be largely volume-based, resulting in drains and bunds that largely act as embankments for standing water. Long-term ponding against the bunds could impact the geotechnical integrity of the embankment and could potentially result in piping failure during the post-closure period. Design and construction of the bunds should therefore consider potential impacts of long-term wetting. Maximum ponding depths for the 1% AEP event vary between 1.5 m and 2.0 m. Proposed Type A bunds (3m high and indicative bottom widths of 6.8 m) is likely to be adequate provided suitable compaction is achieved during the construction stage. A 5-year monitoring program has been proposed post closure. The integrity of bunds should be assessed during the monitoring period, particularly after any flood events.
- Bunds/drains could be over-topped in greater-than-design events, resulting in local failure and high flow velocities. Where water is ponded with significant depths, breaching of a bund by overtopping flows can send a runoff downstream with significant erosion potential. The consequence of a bund is considered low given surface water runoff from internal workings will be captured within the pit voids. Should this be considered a significant risk, the incorporation of a controlled failure point with erosion protection may be warranted in order to prevent bund failure

in an unpredictable location. Pending material availability, the designed overflow point should include some form of energy dissipation to prevent erosion of the downstream toe of the bund.

- The proposed surface water drainage system includes a number of spoil dumps. While these dumps will impact surface water flow in some areas, the dumps have not been designed as drainage structures. Some slope erosion is expected along these dumps, particularly at crests and sedimentation may accumulate at the toe of the eroded slope.

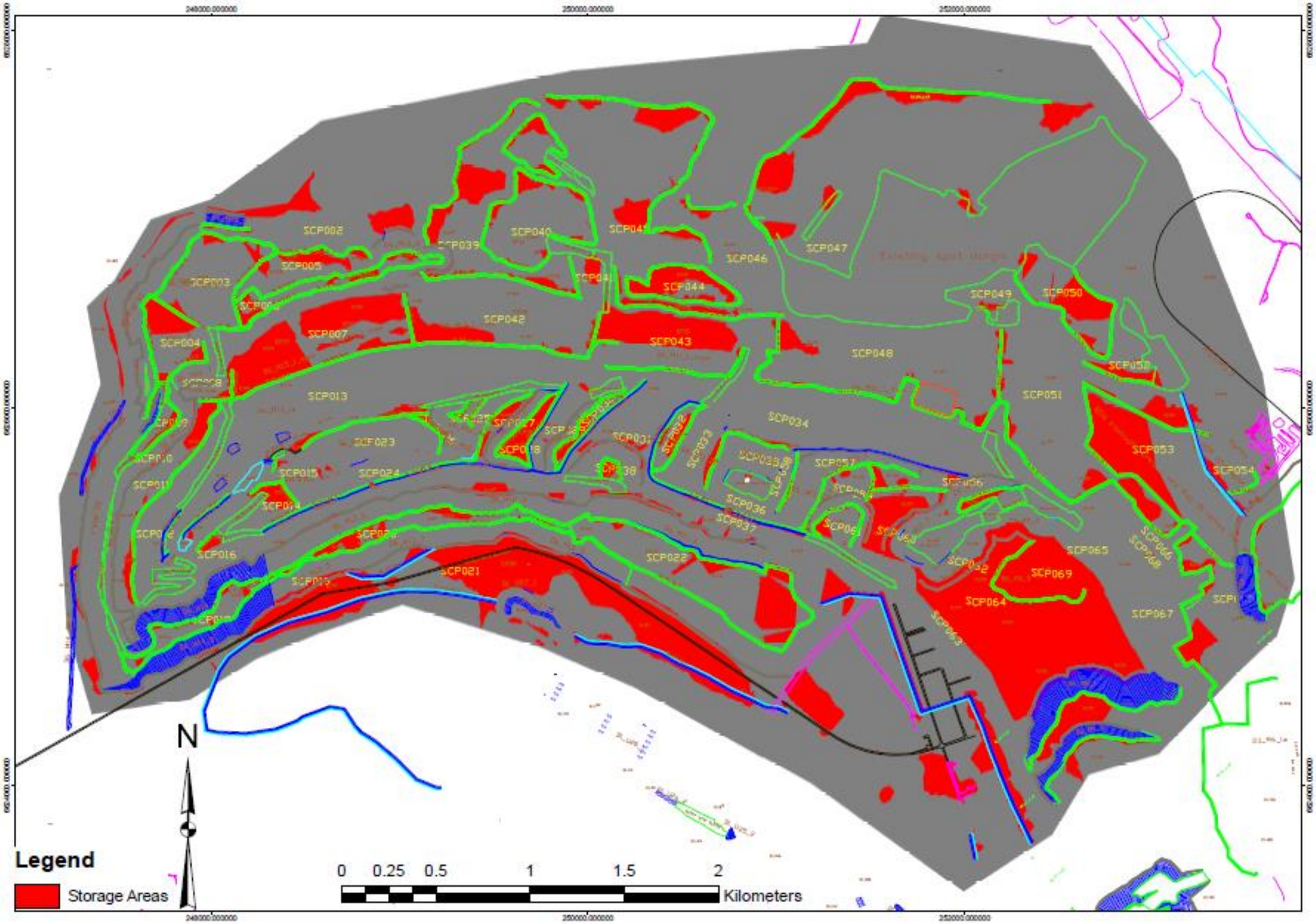

Figure 4-1: Sub-catchments storage areas

4.4 Drains assessment

A number of drains and bunds are proposed to direct excess surface water runoff (i.e. rainfall not captured by evaporation ponds) to the pit voids (CLD Mining 2017). Bunds / drains will direct surface water runoff to settling ponds and drop structures, from where it will flow into the pit voids.

Surface water runoff from 23 sub-catchments within the Map 17 to Map 19 area will contribute runoff to the respective pit voids. Design peaks were calculated (Section 4.2) to inform hydraulic assessment of the various proposed drains.

Locations of proposed drains are shown on **Figure 3-2** and sub-catchments contributing surface water flows summarised in **Table 4-3**. Refer to Design Notes (CLD Mining 2017) for additional detail.

The 70 degree excavator dig angle creates a nearly vertical, 3-metre deep channel. Given the relative strength and durability of the in-situ material, channel walls would be expected to erode over time, with the material eroded from the upper slope accumulating at the toe of the slope. Lateral inflows will exacerbate the erosion, with sheet flow that drains toward the channels concentrating in low points along the crest of the channel and forming rills and gullies. A side slope of 2H:1V or flatter along the drains would reduce the amount of wall erosion but would significantly increase the total top width of the channel. A small bund lining the crest of the drain could capture sheet flow that would otherwise enter yje channel and route the flow to controlled inflow points.

Velocities along the drains under peak flow conditions would typically require armour rock sized according to standard rock sizing methods. In general, armour rock with a median size of 300 to 500 mm would be recommended. The proposed unarmoured channels would likely deteriorate over time. A meandering low flow path may form along the longitudinal profile, for example, with impinging flows directing energy toward the toe of the slope. Undercutting resulting from impinging flows would accelerate slope failures. In general, flow depths are not sufficient to overtop the channel banks of the drains; however, the accumulated sediment in the channel flow path may cause a rise in water surface elevation with overflows in extreme events. Sloping the channel banks to 2H:1V or milder or increasing the bottom width to approximately 5 metres would provide some mitigation to alleviate the issue.

The erodible nature of most of the mine waste materials present (i.e. high clay contents, low coarse fraction, and low infiltration capacity) will likely result in erosion and sediment accumulation along the bunds/drains, impacting their capacity. Even with properly sized and installed rock protection, without maintenance, bank failures would occur over extended, post-closure time periods. A 5-year monitoring program has been proposed. During this monitoring period, the integrity of channel banks should be assessed, particularly after any flood events. Mitigation measures can be implemented in localised areas with observed erosion or sedimentation issues. Recommendations for changes to the closure plan can be determined following assessment of the monitoring results. The value of providing temporary benefits by

increasing the functional life of the drainage control features may warrant further assessment during the monitoring period.

Following each monitoring event, where impinging flows, high velocities, or shear stresses cause erosion along bunds or drains, the placement of some competent facing material with larger particle sizes may be warranted as mitigation. Additional toe protection may be required to accommodate scour, and bund heights may need to be raised or accumulated sediment removed to compensate for aggradation.

Table 4-3: Proposed drains and contributing sub-catchments

Drain	Sub-catchments	Flow (m^3/s)	Flow Depth (m)	Velocity (m/s)	Comment
D6_M14_DR_Sect 1	Retention Dam	220	6.34	4.76	• 0.1% AEP discharge from retention dam with spillway at 219 mAHD
D6_M14_DR_Sect 2		220	7.30	3.97	
D6_M14_DR_2	SC_010 SC_011 SC_012	6.8	1.04	1.95	• SC_010 flows into SC_011 (could be combined into single catchment) • Local high in the centre and southern end of SC_011 that will prevent runoff reaching the drain
D6_M14_DR_3	SC_010 SC_011 SC_012 SC_013 SC_016 SC_017	9.3	0.83	3.39	• Discharge from EP01 (SC_010 to SC_012) • Western part of SC_013 (assumed 7% of area) • Western part of SC_016 (assumed 27% of area) • Western part of SC_017 (assumed 32%) • Flow calculation based on assumption that EP01 settling pond will attenuate inflows and reduce peak flow
D6_M13_DR_2	SC_016 SC_017 SC_027 SC_029 SC_031	12.8	1.02	3.73	• Assumed 73% of SC_016 • Assumed 68% of SC_017
D6_M13_DR_3	SC_016 SC_017	7.46	0.73	3.11	• Assumed 73% of SC_016 • Assumed 68% of SC_017
D6_M12_DR_1	SC_016 SC_017 SC_027 SC_029 SC_031	10.02	0.89	3.41	• Assumed 27% of SC_016 • Assumed 58% of SC_017
D6_M12_DR_2	SC_029	1.38	0.29	1.53	
D6_M12_DR_3	SC_031	3.24	0.88	1.11	
D6_M11_DR_1	SC_031	0.32	0.06	1.76	• Slopes away from drain. Is this needed • Assumed 10% for check
D6_M11_DR_2	SC_031 SC_017 SC_037	8.32	0.82	3.07	• Assumed 58% of SC_017, full contribution from SC_031 and SC_037
D6_M11_DR_3	SC_017 SC_037	5.08	1.09	1.37	• Assumed 58% of SC_017, full contribution from SC_037
D6_M10_DR_1	SC_034	8.81	0.62	3.87	• Assumed 75% of SC_034, full SC_056

4.5 Settling ponds and drop structures

A number of settling ponds and drop structures are proposed to direct excess surface water runoff into the pit voids. Bunds / drains will direct surface water runoff to settling ponds and drop structures, from where it will flow into the pit voids.

Proposed drains are shown on **Figure 3-2** and sub-catchments contributing surface water flows to settling ponds summarised in **Table 4-4** and sub-catchments contributing surface water flows to drop structures summarised in **Table 4-5**.

The following approach was used to estimate peak flow rates:

- Inflows to settling pond EP01 were based on total flows from sub-catchments SC_010 to SC_012. A two-dimensional (TUFLOW) model was configured of EP01 to model storage and attenuation impact on peak flows. The 1% AEP peak inflow reduced by 16% from 8.1 m^3/s to 6.8 m^3/s.
- Inflows to settling pond EP02 were based on outflows from EP01 and drain D6_M14_DR_3.
- Inflows to M1301 were based on flows attenuated through EP02. Peak flow attenuation was estimated to be similar to EP01 (i.e. a reduction of 16%). Outflow from EP02 was used as inflow to M1304.
- M1304 is a small settling pond (22m in length) and given the potentially significant1% AEP event inflows, it was assumed that attenuation would be small; for review purposes no attenuation was assumed.
- There are no settling ponds upstream of drop structures M1303 and M1101 and full sub-catchment inflows were assumed.

Table 4-4: Proposed settling ponds

Settling pond	Runoff source	Design Peak In (1% AEP)	Design Peak Out (1% AEP)	Area (m2)	Length (m)	Width (m)	Longitudinal Slope (m/m)	Side Slopes (V:H)
EP01	SC_010 to SC_012	8.06	6.8	3,310	66	56	0	1:1.3
EP02	D6_M14_DR_3	11.05	9.3	8,690	220	50	0	1:1.3

Table 4-5: Proposed drop structures

Drop structure	Runoff source	Design Peak In (1% AEP)	Base width (m)	Length (m)	Long. Slope (V:H)	Side Slopes (V:H)	Depth (m)	Vel (m/s)	Median rock size (mm)
M1301	EP02	9.3	4	20	0	1:4.5			
M1304	M1301	9.3	9	22	1:1.53	1:1.3	0.2	4.6	800
M1303	SC_013	14.5	9	53	1:3.7	1:1.3	0.4	4.0	700
M1302	M1303 and M1304	23.8	9	288	1:5.4	1:2.5 left; 1:3 right	0.5	4.2	700
M1101	SC_034, SC_056 and SC_057	13.12	9	190	1:3.7	1:2.5	0.3	3.9	550

Note that there is an additional drop structure along the high wall, with runoff collected by drains D6_M13_DR_1 and D6_M13_DR_2. Runoff will flow directly over the high wall. No design was provided for the drop structure.

The functionality of the drop structures is dependent on the proposed design surface of the mine workings at closure; as such, longitudinal slopes of drop structures are largely dictated by site topographic constraints, resulting in relatively steep slopes for this site. Upstream ends (inlets) of drop structures M1304 and M1303 are wider than outflow end; this will result in a constricting effect with an increase in flow velocities through the constriction. Uniform sections along the entire slope of the drop structure is recommended. Incorporation of settling ponds (or inlet basin) upstream of drop structure M1304 to reduce velocities is in line with standard design approach for drop structures; a similar approach could be considered for implementation upstream of drop structures M1303 and M1101.

Table 4-5 shows predicted velocities based on supercritical flows. These velocity estimates are conservative as sustained supercritical flows are not expected along the entire drop structure, due to the roughness and turbulence introduced by the underlying material. **Table 4-5** also shows the median rock size recommended in MRWA 2006 and AustRoads 2013 based on velocity only. The recommended rock sizes were also checked against the methodologies presented in Design of Rock Chutes by Robinson, Rice, Kadavy (ASAE 1988) as well as shear-based methods, both of which allow for the use of somewhat smaller rock classes.

In general, the results show that the proposed use of a well-graded mix of rock classes with a maximum diameter of 500 mm would be insufficient to protect against the predicted hydraulic forces. Custom placement of the proposed conglomerate rocks rather than end dumping can improve the resistance to mobilisation. For custom placement of the conglomerate rock, the largest rocks should be placed in contact with other large rocks, with smaller rock placed in the voids to allow interlocking.

The proposed layer of sedimentary siltstone will likely wash away. It may provide a buffer against further erosion but will also provide a potential risk of accumulating in downstream channels with a corresponding rise in water surface elevations.

ASAE 1998 includes recommendations on construction methods that will extend the life of the drop structure. Of particular importance is keying in the rock at the upstream inlet basin and downstream outlet basin. Typically, the use of high quality geotextiles and properly graded filter rock designed with a gradation that locks the underlying material into place, as described in HEC-23 (FHA 2011), would be required to improve long-term effectiveness; however, in this case the strength of the underlying insitu material may be sufficient to preclude the use of a filter. Monitoring activities may identify problem areas, provided a significant runoff event occurs during the 5-year period.

All rock should be angular; no rounded rock should be used in rock chutes. Energy dissipation rock is recommended at the downstream toe in order to introduce turbulence without adverse erosion impacts, removing energy prior to discharge into unprotected drains. Energy dissipation rock should be sized and placed so that at least 2/3 of the depth if individual boulders is buried, with approximately 1/3 of its height exposed. If large material is unavailable for use as energy dissipation rock, the outlet basin should be configured with custom-placed, interlocking rock lining the walls and bed of the basin. It is noted that for drop structure M1302 the section between EL54 and EL28 will be built entirely of fill material. While this section will be at risk of erosion and head cutting during significant inflow events, eventual groundwater recovery water levels will likely provide a plunge pool acting as energy dissipation, reducing the risk of significant head cutting.

The proposed construction of the M1302 drop structure is based on a three-stage approach:

- Stage 1 - compaction of carbonaceous mudstone on the bed floor of the structure during profiling;
- Stage 2 - individual placement of conglomerate blocks to a thickness of at least 1.5m;
- Stage 3 – sedimentary siltstone dumped over the conglomerate blocks and compacted to fill voids between blocks, followed by a secondary 0.5m layer of compacted sedimentary siltstone to increase thickness of the drop structure bed.

Given the indicative velocities at the respective drop structures (**Table 4-5**), it is recommended that the proposed M1302 drop structure approach be applied to all the drop structures. All drop structures will be subject to erosive forces that may remove sedimentary siltstone dumped and profiled to the surface. There is insufficient information to determine the potential erosion resistance of the underlying, in-situ layer.

Where concentrated flows enter pits, erosion would be expected over time, particularly in the channels that form as head cuts migrate back from the crest. Rock armoured chutes along pit walls are not likely to be sustainable over time given the steep slopes of the pit walls. Placement of crest bunds preventing

concentrated overflows and additional rock at the downstream toe of the slope can reduce the amount of scour.

Without maintenance, rock chute failures may occur over extended, post-closure time periods, even with properly sized and installed rock protection. Typically this would occur in the form of preferential flow paths forming below or beside the armour rock material, eroding the underlying material. Where the underlying material is competent rock, the failure rate would be lower; however, predicting the location of specific failure points is difficult. A 5-year monitoring program has been proposed. Assessment of issues related to erosion and deposition over a series of events is recommended throughout the monitoring period. During that period, all drainage features should be inspected after wet weather events. Mitigation measures should be implemented where failures occur, with updates to the mine closure plan as necessary to prevent further issues. The value of providing temporary benefits by increasing the functional life of the rock chutes may warrant further assessment at that point, in consideration of spontaneous combustion risks that may reduce over time. The greatest benefits to the project occur in the immediate post-closure period, and measures that can improve stability during the first five years following closure should be prioritised.

Appendix A Evaporation basin screen shots

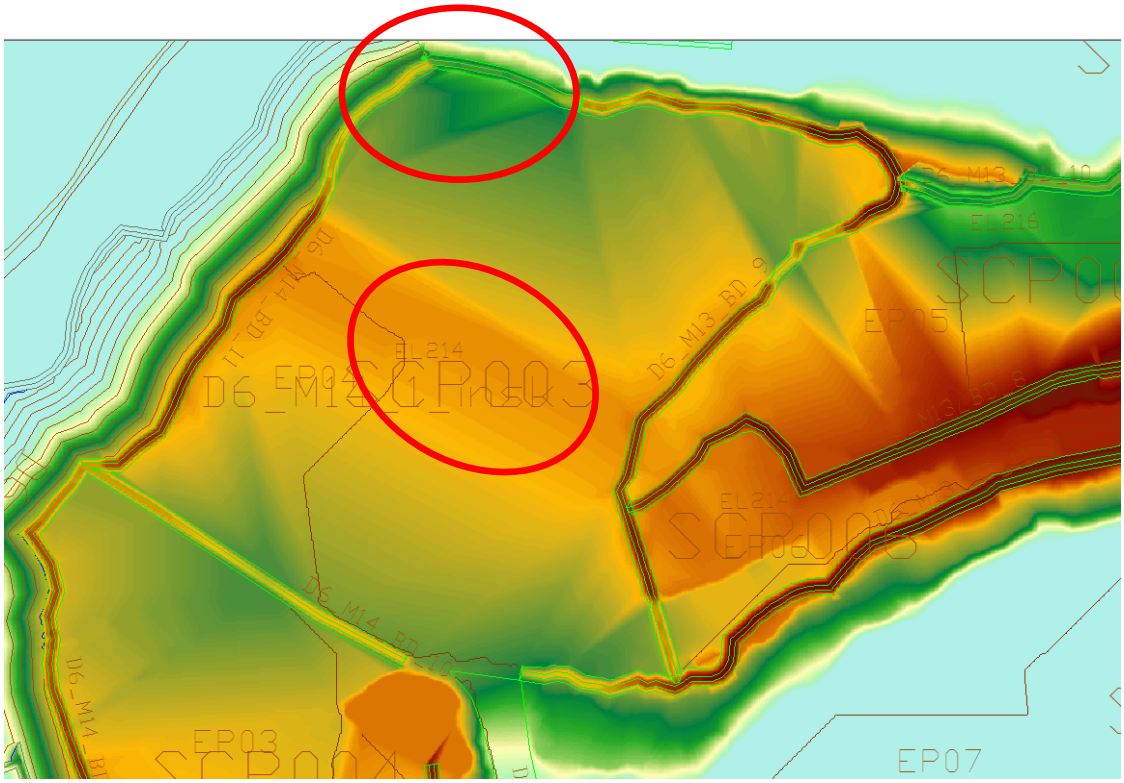

Figure A.1: Sub-catchment SC_003

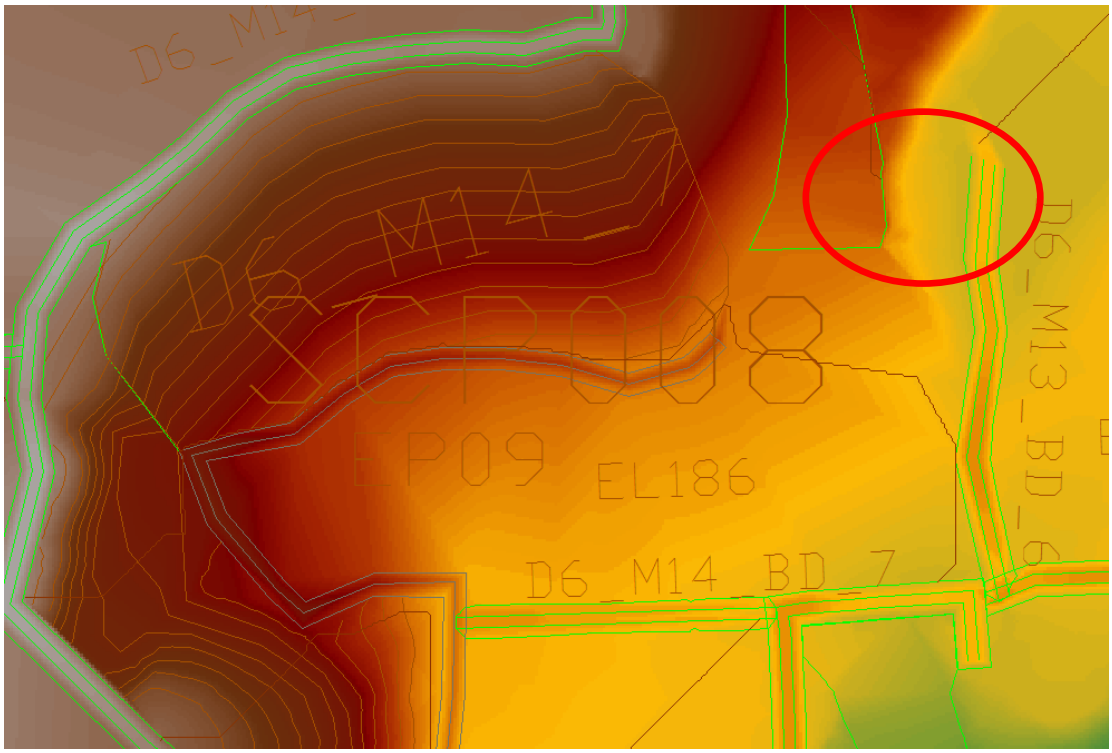

Figure A.2: Sub-catchment SC_008

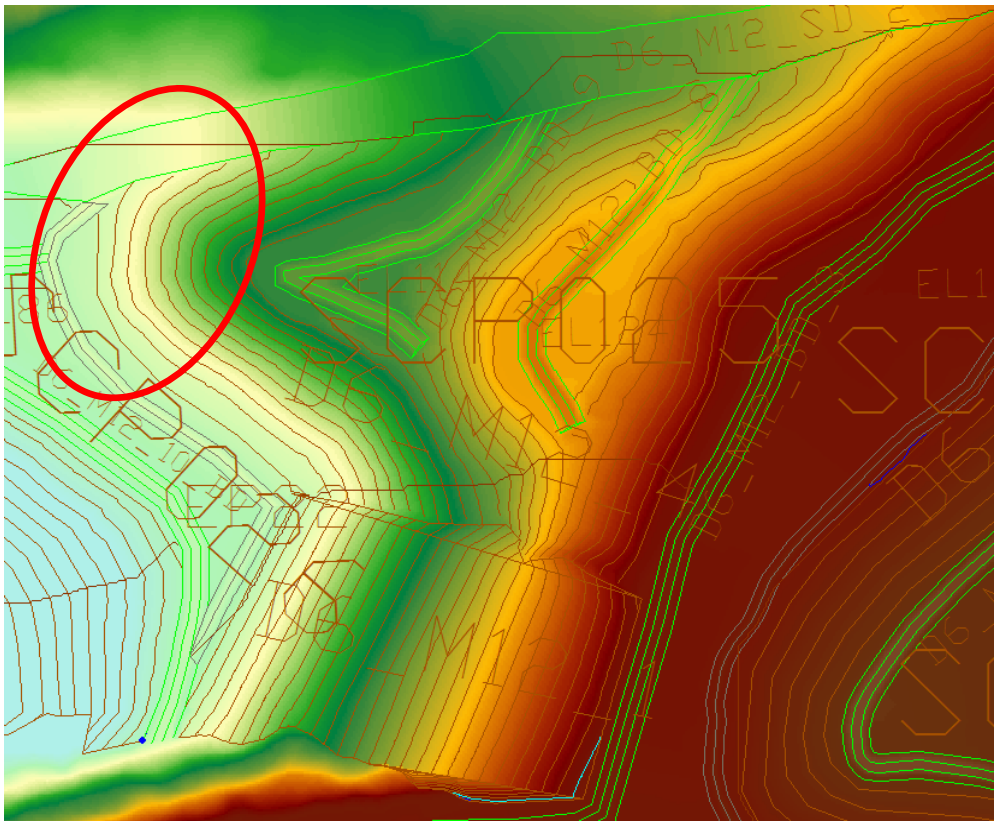

Figure A.3: Sub-catchment SC_025

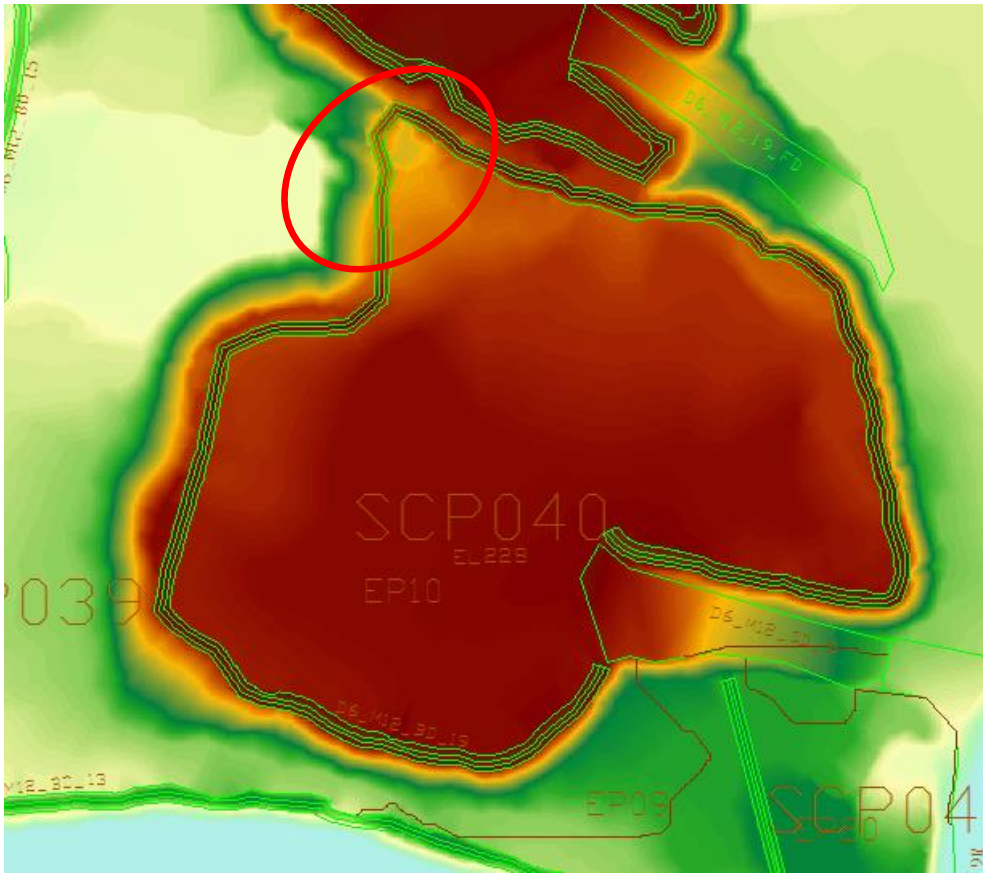

Figure A.4: Sub-catchment SC_040

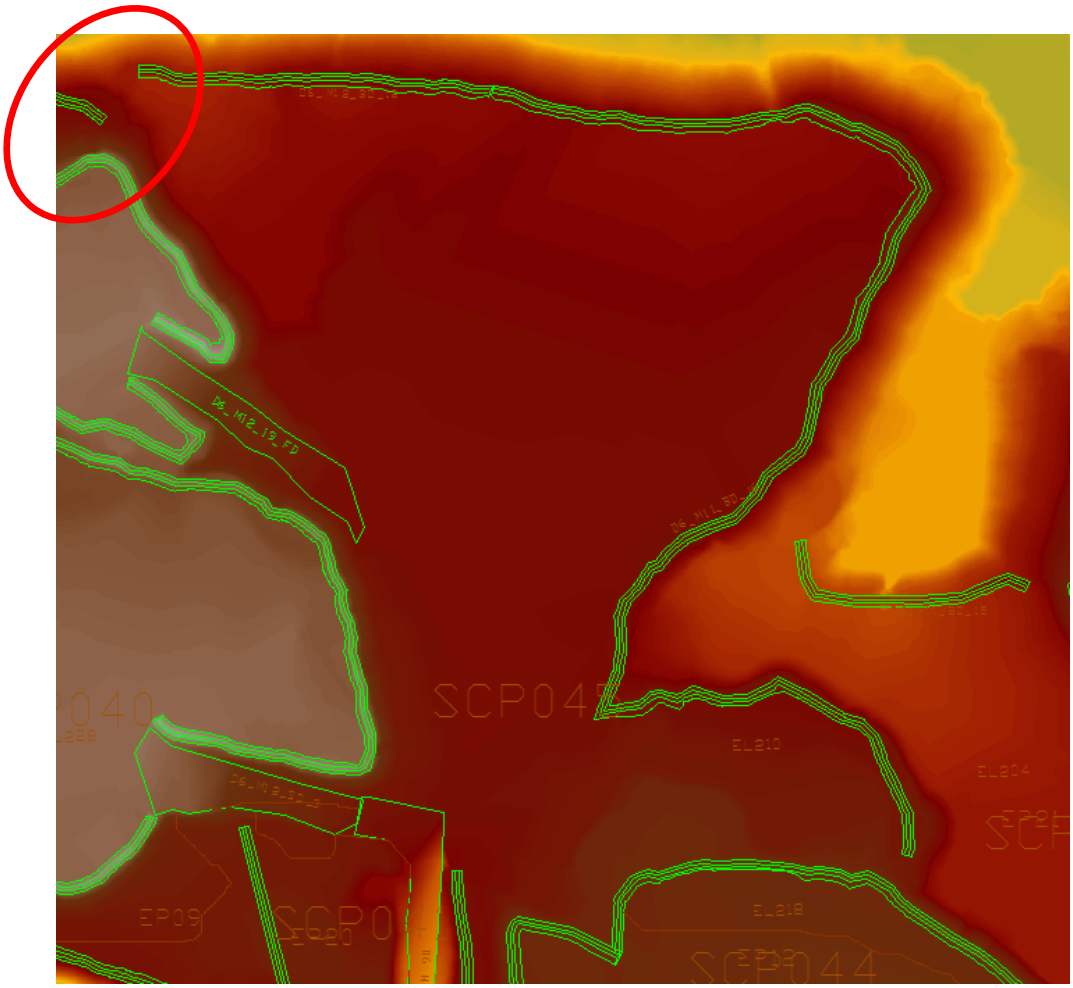

Figure A.5: Sub-catchment SC_045

Figure A.6: Sub-catchment SC_047

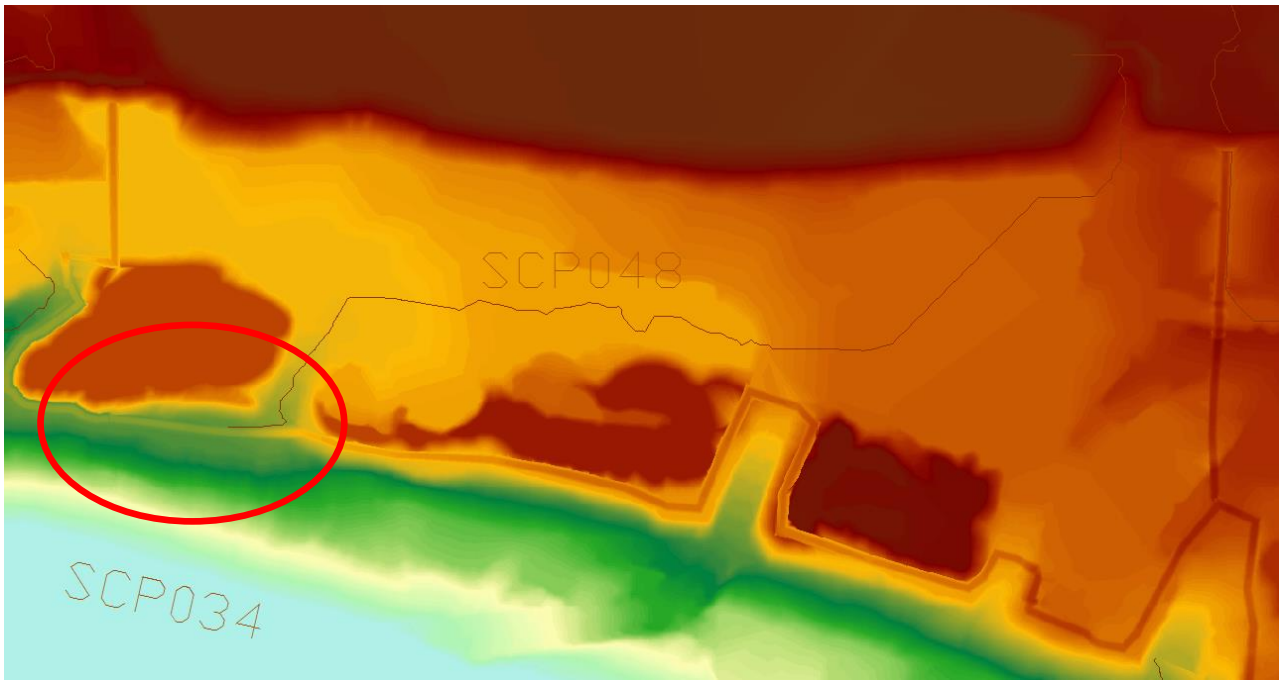

Figure A.7: Sub-catchment SC_048

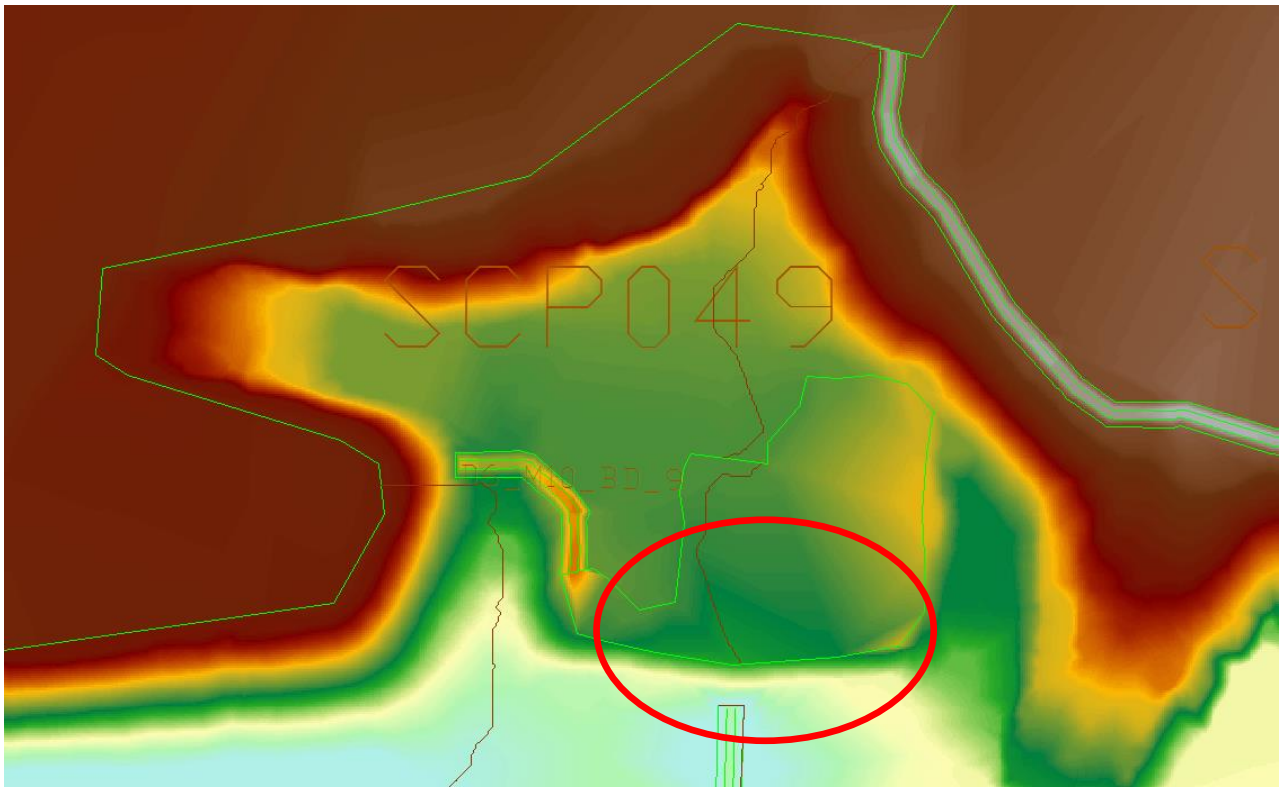

Figure A.8: Sub-catchment SC_049

Figure A.9: Sub-catchment SC_059

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