

Merrimu pre-PSP development phase 3: surface
water and groundwater investigations

DRAFT FINAL REPORT

10th February 2025

alluvium



Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for Country and the waterways within.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for Melbourne Water under the contract titled “Merrimu pre-PSP development phase 3: surface water and groundwater investigations ”

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Cover image: Merrimu escarpment

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1 Introduction

Alluvium Consulting Australia (Alluvium) have been engaged by Melbourne Water to undertake a Stormwater and Groundwater investigation within the Merrimu PSP area. This report summarises the outcomes of these investigations, which are the third phase of technical investigations used to inform Melbourne Water's drainage strategy for the site.

The Merrimu PSP area and the four proposed drainage schemes encompasses the Merrimu plateau, the surrounding escarpment and limited floodplain area to the north of the Werribee River (Figure 1). Melbourne Water have previously commissioned Alluvium to undertake background studies that document the geomorphic and ecological values of the PSP area and to investigate stormwater management options suitable for this landscape.

Phase 1 investigations (Alluvium, 2019) focused on documenting the ecological, geomorphic and biodiversity values and risks associated with the Merrimu PSP area. The Phase 1 investigations identified the presence of sodic, dispersive soils beneath the Merrimu plateau. Sodic soils are exposed at the plateau margin and have resulted in high rates of erosion in several of the tributaries that drain the plateau. **The presence of the eroding tributaries, and the sodic soils beneath the plateau, mean that a business-as-usual approach to the treatment and discharge of stormwater is associated with a higher risk to waterway values than if the sodic soils were not present.**

In light of the risk that sodic soils pose under a business-as-usual approach to stormwater discharge, Phase 2 investigations (Alluvium, 2021) were undertaken. Phase 2 investigations consisted of a preliminary investigation into the feasibility and risks associated with alternative stormwater discharge options. Those options included the disposal of stormwater via evaporation, via infiltration to the groundwater, and the discharge of stormwater via a sealed pipe (bypassing eroding tributaries). Phase 2 investigations concluded that infiltration of stormwater to the groundwater table may be a suitable means of disposing of stormwater, by avoiding delivery of additional flows to the sensitive tributaries on the plateau margin. However, Phase 2 investigations also identified that removal of stormwater volume via infiltration has the potential to cause mounding¹ of the water table and that such mounding has the potential to trigger tunnel erosion when it occurs at the plateau margin.

This report summarises the Phase 3 investigations which build on the earlier investigations by examining surface water and groundwater dynamics in more detail and addressing three key uncertainties identified in the Phase 2 investigations. The three key uncertainties were:

1. The annual and event scale volume of stormwater generated by sub-catchments on the Merrimu plateau.
2. The maximum rate of infiltration and the total annual volume of stormwater that could be infiltrated into the underlying Werribee aquifer, without resulting in an unacceptable rise in water table elevation.
3. The conceptual layout of stormwater infrastructure and land take requirements that would be required to dispose of stormwater given the outcomes of points 1 and 2 above.

Phase 1 and 2 investigations are summarised in more detail in section 2.

This Phase 3 assessment includes a surface water and a groundwater component. Surface water modelling included detailed and spatially explicit surface water modelling of the developed case for the Merrimu PSP area and was used as an input to groundwater modelling. The groundwater assessment consisted of the installation of two groundwater boreholes on the plateau, the insights from which were combined with the output from surface water modelling and input to a groundwater model. Taken together, the surface water and groundwater

¹ Mounding occurs where the water table is locally elevated so that it forms a cone shaped body of groundwater below an infiltration point.

modelling were then used to identify, at a high level, areas of the plateau where stormwater infiltration assets have the potential to cause unacceptable water table mounding.

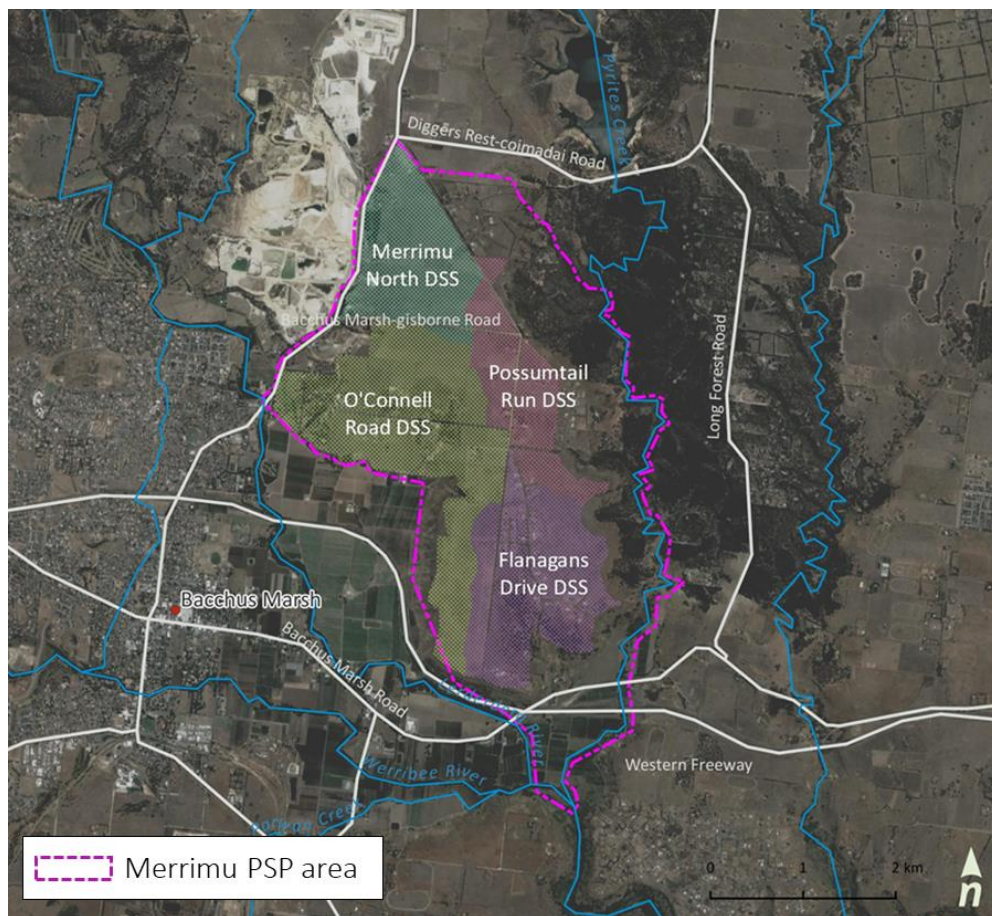


Figure 1. *Merrimu PSP study area and the extent of the four DSS proposed*

2 Background to this project

This project is the third phase of the pre PSP background investigations undertaken by Alluvium and CDM Smith in the Merrimu PSP area.

Phase three builds on two earlier phase/investigations undertaken by Alluvium on behalf of Melbourne Water:

1. **Phase one:** investigations that characterised the geomorphology and ecology of the Merrimu PSP area.
2. **Phase two:** risk assessment of potential stormwater management options for the Merrimu PSP area.

2.1 Phase 1 investigations

Phase 1 constituted work that Alluvium carried out in 2019 during the assessment of vegetation and geomorphology for the Merrimu PSP. The objective of the 2019 study was to generate a baseline to provide an indication of the likely geomorphic response to hydrological change on the plateau. The interaction between geomorphic processes and response of vegetation to potential geomorphic change was considered.

The 2019 study highlighted the extremely sensitive nature of sodic dispersive soils in the study area.

The assessment proposed the following two options:

- Do not develop the plateau. This may be a challenging option given the process that has been undertaken to date. However, the sensitivity of the landscape means that this option should be considered, or
- Development proceeds but with significant controls on stormwater. These controls would need to be higher than that typically applied to stormwater management in the greater Melbourne metropolitan area such as;
 - All additional runoff is retained on site and reused, infiltrated or evaporated and/or;
 - All additional runoff bypasses the tributary waterways and is discharged off-site either; below the escarpment in the more robust downstream reaches of Pyrites Creek and/or via temporary storages and pumped to other storages such as Merrimu Reservoir

All options would require a comprehensive risk assessment and cost benefit analysis that considers current risks and identifies future management and maintenance costs.

This study made the following recommendations relevant to groundwater and erosion risk.

Recommendation 1: Development does not proceed on the plateau without the prior identification of a clear pathway for the management of risks associated with development and associated changes to the hydrologic regime. This pathway could be informed by;

- A risk assessment within an agreed risk management framework.
- Further detailed assessments including the development of integrated surface water and groundwater models for the current and for any proposed future development scenarios.
- Further exploration and development of options consistent with the risk framework and detailed assessments

A risk management framework could consider waterway characteristics and/or processes that increase the likelihood of erosion events. The framework may consider but not be limited to factors such as landform, sensitivity, failure modes and event scenarios.

Recommendation 2: Conduct further evaluation of novel approaches and options. Further evaluation of novel approaches and options, potentially in workshops situations, to be developed in consideration of the risk assessment approach as proposed above.

Recommendation 3: Conduct an additional ecological assessment for values that may be influenced by options in response to recommendations 1 and 2. Also conduct a further ecological assessment that focuses on Seasonal Herbaceous Wetlands (SHW) on private land in an appropriate season when SHW flora is expressed. This critically endangered community requires further consideration and needs to be included in any risk management scenario that addresses natural values, geomorphic sensitivity and socio-economic impacts.

2.2 Phase 2 risk assessment

Phase two included a risk assessment for various stormwater management options for the Merrimu PSP area (as recommended by the phase one report), a field assessment of seasonal herbaceous wetlands, conceptual level hydrologic modelling and a characterisation of the subsurface geology and groundwater storage potential. The recommendations of the phase two investigation (abridged) were:

1. Establish a buffer to exclude stormwater infrastructure from the plateau margin.
2. Use a distributed approach to manage stormwater on the plateau.

3. Ensure that ecological values are a primary consideration in the future management of Wetland A.
4. That future stormwater management arrangements and designs are supported by appropriate evidence, including detailed investigations of:
 - The elevation of the water table within the Werribee formation. This can be measured by installation of a borehole(s) that penetrates through the Werribee formation and intersects the water table.
 - The impact of increased infiltration or direct injection and recovery of stormwater on groundwater elevations.
 - More detailed, event-based modelling of runoff volumes generated during storm events (including the 50%,20%,10%,5%,2% and 1% AEP events). This modelling should be spatially explicit so that the excess flow delivered to each waterway, and the potential impact on the moderately sensitive waterways that would receive runoff exported from the plateau, can be assessed.
 - A detailed feasibility assessment of aquifer storage and recovery for the Werribee aquifer.

2.3 Objectives of Phase 3 investigations

The objective of this project is to address several of the recommendations stemming from Phase 2 investigations, specifically to:

1. Delineate sub catchments on the Merrimu plateau so that detailed, and spatially explicit runoff modelling can be undertaken.
2. Determine the approximate footprint and potential locations of stormwater assets and the resulting stormwater infiltration rates.
3. Determine the elevation of the water table beneath the Merrimu plateau.
4. Identify areas where the infiltration of realistic volumes of stormwater at achievable rates has the potential to cause mounding of the water table beneath the plateau and:
 - a. Areas where any mounding is likely to interact the land surface

2.4 Phase 3 project approach

This project uses a combination of surface water modelling and groundwater modelling to address the recommendations of Phase 2 investigations and provide the necessary technical information to aid development of the Merrimu PSP DSS.

The surface water modelling is spatially explicit (rather than averages across the entire Merrimu plateau) and relies on both MUSIC and RORB model outputs to estimate the volume of stormwater runoff generated in subcatchments within the Merrimu PSP area. Sub catchment delineation and estimates of the stormwater runoff volumes and rates was used to design a preliminary and high-level layout of assets, which in-turn informs the groundwater modelling component of this project.

The groundwater component of this project has two parts: installation of groundwater bores on the plateau and then groundwater modelling. The boreholes are required to determine:

- The thickness of the Werribee Aquifer beneath the plateau – the subsurface reservoir being targeted by groundwater infiltration.
- The range of possible Permeability and hydraulic conductivity values that should be assigned to the Werribee aquifer in the subsequent groundwater modelling exercise.

The groundwater modelling uses the information obtained from the borehole drilling and the predicted rates and volumes of stormwater runoff generated by the surface water modelling to assess the potential for mounding of the groundwater table below the plateau. The groundwater modelling assumes all stormwater is disposed of via infiltration. This aim of this conservative assumption is to identify, at a high level, areas of the

plateau where groundwater infiltration has the potential to trigger mounding substantial enough that the water table intersects with the land surface, and the potential for tunnel erosion at the plateau margin exacerbated.

The implications of the updated understanding of groundwater and surface water dynamics for the DSS layout are considered in section 5 and future investigations that will reduce the uncertainty associated with model outputs are summarised in section 6.

3 Surface water assessment

This section investigates the land take requirements that would be required to manage urban stormwater on the Merrimu plateau in order to:

1. Meet the Stormwater Best Practice Environmental Management (BPEM) Guidelines (CSIRO 1999) pollutant load reduction targets (**stormwater treatment objective**)
2. Ensure developed peak flow rate are attenuated to the existing condition peak flow rate for the 1% AEP event (**flow retardation objective**)
3. Ensure “no additional” runoff volume entering the tributaries on the escarpment compared to the existing (i.e. pre-developed) condition to protect the tributaries from increased stormwater flows arising from development (**stormwater retention objective**).

The business-as-usual approach for stormwater management in greenfield areas typically only addresses objectives 1 and 2 above. However, in the case of greenfield development on the Merrimu plateau, retention of stormwater from impervious surfaces (objective 3) is also recommended to protect the sensitive tributaries on the escarpment. Investigations undertaken in Phase 2 of the project identified a requirement to retain close to 99 % of the average annual developed stormwater runoff volume to ensure “no additional” runoff entering the tributaries. This was based on reducing the annual average stormwater volume from a developed land parcel with a fraction imperviousness of 70% (i.e. developed scenario) back to the stormwater volume generated from the same land parcel with a fraction imperviousness of 0 % (i.e. current condition).

3.1 Approach and methods

We investigated land take requirements for stormwater management assets that address the three above objectives at 11 locations on the plateau. These asset locations were informed from the stormwater management strategy of the Merrimu Plateau developed by RAIN consulting for Bacchus Marsh Developments (see RAIN, 2022). For the purpose of this project, these asset locations provide a feasible initial layout to test land requirements for centralised stormwater assets, and to inform the pre-feasibility of treated stormwater infiltration into the Werribee Formation via injection bores (section 2).

The Future Urban Structure Plan (**Figure 2**) shows the locations of centralised stormwater assets – wetland retarding basins (RBWL) – which have outfalls into selected tributaries on the escarpment. It should be noted that the feasibility of these outfalls was assessed by Streamology (RAIN, March 2022) and found to be suitable to receive increased stormwater flows arising from development on the plateau (with either little to no erosion mitigation works or some erosion mitigation works) based on a geomorphic and soil erosivity assessment. This project has not undertaken an independent, detailed assessment of whether locating outfalls at the proposed tributaries is likely to trigger erosion. Such an erosion assessment should be undertaken in the next phase of investigations so that outfall locations and the scope of any associated erosion mitigation works can be confirmed.

The asset footprint at each location was determined following the steps below:

- A stormwater treatment wetland (with sediment pond) was selected as the treatment asset type to meet BPEM pollutant load reduction targets. The sizing of the asset was undertaken in MUSIC (Model for Urban Stormwater Improvement Conceptualisation).
- A storage pond was proposed downstream of the treatment wetland to store and infiltrate the treated water into the Werribee Formation via injection bores. The sizing of the storage pond to meet the stormwater retention requirement was undertaken in MUSIC.
- The flow retardation storage volume requirement was determined in RORB at each location to ensure the developed peak flow rate was attenuated to the existing peak flow rate for the 1% AEP event. The combined wetland and storage pond asset was proposed to provide a flow retardation function (volume above the Total Extended Detention).

The analysis and modelling undertaken in each step is outlined below.

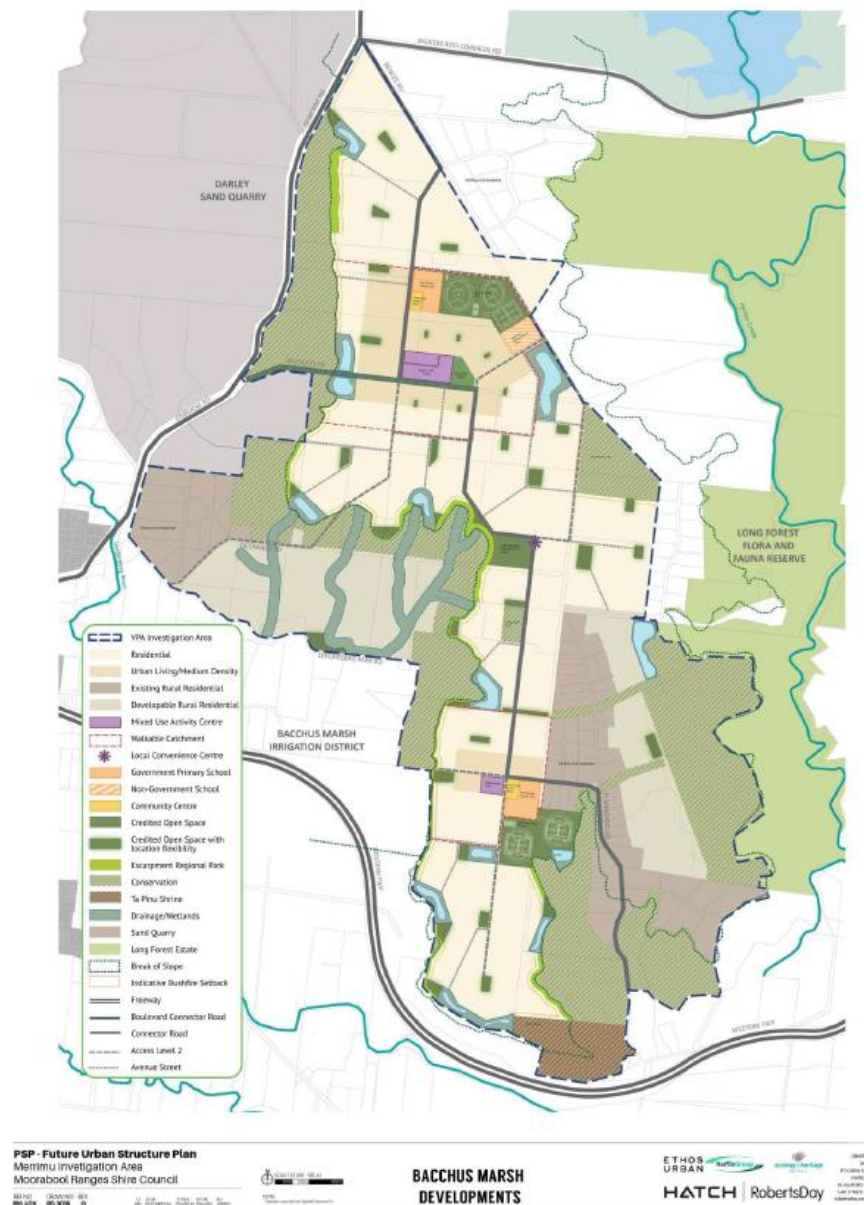


Figure 2. Future Urban Structure Plan developed for “Bacchus Marsh Developments”

Catchment delineation

The catchment areas on the Merrimu Plateau were delineated based on the data sources in **Table 1**. The tributaries along the Merrimu Plateau escarpment were mapped using LiDAR. The catchment area contributing to each tributary was in turn delineated up to the break of slope (**Figure 3**). For the developed scenario, the urban catchments were delineated based on the Melbourne Water DSS layer which was modified either to the extent of developable area (i.e. plateau break of slope) or the VPA investigation boundary (**Figure 4**). The developed catchments were further split into sub-catchments contributing flows to the centralised stormwater management asset locations (**Figure 5**).

Table 1. Data source

GIS Layer	Data Source
Break of Slope	Bacchus Marsh Urban Growth Framework; Future Urban Structure Plan (Alluvium Georeferenced)
VPA Site Investigation Boundary	Bacchus Marsh Urban Growth Framework; Future Urban Structure Plan (Alluvium Georeferenced)
Contours	Geoscience Australia
Developed catchments	Modification to Melbourne Water DSS layer
Tributaries along Merrimu Plateau escarpment	This is a new layer created by Alluvium taking information from the Melbourne Water Natural Waterways Centreline layer, and the Melbourne Water Waterways above MW Limit layer. Where gaps exist, tributaries were mapped using LiDAR up to the break of slope.

Catchment imperviousness

Current land use on the Merrimu Plateau consists of a mixture of rural residential living (in sub-catchment 11 mainly) and open paddocks or undeveloped land.

According to the Future Urban Structure Plan, development on the plateau will comprise of over 5,000 new dwellings comprising mostly of residential housing with lots size around 600 m² (i.e. standard residential). There are areas allocated for medium density residential with lot size of around 275 m². Low density residential is also proposed with a lot size of approximately 10,000 m². Future land use in sub-catchment 11 was not available, hence we have assumed that the current Rural Residential land use would persist in the future.

Based on the proposed land uses, imperviousness of the developed catchments has been derived using typical fraction imperviousness values for different land use zones in the Future Urban Structure Plan (see Table 2 and Table 3).

Based on these assumptions, the imperviousness of the overall PSP catchment area in the future developed scenario is estimated to be around 55 %. Excluding the “Existing Rural Residential”, “Developable Rural Residential” and “conservation” zones, the catchment area imperviousness is estimated at 71% (Table 2). As such, we have adopted a fraction imperviousness of 70 % for all sub-catchments in the developed scenario, except for sub-catchment 6 (65%) and sub-catchment 11 (20%) which will partly consist of Rural Residential land use (Table 4).

Table 2. Developed catchment imperviousness based on proposed land uses (refer to Table 3)

Catchment	Total area (ha)	Impervious area (ha)	Fraction imperviousness
Merrimu North	156	111	71%
O’Connell Road	207	152	73%
Possumtail Run	149	69	47%
Flanagans Drive	212	67	32%
Total (all land uses included)	724	399	55%
Total (excluding existing rural, developable rural and conservation zones)	526	374	71%

Table 3. Fraction imperviousness assumptions for specific land uses

Land use zone	Fraction imperviousness
Standard residential (300-600 sqm)	0.75
Mixed use	0.75
High density (<300 sqm)	0.85
Low density (>1000 sqm)	0.2
Public park/open space	0.1
Conservation	0.05

Table 4. Developed sub-catchment areas and fraction imperviousness assumptions for MUSIC modelling

Sub-catchment	Area (ha)	Fraction imperviousness
1	26	0.7
2	103	0.7
3	65	0.7
4	33	0.7
5	30	0.7
6	91*	0.65
7	59	0.7
8	41	0.7
9	47	0.7
10	34	0.7
11a	17**	0.2
11b	17***	0.2

*Does not include conservation zone

** includes proposed zone and the conservation zone crossing the proposed areas

***Only includes proposed zone

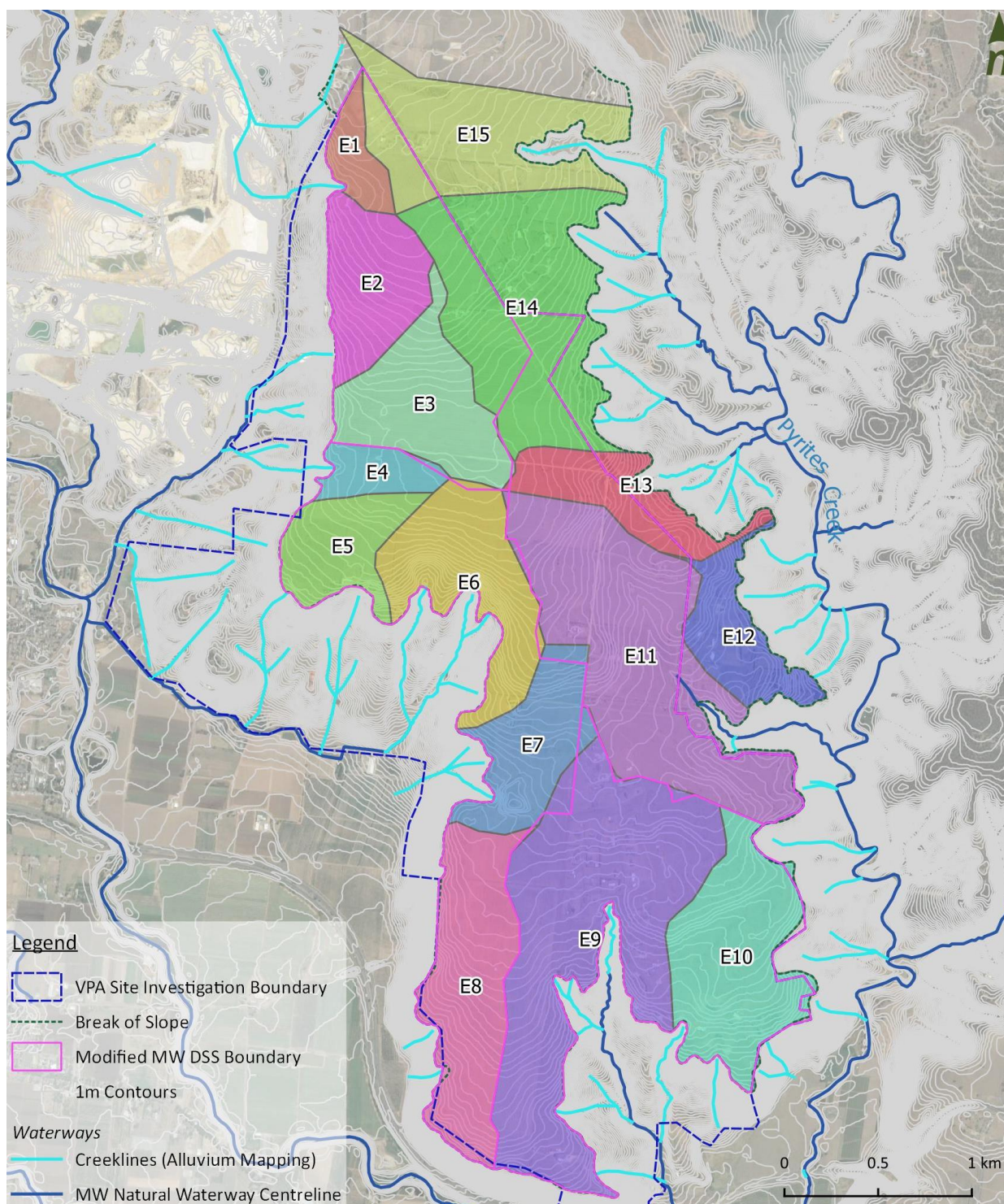


Figure 3. Existing catchments of mapped tributaries

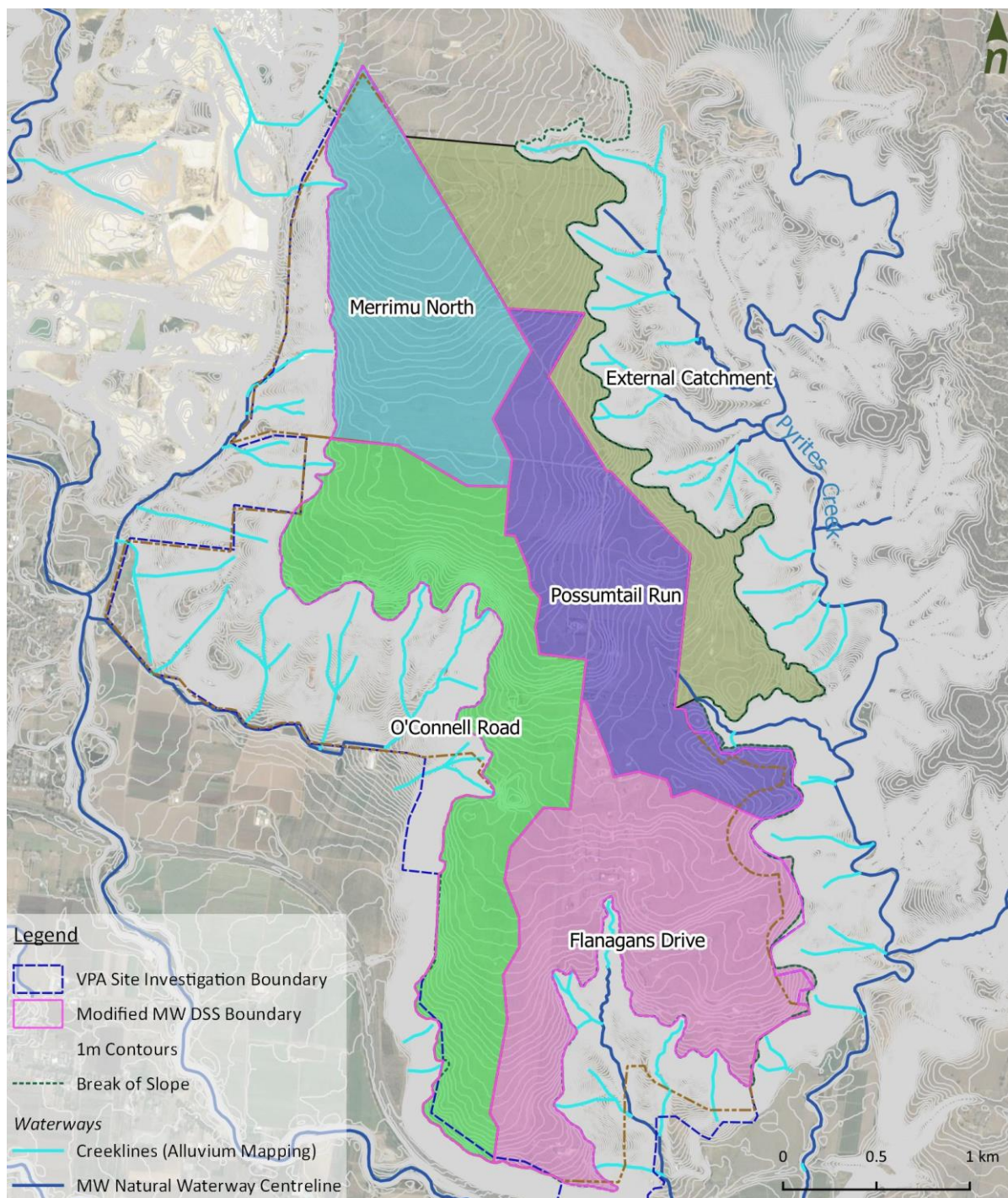


Figure 4. *Developed catchments*

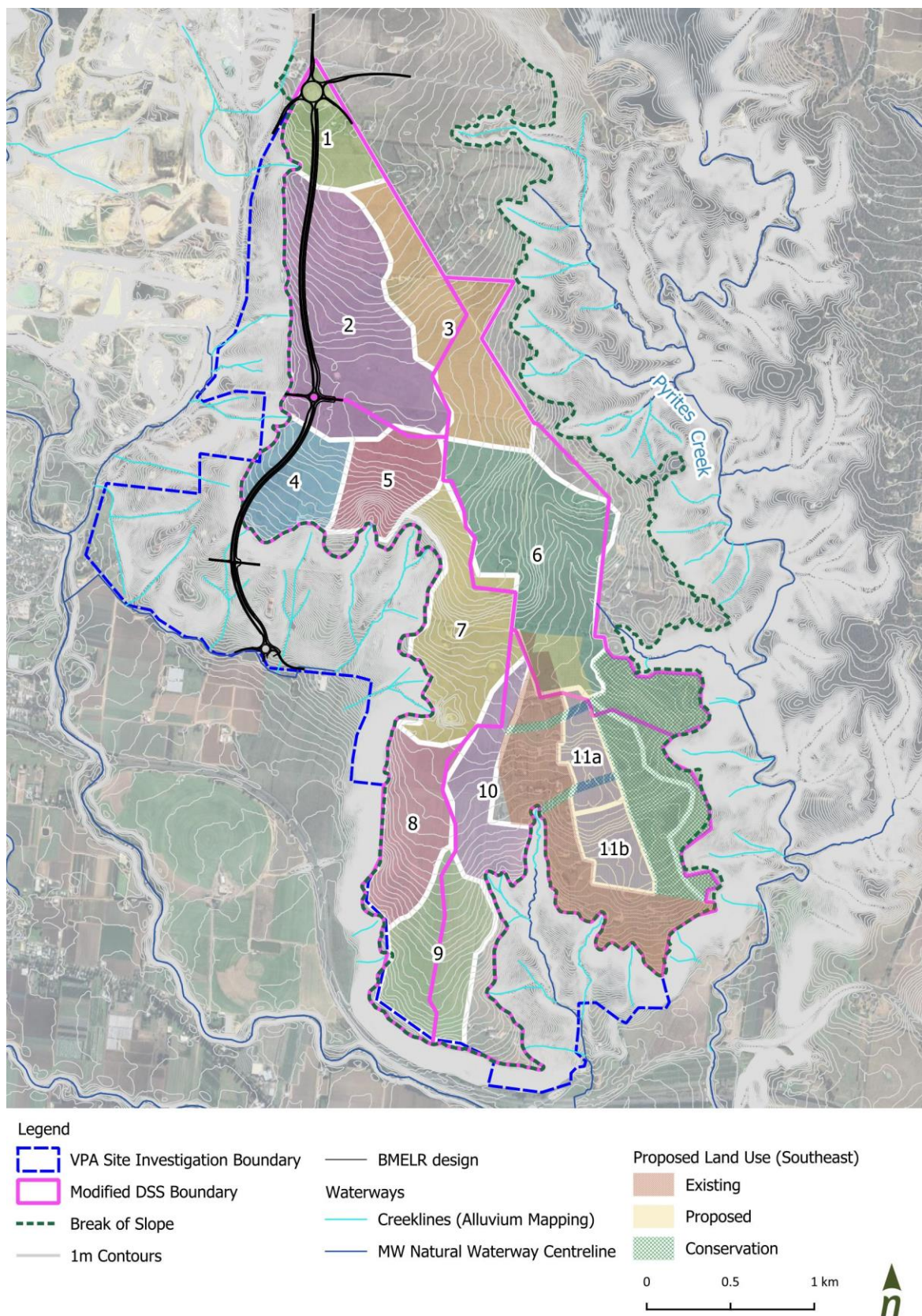


Figure 5. Developed sub-catchment. Catchment 11a and 11b cover the proposed area in catchment 11

Stormwater treatment asset sizing

A key requirement in greenfield development is that stormwater is treated in accordance with the Urban Stormwater Best Practice Environmental Management (BPEM) Guidelines (CSIRO 1999) to meet the following pollutant load reduction targets:

- 70% removal of the Total Gross Pollutant load
- 80% removal of Total Suspended Solids (TSS)
- 45% removal of Total Nitrogen (TN)
- 45% removal of Total Phosphorus (TP).

A MUSIC model was developed for each sub-catchment. The Melbourne Water's standard 10-year rainfall templates have not been used for this project as longer time series dataset is needed for assessment of storage pond sizing (see section below). Rainfall datasets at 6-minute intervals were obtained via eWater for rainfall gauges near Merrimu (**Figure 6**). The Parwan Gauge dataset for the period 1955-1973 was selected as it had the most consistent record. The developed sub-catchment areas and fraction imperviousness assumptions used in the MUSIC model are provided in **Table 4**. Stormwater treatment wetland (with sediment pond) was selected as the default treatment asset with an assumed Extended Detention Depth (EDD) of 350mm and a detention time of 72 hours.

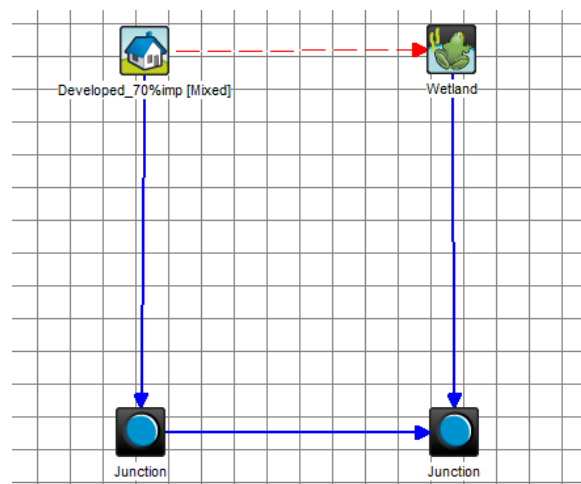


Figure 6. MUSIC Model for sizing stormwater treatment asset

Stormwater retention asset sizing

A key objective to protect the receiving tributaries from increased stormwater flows arising from development on the plateau is to ensure “no additional” runoff entering the tributaries compared to the existing (i.e. pre-developed) condition. Investigations undertaken in Phase 2 of the project identified a requirement to retain around 99 % of the average annual developed stormwater runoff volume to ensure “no additional” runoff volume entering the tributaries. The proposed approach to achieve this requirement is to collect stormwater runoff in a storage pond (downstream of the stormwater treatment asset) for injection into the Werribee Formation by gravity using bores (**Figure 7**). Given the requirement to retain 99 % of the average annual developed stormwater runoff volume, there will be times when the storage pond receives untreated stormwater (e.g. when treatment wetland design flows are exceeded).

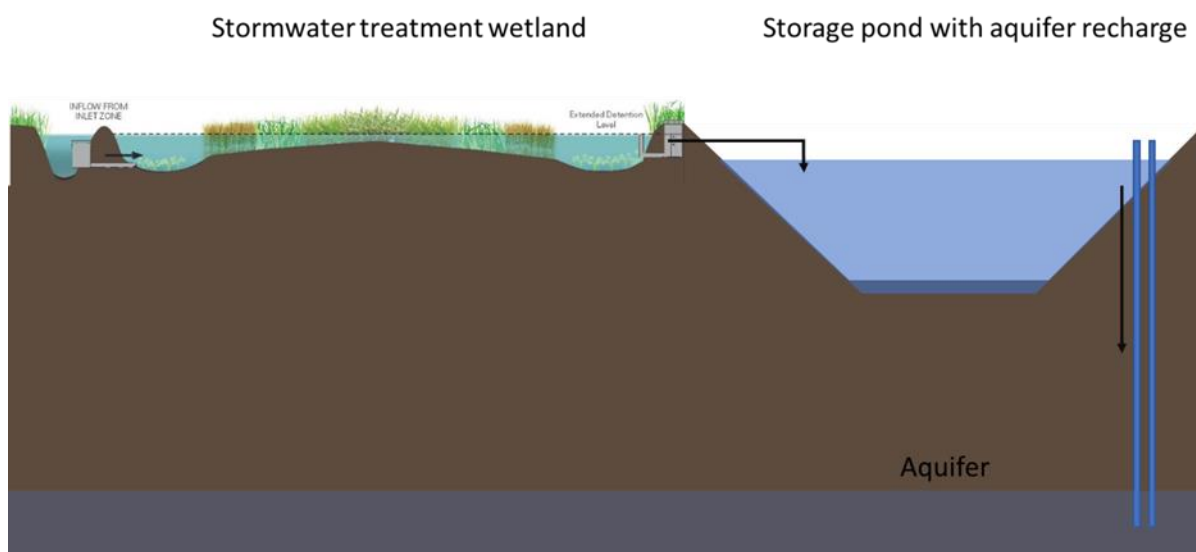


Figure 7. Schematic of stormwater treatment followed by storage and injection into the Werribee Formation

The MUSIC model developed consisted of a stormwater treatment wetland and storage pond arrangement (**Figure 8**). Assuming a storage pond depth of 3 metres with a maximum drawdown of 2 metres and injection rate of 20 L/s, the storage pond volume has been adjusted to achieve the stormwater retention target i.e. 99% reduction in average annual developed stormwater runoff. Injection rates into the aquifer have been modelled by using the re-use functionality parameter in the MUSIC pond node. The injection rate is based on the assumption that the maximum injection rate from a single bore is 10 L/s and that multiple bores can be used at each injection site (see groundwater assessment in section 4). In reality, this will depend on the horizontal hydraulic conductivity (K_h) of the aquifer and in turn on bore spacing required. For this assessment, we have assumed two bores at each injection site. The exception is sub-catchment 11 where only one bore has been proposed at each injection site given the small catchment area and average annual developed runoff volume.

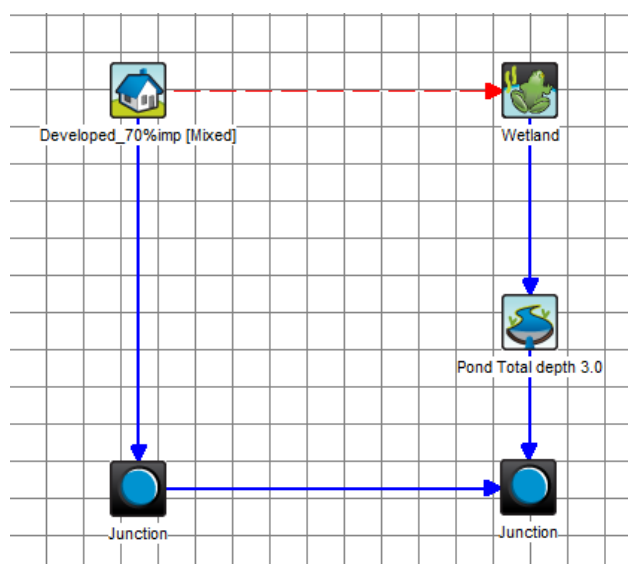


Figure 8. MUSIC Model for sizing storage pond (stormwater retention) asset

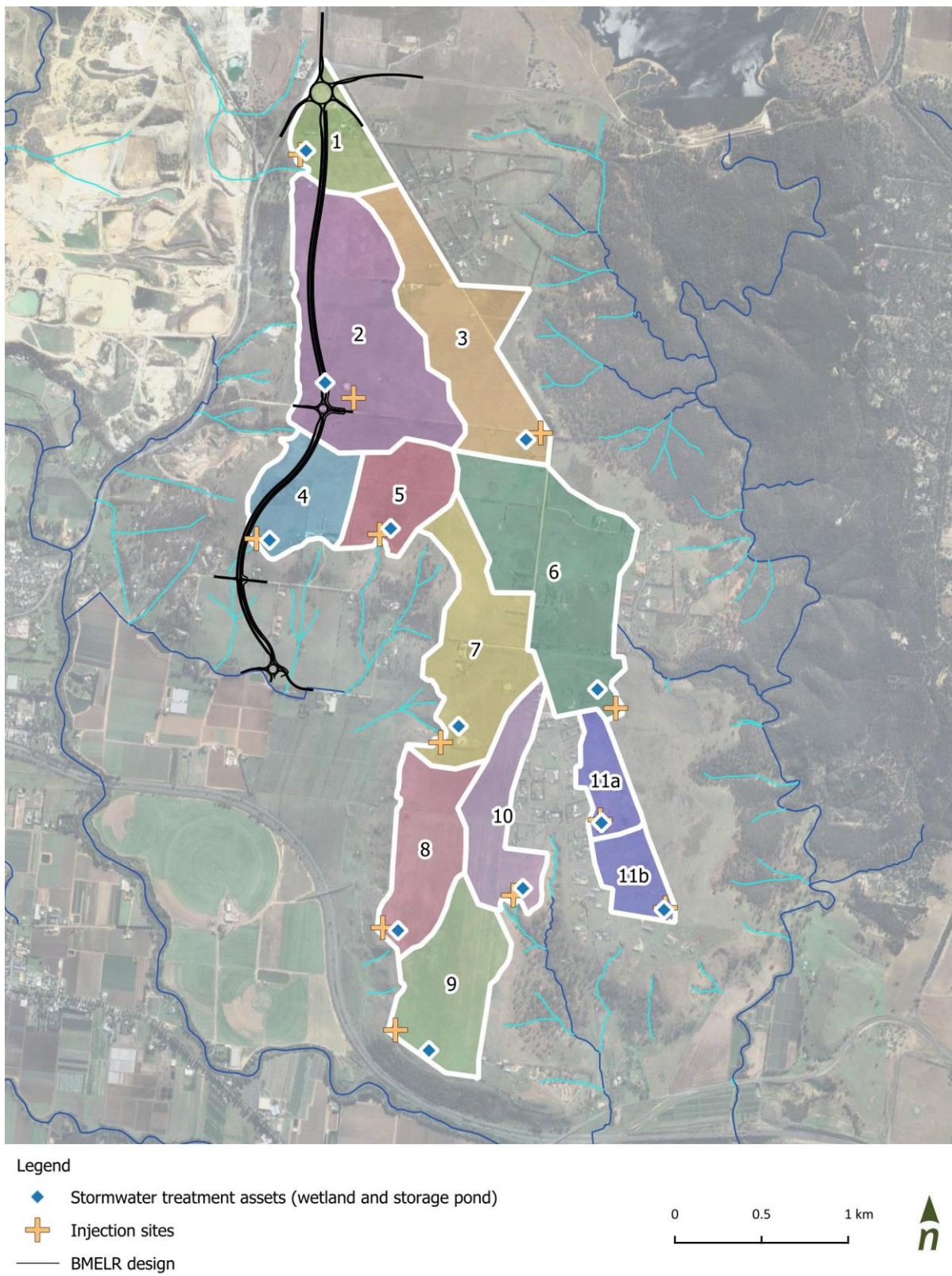


Figure 9. *Locations of stormwater management assets and injection sites*

Stormwater retardation volume requirement

The retardation storage volume required at each asset location was determined using RORB (v6.31). A combined RORB model was created to estimate the:

- Existing peak flow rate for the 1% AEP event for each sub-catchment.
- Developed peak flow rate (without retardation) for the 1% AEP event for each sub-catchment.
- Retardation storage volume requirement to ensure developed peak flow rate are brought back to existing peak flow rate for the 1% AEP event.

The catchment area contributing flows to each proposed stormwater asset location was delineated for the existing and developed scenario (**Figure 11**) (see **Figure 32** to **Figure 42** in Appendix – RORB for detailed information of each sub-catchment). The catchment area can differ significantly for the existing condition and developed condition based on surface water flow paths. In the existing conditions, surface runoff spills off the plateau into numerous tributaries. In the developed condition, surface runoff is conveyed to selected locations on the plateau (via pipes and roads) for treatment, retention, and retardation before discharge into selected tributaries. As such, the catchment area contributing flows to each proposed outfall is typically larger for the developed scenario compared to the existing scenario.

The design rainfall parameters for this analysis were adopted based upon the Bureau of Meteorology's (BOM) "Intensity Frequency Duration (IFD) Tool – AR&R 2019" (see **Figure 10**). Initial Loss (IL) and Continuing Loss (CL) were adopted based on the ARR datahub, with standard factors applied for the developed conditions scenario (**Table 5**).

Table 5. Input variables adopted for RORB model

Parameter	Value	Method of derivation
Existing conditions		
m	0.8	Standard value
IL	23.00	Sourced from ARR datahub
CL	2.1	Sourced from ARR datahub
Developed Conditions		
m	0.8	Standard value
IL	16.1	Median of 60% - 80% of existing conditions IL
CL	2.1	Same as existing conditions CL

In line with the Australian Rainfall & Runoff (2019), calibration of the RORB model was undertaken to determine the estimation of rainfall intensities for a specific site. For ungauged catchments the Australian Rainfall & Runoff 2019 (ARR2019) guidelines recommend the routing parameter k_c be estimated using regional relationships. Sanity checks should then be used to compare flow results with approximate methods that include the Regional Flood Frequency Estimation method (RFFE), Nikoloau/Vont Steen equations (DNRE) and rule of thumb methods (i.e. Rational method).

The k_c equations considered for the investigation were:

- Melbourne Water's regional equation for the Yarra and Maribyrnong ($k_c = 1.19 * A^{0.56}$)
- Pearse et al. Victoria equation ($k_c = 1.25 * \text{dav}$)
- Australian equation for Annual mean rainfall less than 800mm ($k_c = 0.49 * A^{0.65}$)

Sanity checks for modelled flowrates were compared with upper and lower of RFFE, rural rational method and the DNRE equation. Results from the sanity check are provided in **Table 6** for three sub-catchments. The RFFE medium flowrate was less than estimated rational method and DNRE flowrates for all catchments. The Pearse et

al. region equation was adopted for all catchments as it produced flowrates within the confidence limits of the RFFE while being more in line with the other estimation method.

Table 6. RORB kc calibration results and critical flows

		Unit	Sub-catchment 1	Sub-catchment 2	Sub-catchment 3
Catchment	Area	km ²	0.075	0.601	0.235
	Dav	km	0.22	0.55	0.57
Critical Flows					
Kc equations	MW Yarra/ Maribyrnong	m ³ /s	0.38	1.77	0.93
		Kc	0.56	1.22	0.94
	Pearse et al. (2002)	m ³ /s	0.77	2.65	1.66
		Kc	0.28	0.69	0.71
	Less than 800mm	m ³ /s	0.73	3.20	1.81
		Kc	0.21	0.50	0.37
	RFFE lower limit	m ³ /s	0.12*	0.63	0.30*
	RFFE	m ³ /s	0.40*	2.01	0.96*
Estimation models	RFFE upper limit	m ³ /s	1.27*	6.44	3.09*
	DNRE	m ³ /s	0.65	3.17	1.55
	Rural Rational (Bransby Williams)	m ³ /s	1.42	4.72	2.19
	Rural Rational (ARR)	m ³ /s	1.17	5.77	2.79

**The catchment is outside the recommended catchment size of 0.5 to 1,000 km². Results have lower accuracy and may not be directly applicable in practice.*

Based on the calibration results, the Pearse *et al* 2002 equation was selected to determine kc values for all the remaining sub-catchments. **Table 7** represents the input parameters for existing and developed conditions. For existing conditions, a fraction imperviousness value of 0 was adopted for all sub-areas and reach types were set to type “1. Natural”. For developed condition, all sub-areas were updated to have a fraction imperviousness value of 0.70. As the RORB model investigation considers only the 1% AEP rainfall event, it is assumed that stormwater in the developed conditions would be conveyed by a combination of pipe network and overland flow. As such, for developed conditions reach types were updated to be type “2. Excavated but unlined”, to reflect the large wetted perimeter and shallow depths of street overland flow. Kc values for developed conditions were adjusted to ensure a consistent ‘kc/dav’ ratio between existing and developed conditions.

Table 7. Summary of RORB input parameters

Catchment	Existing condition				Developed condition			
	Kc	m	IL (mm)	CL (mm)	Kc	m	IL (mm)	CL (mm)
1	0.28	0.8	7.7	2.1	0.5	0.8	2.7	2.1
2	0.69	0.8	13.6	2.1	1.09	0.8	2.7	2.1
3	0.71	0.8	7.7	2.1	0.9	0.8	2.7	2.1
4	0.48	0.8	7.7	2.1	0.58	0.8	2.7	2.1
5	0.45	0.8	7.7	2.1	0.48	0.8	2.7	2.1
6	0.96	0.8	13.6	2.1	1.19	0.8	2.7	2.1
7	0.57	0.8	7.7	2.1	0.79	0.8	2.7	2.1
8	0.61	0.8	7.7	2.1	0.94	0.8	2.7	2.1
9	0.61	0.8	7.7	2.1	0.9	0.8	2.7	2.1
10	0.61	0.8	13.6	2.1	0.75	0.8	2.7	2.1
11a	0.56	0.8	7.7	2.1	0.45	0.8	2.7	2.1
11b	0.64	0.8	7.7	2.1	0.75	0.8	2.7	2.1

The hydrologic modelling considered an ensemble simulation for the 1% Annual Exceedance Probability (AEP) event, for durations 10 minutes to 72 hours. From the ensemble simulation, ten temporal patterns were used to determine peak runoffs for each duration. The median flows (i.e. 6th highest peak flow) for each storm duration was determined, and the peak critical flow with respect to storage, was calculated. The RORB model was computed for the existing and developed conditions for 1% AEP flood event with results (**Table 8**).

Table 8. Summary of peak flow rates from RORB for existing and developed conditions

Sub-catchment	Existing condition				Developed condition (no attenuation)			
	Area (ha)	Dav (km)	Peak flow (m ³ /s)	Storm duration	Area (ha)	Dav (km)	Peak flow (m ³ /s)	Storm duration
1	7.50	0.22	0.77	1.5 hr	30.00	0.40	5.32	20 min
2	60.10	0.55	2.65	3.0 hr	100.00	0.87	15.01	25 min
3	23.50	0.57	1.66	1.5 hr	70.00	0.72	10.60	25 min
4	17.80	0.39	1.26	1.5 hr	30.00	0.50	6.75	20 min
5	27.60	0.36	2.16	1.5 hr	30.00	0.39	6.63	20 min
6	80.00	0.77	3.50	3.0 hr	90.00	0.95	13.22	25 min
7	35.20	0.46	2.48	1.5 hr	60.00	0.63	11.22	20 min
8	16.70	0.17	1.30	1.5 hr	41.00	0.31	6.25	20 min
9	17.80	0.27	1.56	1.5 hr	49.00	0.35	7.42	20 min
10	25.40	0.27	1.14	3.0 hr	34.00	0.28	6.34	20 min
11a	25.00	0.44	1.85	1.5 hr	25.00	0.36	3.41	45 min
11b	29.50	0.51	2.19	1.5 hr	31.00	0.6	3.49	45 min

Following the establishment of existing and developed peak flows, retarding basins were incorporated in the model and sized to attenuate the developed 1% AEP peak flow rates back to existing condition. The retarding basin stage storage relationships were developed in a spreadsheet with a base area equivalent to the NWL of the stormwater treatment wetland and storage pond (see sections above) with a length to width ratio of 4 to 1, and a batter slope of 1 in 6. The storage outlet size in RORB was adjusted until the developed 1% AEP peak flow rate was equal or less than the existing condition peak flow rate.

IFD Design Rainfall Depth (mm)

Issued: 01 June 2022

Rainfall depth in millimetres for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).

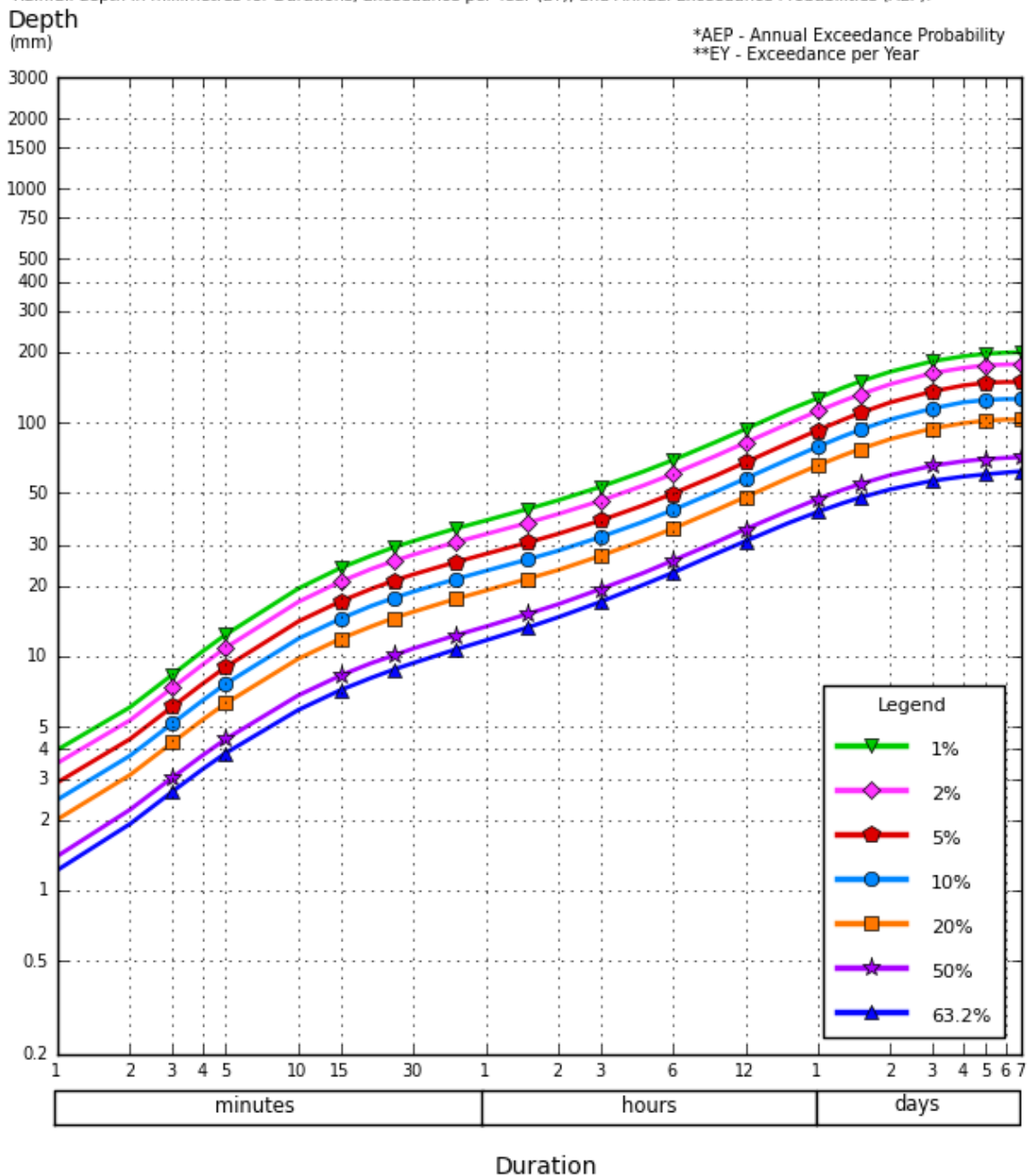


Figure 10. Design IFD data for subject site (Bureau of Meteorology Design Rainfall Data System, 2016)

3.2 Stormwater asset sizing and results

Table 9 outlines the stormwater treatment asset footprint required to meet BPEM pollutant load reduction targets. These asset footprints are higher than those in the stormwater management strategy by RAIN consulting (see RAIN, 2022) because of the higher fraction imperviousness adopted in our study for developed sub-catchments (70%) and use of a different meteorological template.

Table 9. Stormwater treatment asset footprint to meet BPEM targets

Sub-catchment	Area (ha)	Sediment pond area (m ²) at NWL	Wetland area (m ²) at NWL	Total asset footprint (m ²) at NWL
1	26	700	6,400	7,100
2	103	2,600	26,000	28,600
3	65	1,650	16,500	18,150
4	33	830	8,300	9,130
5	30	750	7,500	8,250
6	91	2,200	21,000	23,200
7	59	1,500	15,000	16,500
8	41	1,100	10,000	11,100
9	47	1,200	12,000	13,200
10	34	900	9,000	9,900
11a	17	250	1,320	1,570
11b	17	250	1,350	1,600

Table 10 outlines the storage volumes required to ensure “no additional” runoff entering the tributaries compared to existing (pre-development) condition. The storage pond footprint calculation is based on the assumption that the pond has an average depth of 3 metres.

Table 10. Storage volume requirement and storage pond footprint to meet stormwater retention objective

Sub-catchment	Sub-catchment area (ha)	Number of bores	Injection rate into Werribee formation * (L/s)	Storage volume requirement (m ³)	Storage pond area (m ²) at NWL (pond depth 3.0 m)
1	26	2	20	15,000	5,000
2	103	2	20	93,000	31,000
3	65	2	20	49,500	16,500
4	33	2	20	19,800	6,600
5	30	2	20	18,000	6,000
6	92	2	20	72,000	24,000
7	59	2	20	40,500	13,500
8	41	2	20	25,500	8,500
9	47	2	20	30,000	10,000
10	34	2	20	21,000	7,000
11a	17	1	10	5,700	1,900
11b	17	1	10	5,700	1,900

*Based on assumption that the maximum injection rate that one bore can handle is 10 L/s

Table 11 outlines the retardation storage volume required to ensure developed peak flow rates are brought back to existing peak flow rates for the 1% AEP event.

Table 11. Indicative retarding basin storage volume requirements

Sub-catchment 1	Existing condition peak flow rate (m ³ /s)	Developed condition peak flow rate with retardation (m ³ /s)	Retardation volume required (m ³)	Retarding basin outlet structure modelled
1	0.77	0.71	8,360	1 x 450mm dia. pipe
2	2.65	2.29	52,800	1 x 750mm dia. pipe
3	1.66	1.52	25,000	1 x 675mm dia. pipe
4	1.26	1.09	9,820	1 x 600mm dia. pipe
5	2.16	1.88	6,710	1 x 750mm dia. pipe
6	3.50	3.01	28,600	1 x 900mm dia. pipe
7	2.48	2.19	17,400	1 x 825mm dia. pipe
8	1.30	1.12	14,400	1 x 600mm dia. pipe
9	1.56	1.39	16,300	1 x 525mm dia. pipe
10	1.14	1.01	11,400	1 x 750mm dia. pipe
11a	1.85	1.64	3,730	1 x 750mm dia. pipe
11b	2.19	1.87	5,320	1 x 750mm dia. pipe

Table 12 provides a summary of the land take requirements for stormwater management on the Merrimu plateau to meet all three objectives (stormwater treatment, retention and retardation). For each sub-catchment, the asset footprint consists of stormwater treatment wetland and storage pond. These two assets form the base of the retarding basin. The land take requirements for a business-as-usual approach (stormwater treatment and retardation functions only) are also provided for comparison. At this pre-feasibility stage, the land take for the stormwater management assets across the plateau (expressed as a proportion of the sub-catchment areas) is estimated to be 8.2% compared to 4.8% for the business-as-usual approach.

Table 12. Land take requirements for stormwater management on the Merrimu plateau to meet all three objectives (stormwater treatment, retention and retardation) compared to business-as-usual approach.

Sub-catchment	Area (ha)	Business-as-usual asset footprint (m ²) *	Proposed asset footprint to meet all stormwater mgt objectives (m ²) **	Additional asset footprint required (m ²)
1	26	15,035	22,813	7,777
2	103	47,640	84,076	36,436
3	65	31,373	54,842	23,469
4	33	18,057	28,995	10,938
5	30	16,758	26,907	10,148
6	92	37,753	71,382	33,629
7	59	28,409	48,510	20,100
8	41	21,125	34,495	13,371
9	47	24,077	39,333	15,256
10	34	19,156	30,574	11,418
11a	17	6,479	10,693	4,214
11b	17	7,389	10,726	3,337

Sub-catchment	Area (ha)	Business-as-usual asset footprint (m ²) *	Proposed asset footprint to meet all stormwater mgt objectives (m ²) **	Additional asset footprint required (m ²)
	Total	273,251	463,346	190,093
	Land take (% of sub-catchment area)	4.8%	8.2%	3.4%

* Asset footprint to provide stormwater treatment and retardation functions only. Retarding basin base area is determined by stormwater treatment wetland area requirement. Asset batters of 1 in 6 up are proposed for a height varying between 1.95 -2.70 m above asset base to provide sufficient cover for incoming stormwater pipes and volume (above wetland TED) for flood retardation storage and freeboard (600mm) above peak flood water level for the 1% AEP event.

** Asset footprint to provide stormwater treatment, retention and retardation functions. Retarding basin base area is determined by stormwater treatment wetland and storage pond area requirements. Asset batters of 1 in 6 up are proposed for a height of 1.95 m above asset base to provide sufficient cover for incoming stormwater pipes and sufficient volume (above wetland TED) for flood retardation storage and freeboard (600mm) above peak flood water level for the 1% AEP event.

4 Groundwater assessment

The groundwater assessment is used to identify the potential for, and magnitude of, water table mounding beneath the Merrimu Plateau, assuming stormwater is disposed via infiltration from localised assets (rather than widely distributed infiltration areas). Note that infiltration describes the overall process of water percolating downwards through the ground and towards the water table (the zone below which the aquifer is completely saturated). Stormwater injection bores are the engineering mechanism used to deliver stormwater from the plateau surface to the underlying aquifer where it then percolates downwards. Injection bores are necessary to bypass the very low permeability basalt soils that cap the Merrimu Plateau.

The groundwater assessments comprised two complementary assessments:

1. A preliminary assessment of the feasibility for an infiltration disposal option consisting of 11 injection bores located across the plateau (assessment 1).
2. A preliminary optimisation for the location of the injection bores. Two alternative layouts for injection bores were assessed (assessments 2 and 3). Each of those alternative injection well layouts also included an assessment of the impact of using multiple injection bores at each injection site (assessments 2b and 3b).

Two groundwater bores and a simple groundwater model have been developed to evaluate the pre-feasibility of a stormwater infiltration option to the Werribee Formation via injection bores. The feasibility assessment is preliminary, as simplifications have been adopted for the representation of the Werribee Formation aquifer. The preliminary assessment aims at evaluating if it is reasonable to include the injection bores option in planning for management of stormwater at the site. In which case, recommendations for model refinement will be made. The groundwater model is built to estimate mounding at the water table generated by the infiltration of stormwater via injection bores and to assess if mounding could cause the outcropping of the water table at the ground surface. It is considered that the increase of groundwater levels to ground surface would be an adverse effect as it may cause erosion along the slopes of the plateau or water logging elsewhere.

This section summarises relevant background context of groundwater dynamics beneath the Merrimu PSP area, findings from the borehole installation and the groundwater modelling results. All groundwater assessments are described in greater detail in Attachment A. Note that the term managed aquifer recharge is synonymous with disposal of stormwater via infiltration for the purposes of this investigation.

4.1 Background review

A desktop review of the geology and hydrogeology of the Merrimu Plateau was undertaken by CDM Smith in April 2021 using publicly available information (as part of Phase 2 investigations). This review developed a desktop hydrogeological conceptual model for the site, which is summarised below:

- **Geology.** The surface geology comprises thin Quaternary sediments and Newer Volcanics basalt up to 20 m thick. These are underlain by Werribee Formation (sand, silt, clay and gravel) up to 90 m thick above Ordovician and Permian aged fractured rock basement.
- **Hydrostratigraphy.** The Quaternary sediments and basalts on the plateau are unsaturated, with the water table likely residing in the Werribee Formation (making the Werribee Formation an unconfined aquifer across the plateau). The Werribee Formation is a regionally important aquifer with good yields and low salinity, extending from the site to Port Phillip Bay. The basement rocks form a fractured rock aquifer that is unconfined where it outcrops and is confined where it is overlain by younger units. The basement aquifer is generally a poor yielding aquifer.
- **Groundwater depth and flow direction.** Regional groundwater flow in the Werribee Formation aquifer is most likely south-easterly, towards Port Phillip Bay. Groundwater elevation data sourced from State Observation bores (mostly located in the adjacent valleys) supports this and suggests depth to groundwater in the valley is between 2 m and 20 m, sometimes effected by pumping in the Werribee Formation. Depth to groundwater across the plateau is unknown.
- **Groundwater salinity.** The groundwater quality of the Werribee Formation aquifer is likely to be brackish, with local bore data indicating an average salinity of ~1,900 mg/L TDS

This desktop review suggested the site would be suitable for managed aquifer recharge of stormwater with the Werribee Formation being the primary target aquifer. Further investigative work was recommended consisting of exploration bores in the southern half of the plateau aiming to support the conceptualisation with regards to aquifer extent, aquifer thickness, depth to groundwater and groundwater quality – this report summarises the outcome of those further investigations.

4.2 Borehole installation and findings

Based on the recommendations from the desktop review, site investigations were undertaken to better understand the geology and hydrogeology across the Merrimu Plateau and suitability of the Werribee Formation as a target aquifer for managed aquifer recharge. Three groundwater monitoring wells were proposed in the south of the plateau to target the Werribee Formation, with the aim of penetrating the full thickness of the Werribee Formation (1 x deep bore) or installing below the water table (2 x shallow bores). Bore locations were selected based on expected geology as well as access and landholder constraints.

During drilling of the first location (the deep bore), the depth to basement was greater than expected, and no water table was encountered within the Werribee Formation. Shallower bores would not provide useful information for the conceptual model if they wouldn't intercept the water table, and therefore two deep wells were drilled to provide full thickness data for the Werribee Formation.

The two (2) new groundwater monitoring bores were installed by Star Drilling Pty Ltd under the supervision of a CDM Smith engineer between 16 May and 26 May 2023. Sonic drilling method was used to progress the two boreholes in order to accurately record geological contacts. Dial before you dig (DBYD) plans were reviewed prior to drilling and service clearance was obtained before breaking ground. The final bore installations were surveyed by a licensed surveyor (Heading Surveyors) on 28 June 2023. The bore details are shown in Table 1-1, photos of final well installations are shown in Figure 12, and the locations shown in Figure 13.



Figure 12. Left- GW01 final installation and, right- GW03 final installation.



Figure 13. Locations of GW01 and GW03

Encountered Geology

The geology aligns broadly with the mapping for the area: Newer Volcanics Basalt overlying Werribee Formation sand, gravel and clay overlying Castlemaine Formation Siltstone basement rocks. The Newer Volcanic Basalts at the site consist of hard and fractured blue basalt with occasional clay layers. The unit is between 10 to 14 m thick at the drilled locations and is overlain by a topsoil consisting of brown sand.

The regional 3D geological mapping for the area (the Victorian Aquifer Framework – VAF) indicates thickness of Werribee Formation between 4 and 53 m at the drilling locations. GW03 was progressed first and indicated a thicker Werribee Formation than predicted from the VAF (74.5 m compared to 53 m). Nearly 50 m of Werribee Formation was encountered at GW01 compared to the VAF thickness of 4 m. The Werribee Formation consists of sand with layers of clay and gravel. The Werribee Formation at GW03 contains more clay layers and clays of greater thicknesses (up to 9.7 m) than those seen in GW01 (up to 2.5 m). There are also some clay layers in the formation that contain small amounts of coal. The drilled thicknesses are shown in Table 13 and photos of the various lithologies in **Figure 14**.

Table 13. Encountered geology in boreholes

ID	Depth to top of basalt (m)	Depth to base of basalt (m)	Depth to basement (m)	Thickness of Werribee Formation (m)	Depth and thickness of main clay layers in Werribee Formation (m) [thickness in m]
GW01	2.0	15.8	65.0	49.2	18.0-20.5 [2.5], 23.0-23.8 [0.8], 41.0-43.3 [2.3]
GW03	3.8	13.8	88.3	74.5	14.8-16.3 [1.5], 20.0-20.8 [0.8], 21.5-31.2 [9.7], 37.8-40.0 [2.2], 43.0-44.4 [1.4], 47.5-56.6 [9.1], 59.0-61.5 [2.5], 65.0-68.0 [3.0], 84.0-85.7 [1.7], 87.0-88.3 [1.3]



Figure 14. Left to right: Basalt, Werribee Formation sand, Werribee Formation gravel, Werribee Formation clay, Werribee Formation coal and Basement (siltstone).

Groundwater conditions

The bores were developed using airlift technique on 25th May 2023. At GW03 the drilling fluid was removed from the well and no further water entered the bore. A groundwater level measurement taken one week later indicates the groundwater is below the base of the screen (i.e. the bore is effectively dry). GW01 was developed for 90 minutes with an initial good flow whilst drilling fluid was ejected, slowing to a trickle of water for the remaining 80 mins. A total of 115 L of water was evacuated from the well (100 L of that predicted to be water introduced during drilling). Final field chemistry readings for GW01 show a pH of 8.7 and an electrical conductivity of 593 $\mu\text{S}/\text{cm}$. This is a lower salinity than would be expected for such a deep water table and may be indicative of mixing of drilling water with the groundwater.

The monitoring wells were dipped using a Solinst Interface meter on 28 June 2023. GW01 recorded a depth to groundwater of 72.84 m, GW03 was dry. This equates to a water table elevation of 107.8 m AHD at GW01 and >94.5 m AHD at GW03.

4.3 Updated groundwater conceptualisation

The results of the drilling have provided updated information to inform the conceptualisation of the hydrogeology at the site. The conceptualisation is summarised below.

Geology and Hydrostratigraphy

The geology and hydrostratigraphy of the Merrimu Plateau are shown in Table 14. The drilling has confirmed a thicker sequence of Werribee Formation in the area, extending further north than the regional aquifer mapping (VAF) would suggest.

The Bacchus Marsh geological map includes a cross section through the plateau (Figure 15) and indicates the Werribee Formation is present beneath the majority of the plateau, extending north to a fault located within the Merrimu Reservoir. This map suggests the basement high results in a thinning of the Werribee Formation to around 15 m in the area of GW01. The drilling indicates a thicker sequence at this location.

Table 14. Hydrostratigraphy of the Merrimu Plateau

Geological unit	Depth and thickness	Lithology	Hydrogeological characteristics
Quaternary Sediments	0 to 4 m bgl (2 - 4 m thick)	Sandy/gravelly clay	Unsaturated on the plateau, low permeability potentially restricting recharge – rainfall will likely form runoff or be evaporated from the surface and/or from the shallow soil
Newer Volcanics Basalt	2 to 17 m bgl (10 - 15 m thick)	Hard blue basalt with layers of sandy clay and clayey sand (weathered basalt)	Unsaturated on the plateau, fractured basalt will transmit water, competent basalt and clay layers will impede recharge
Werribee Formation	14 to 88 m bgl (46 - 74 m thick)	Sand, sandy clay, clayey sand, clay, gravel, some cemented sand layers, coal	Unsaturated at the drilled locations, suspected unsaturated across much of the plateau based on the elevations encountered during drilling. Infiltrating water will flow through the sand layers but may be impeded by clay layers. This layering introduces a high degree of anisotropy.
Ordovician Bedrock	More than 63 or 88 m bgl	Fine grained siltstone and weathered siltstone	Partially saturated beneath the plateau, hard rock with low permeability.

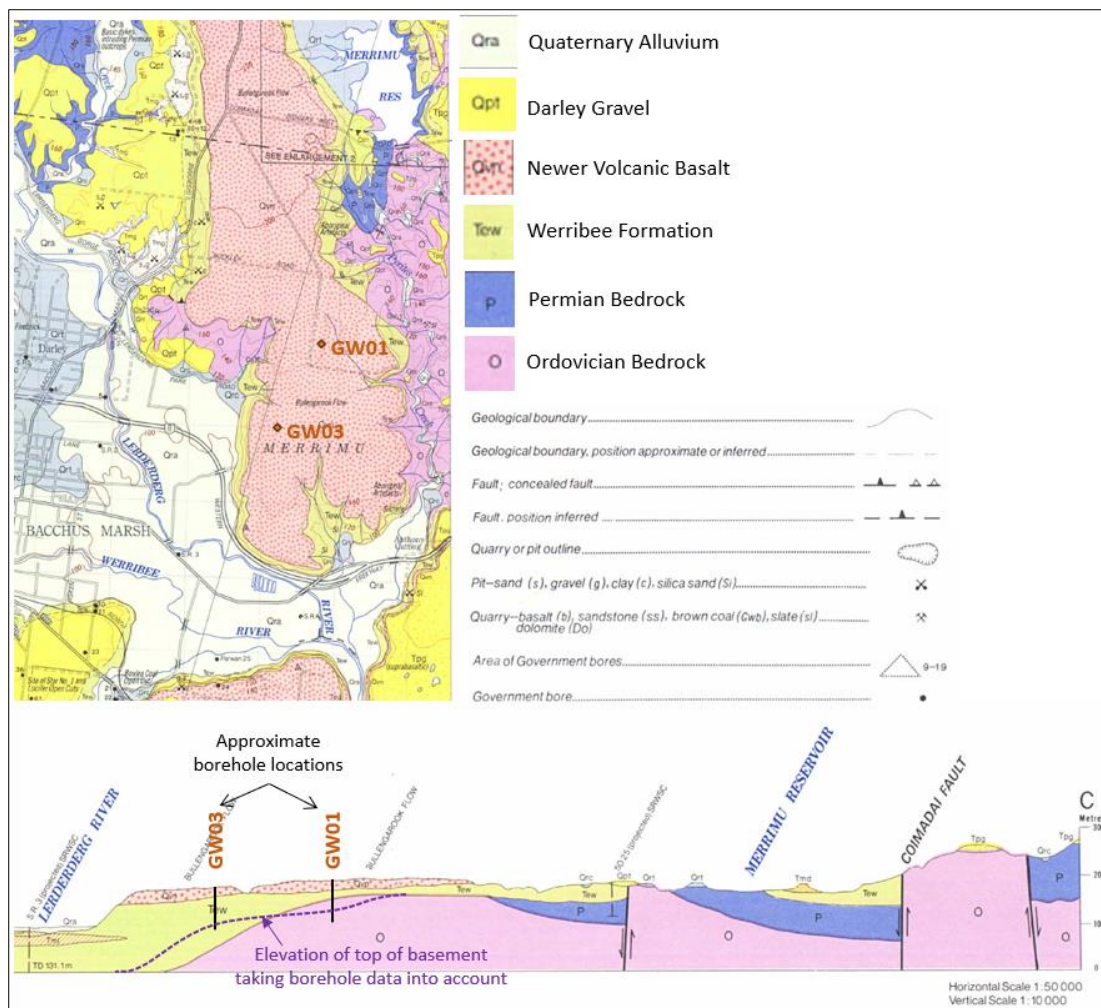


Figure 15. Extract from Bacchus Marsh geological map (GSV, 1985)

Groundwater levels and flow

The Quaternary Sediments, Newer Volcanics Basalt and Werribee Formation appear to be unsaturated across the plateau, with a deep water table potentially contained within the Basement rocks. At GW03, the water table is deeper than the base of the screen, which is located below the level of the adjacent valley floor (screen base 95 m AHD compared to valley to the west at 100 m AHD). The water table elevation is measured in the valley in a number of state observation bores to be around 97 m AHD to the west of GW03 and 94 m AHD to the southwest of GW03. Water table elevation usually reflects a subdued version of the topography, and therefore a higher water table would be expected under the elevated plateau. A lack of water table at GW03 (i.e. >94.5 m AHD) indicates either a low rate of recharge across the plateau, a high permeability of Werribee Formation sediments (allowing for groundwater transport away from the plateau) or a combination of these factors.

The site is located in the upper groundwater catchment for the Werribee Formation, which extends to Port Phillip Bay. Groundwater is likely to flow to the southeast.

Aquifer testing was not undertaken at the site due to the lack of groundwater encountered in the bores. Documented aquifer properties for the four aquifers that occur in the study area are summarised in Table 15.

Table 15. Aquifer Hydraulic Properties.

Aquifer	Thickness (m)	Transmissivity (m ² /d)	Hydraulic Conductivity (m/d)	Storativity	Porosity	Well Yields (L/s)
Quaternary alluvial aquifer	<5 ^[3]	-	-	-		-
Volcanic Plains aquifer	~20 ^[3]	<50 – >300 ^[2]	0.09 to 20 ^[2]	<0.03 - >0.05 ^[1]		0.4 – 40 (average <1.2) ^[2]
Werribee Formation aquifer	<90 ^[3]	50-110 ^[4]	3 to 8 ^[4]	0.0002 to 0.00035 ^[4]	30%	0.6 – 30 ^[2]
Basement aquifer	n/a	<50 ^[1]	0.001 to 0.56 ^[2]	0.02 – 0.05 ^[1]		Generally <0.6 ^[2]

Notes: “-” denotes no data available

1. Dahlhaus et al. (2004)
2. Leonard (2006)
3. DELWP (2012)
4. Stuyfzand & Osma (2019)

Implications for Managed Aquifer Recharge

The Werribee Formation encountered in the drilling program shows attributes which mean it would be suitable as a target for a Managed Aquifer Recharge scheme, including:

- A thick unsaturated zone is desirable at a managed aquifer recharge scheme as it provides a lot of potential storage for recharged water. However, given the plateau has steep drop offs to the east, south and west, the large storage is restricted to the plateau footprint.
- Although there is a degree of heterogeneity in the formation, the sand and gravel units encountered are thick and the grain size is large, suggesting a good degree of storage and high transmissivity. Some thick clay layers were encountered, which would impede vertical migration of infiltrated water. However, appropriately design recharge bores (i.e. large diameter targeting the sand and gravel layers) instead of surface infiltration, will maximise the recharge potential.
- The large grain size also reduces the potential for aquifer clogging during injection, as does injecting into the unsaturated zone. Appropriate treatment to remove suspended sediments and any potential pollutants (as this location is at the top of the groundwater catchment and the aquifer is heavily used lower in the catchment) will reduce the risk of clogging or aquifer pollution.

4.4 Groundwater modelling approach and methods

Groundwater modelling undertaken for this Phase 3 investigation has been completed at a pre-feasibility level and relies on complementary assessments. The methodology for the respective assessments is outlined below:

- **Assessment 1: Well localisation optimisation.** This assessment process uses the model to estimate mounding in the Werribee Formation aquifer from a single injection bore and compares it with the map of the depth to water table. If the mounding exceeds the depth to water table, the process records the magnitude of the breach by summing the exceedance (i.e., by how many meters the predicted mounding exceeds the depth to water table) over all the model cells that have been breached. The exceedance amount is then attributed to the injection bore location. The process is repeated automatically for a new injection bore location and repeated hundreds of times until the whole plateau has been assessed. The several hundreds of resulting exceedance magnitudes are then

expressed as exceedance percentile to produce the final map. On this map, the case where there is no exceedance will be evaluated as the most favourable location. For the cases where mounding does exceed depth to water table, the case where the mounding exceeds the depth to water table only marginally across a small area will be evaluated more favourably than the case where the mounding vastly exceeds the depth to water table and over a larger area. The methodology is illustrated on Figure 16.

- **Assessment 2: Preliminary feasibility of 11 injection wells.** This assessment process uses the numerical groundwater model to estimate the mounding in the Werribee Formation aquifer from the simultaneous injection of stormwater at 11 well locations. This mounding is then compared to a map of depth to water table (map sourced from the Victoria State-wide Watertable Mapping (SKM, 2010)). This assessment consists of estimating if and where the resulting groundwater level may reach ground surface (i.e. if mounding is greater than the depth to water table, groundwater may be expressing at the surface). The locations and injection rates for each well in this part of the assessment were provided by Alluvium. These rates and locations are derived from Alluvium's assessment of injection requirements based on the modelling of surface water runoff for each sub-catchment.
- **Assessment 3: Preliminary feasibility of alternative injection well arrangement.** This assessment uses the numerical groundwater model in the same way as Assessment 2, with rates and locations for injection bores provided by Alluvium that reflect an alternative well arrangement. This alternative well arrangement uses the analysis described in Assessment 1 to select the locations more suitable for injection and transferring surface runoff across catchments. This means that runoff from sub catchments 1-5 is transferred (via pumping) to sub-catchment 6 for injection at sub-catchment 6.

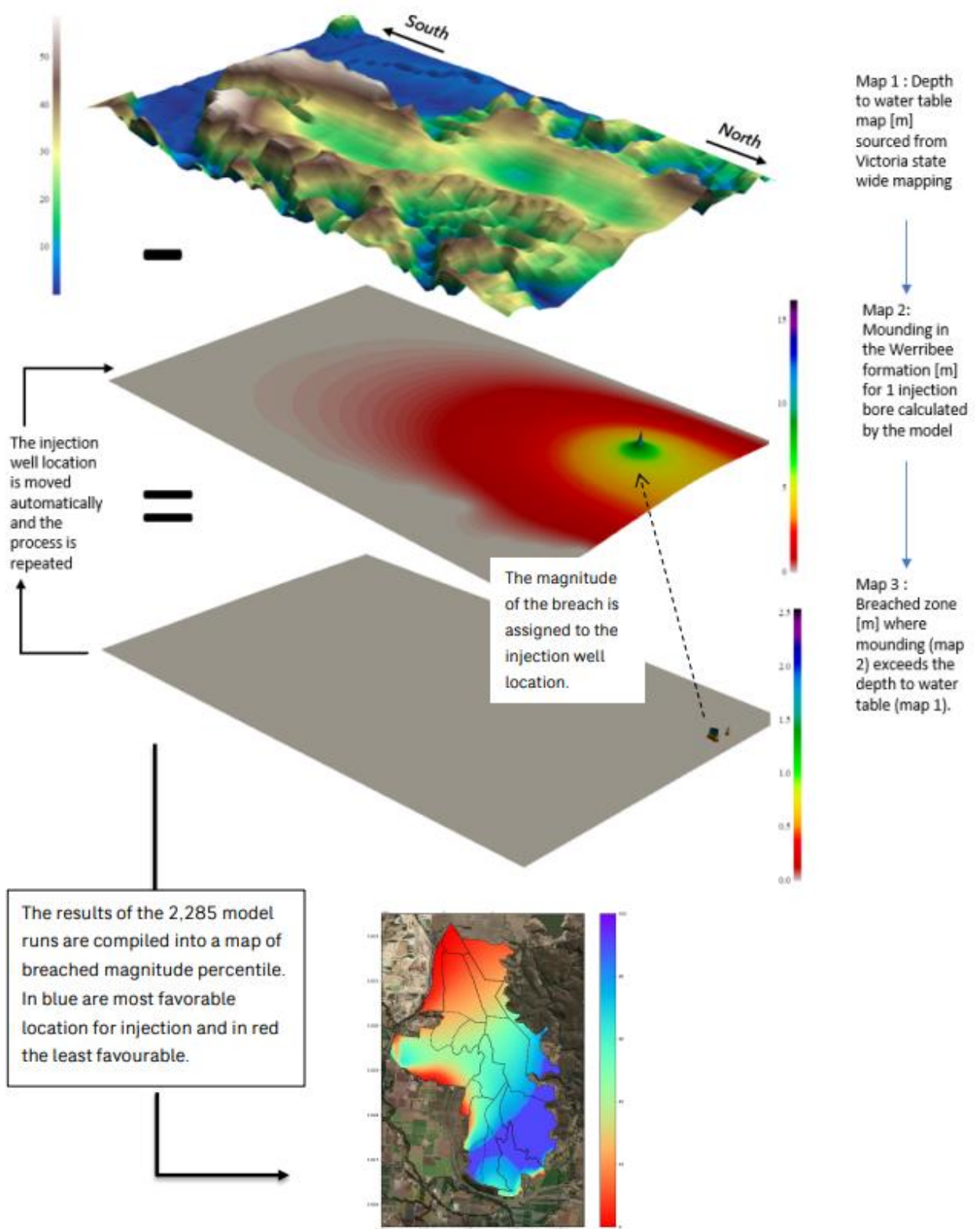


Figure 16. Assessment 1 (injection location optimisation) methodology.

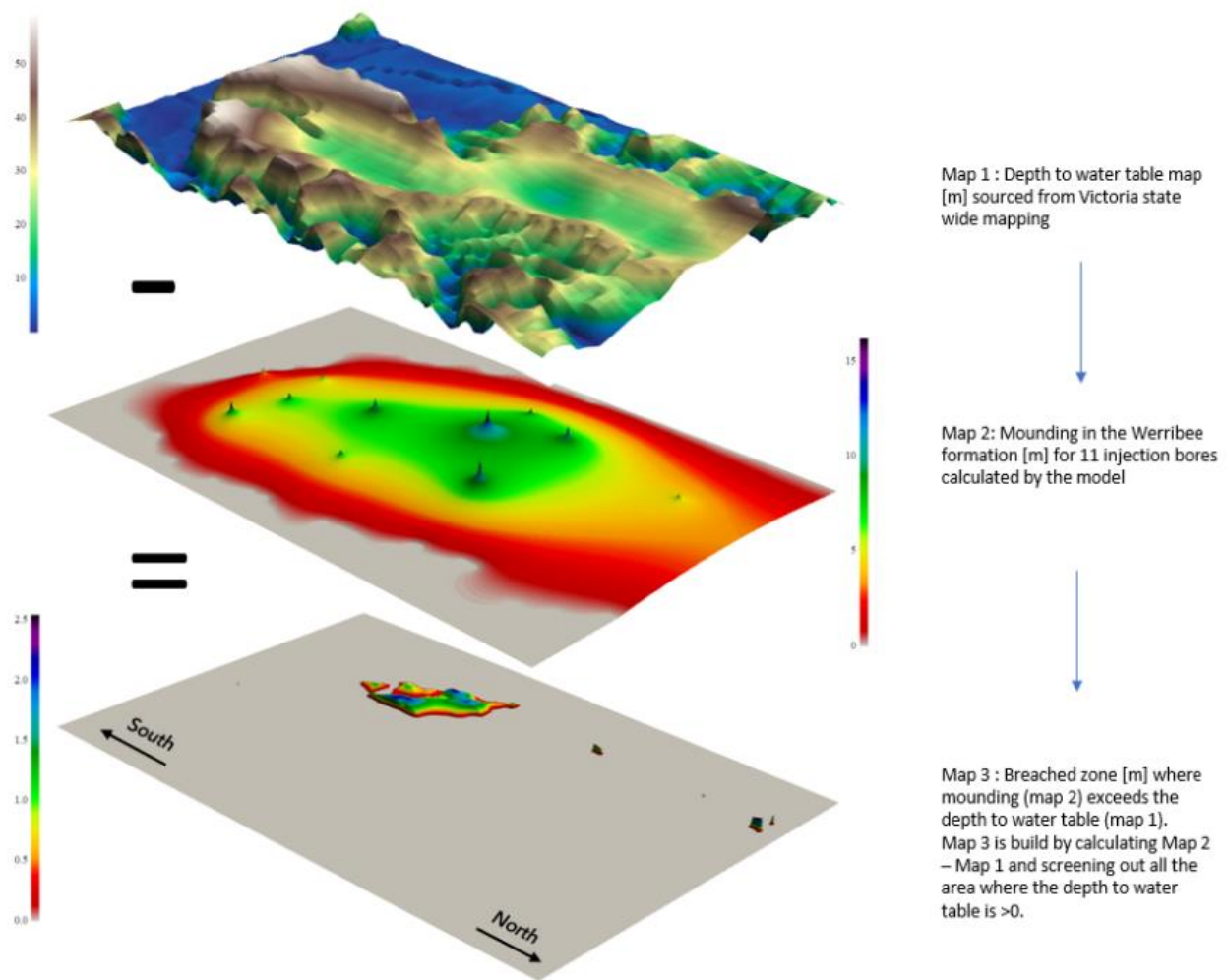


Figure 17. Assessment 2 and 3 methodology.

4.5 Groundwater modelling results

Assessment 1: Well localisation optimisation

For the well location optimisation, the model was run 2,285 times with the injection wells covering the potential locations provided in Figure 18. The adopted injection rate for each well per run was set at 180 ML/yr, corresponding to the 85th percentile infiltration rate for the 11 proposed injection bores detailed in section assessment 2.

The results presented in Figure 19 show the percentile of the magnitude of the breach of ground surface from groundwater mounding. This method allows a sorting of the injection well locations smoothly from the optimum location (100%) to the least favourable (0%). The blue area shows the optimum location for placing an injection well. Injection wells placed within the blue zone didn't trigger any breaches in the model. Locations to the west are less optimal as water table is expected to be shallow over the western fields. Locations to the north are less favourable due to the proximity of the quarry and the pinching of the aquifer to the north, which render the mounding in this area more pronounced.

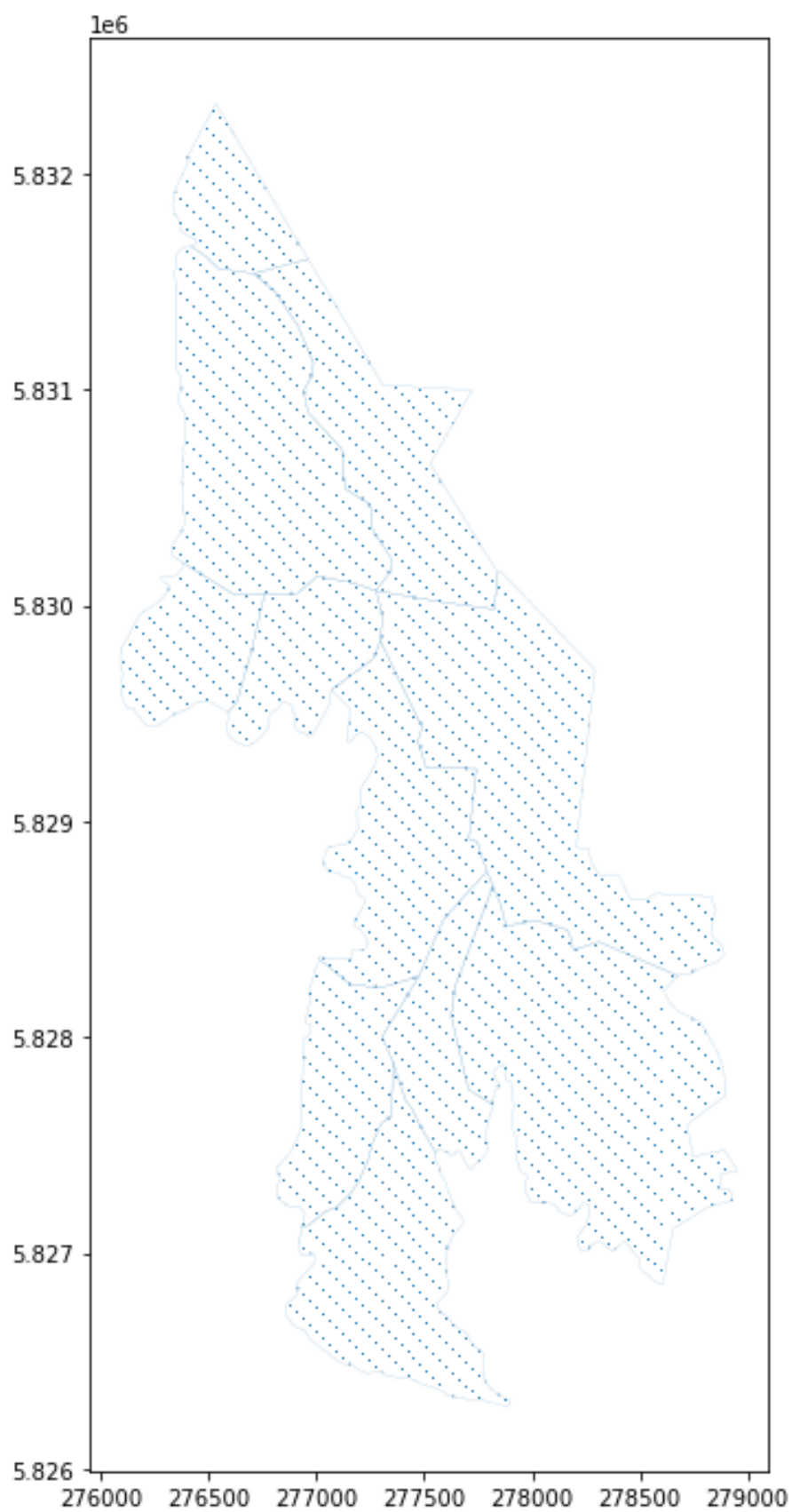


Figure 18. Injection wells location assessed.

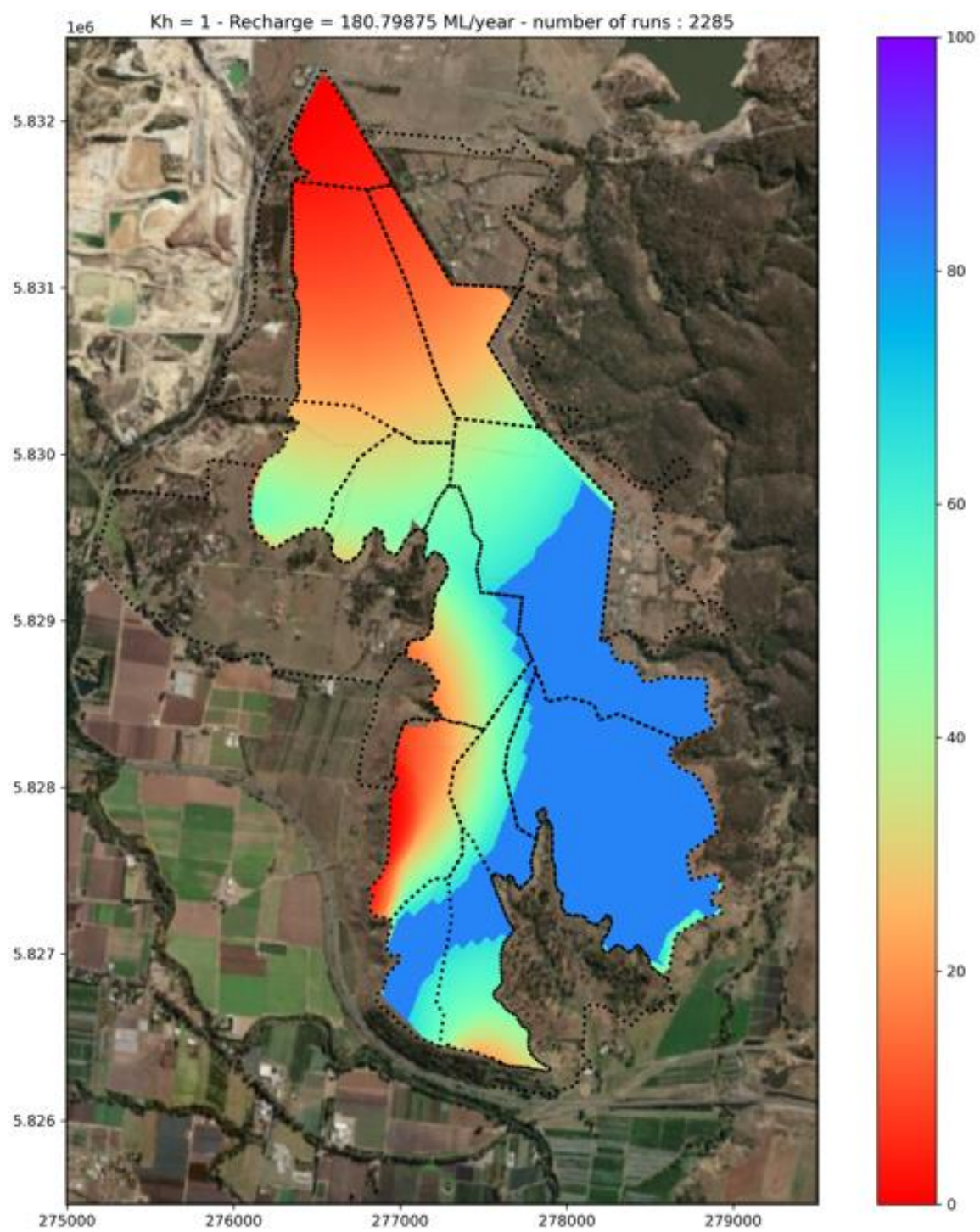


Figure 19 Injection well localisation optimisation

Assessment 2: Preliminary feasibility of 12 injection wells

This scenario consists of 12 injection bores accounting for a total injection rate of 1,093 ML/year. The location of the injection wells is illustrated on Figure 20 and the individual infiltration rates are provided in Table 16. The rates were provided by Alluvium based on surface water modelling across the plateau sub-catchments.

The resulting mounding from injection at the 12 injection wells is illustrated in Figure 21. Calculated mounding is up to 15 m at bore 2 and averages approximately 4 m beneath most of the plateau. The maximum mounding occurs at injection bore 2 due to higher injection rate and interference with nearby injection bores 4 and 5.

Figure 22 illustrates the breaching of the ground-surface by the mounding groundwater. The breached zones are the zones where the calculated mounding exceeds the estimated depth to water table, and hence the zone of potential groundwater outcropping. The breached zones are located on the western side of the plateau, primarily in the south-west area due to the widespread area of shallow water table (according to the statewide mapping). There is also a predicted breach of the ground surface to the northwest of the plateau due to assumed shallow water table within the quarry.

Table 16. Injection rate requirement by sub-catchment for Assessment 2

Sub-catchment	Sub-catchment area [ha]	Modelled stormwater injection rate [ML/yr]
1	26	55
2	103	205
3	65	133
4	33	70
5	30	65
6	92	166
7	59	122
8	41	86
9	47	97
10	34	73
11	17	10
12	17	10
Total		1,093

*Annual injection volumes in this table are based on MUSIC modelling outputs in section 3.

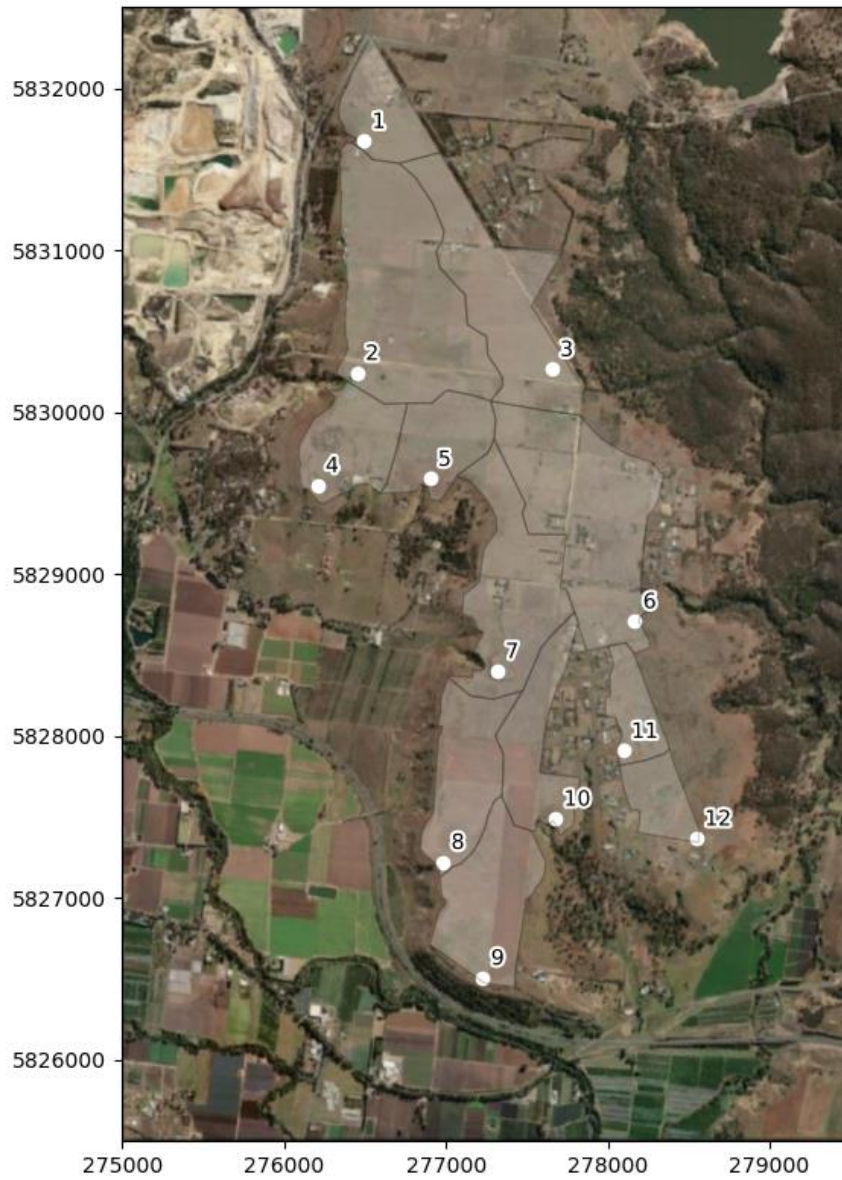


Figure 20. *Injection well locations for Assessment 2.*

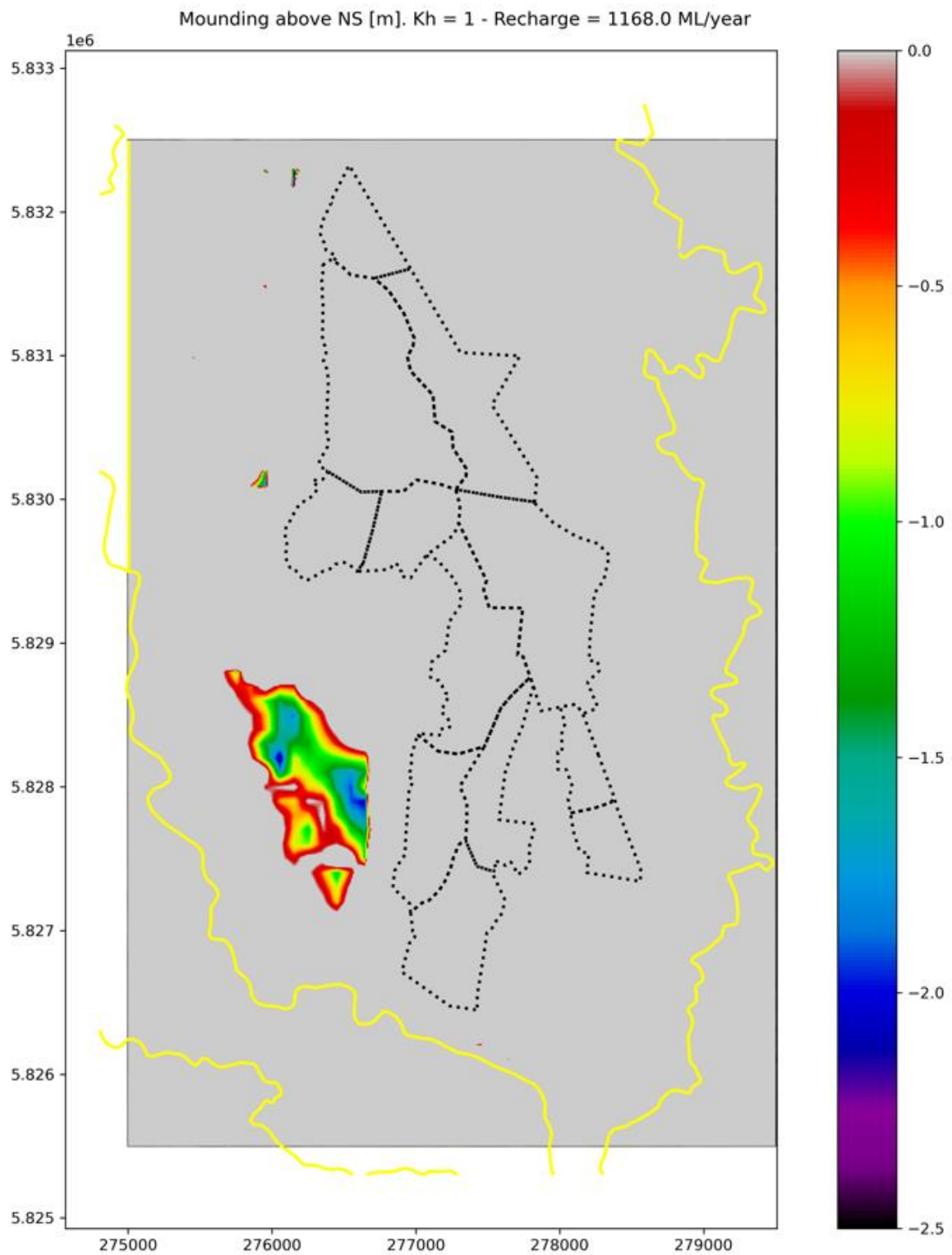


Figure 21. Calculated steady state mounding from the 12 injection wells (Assessment 2).

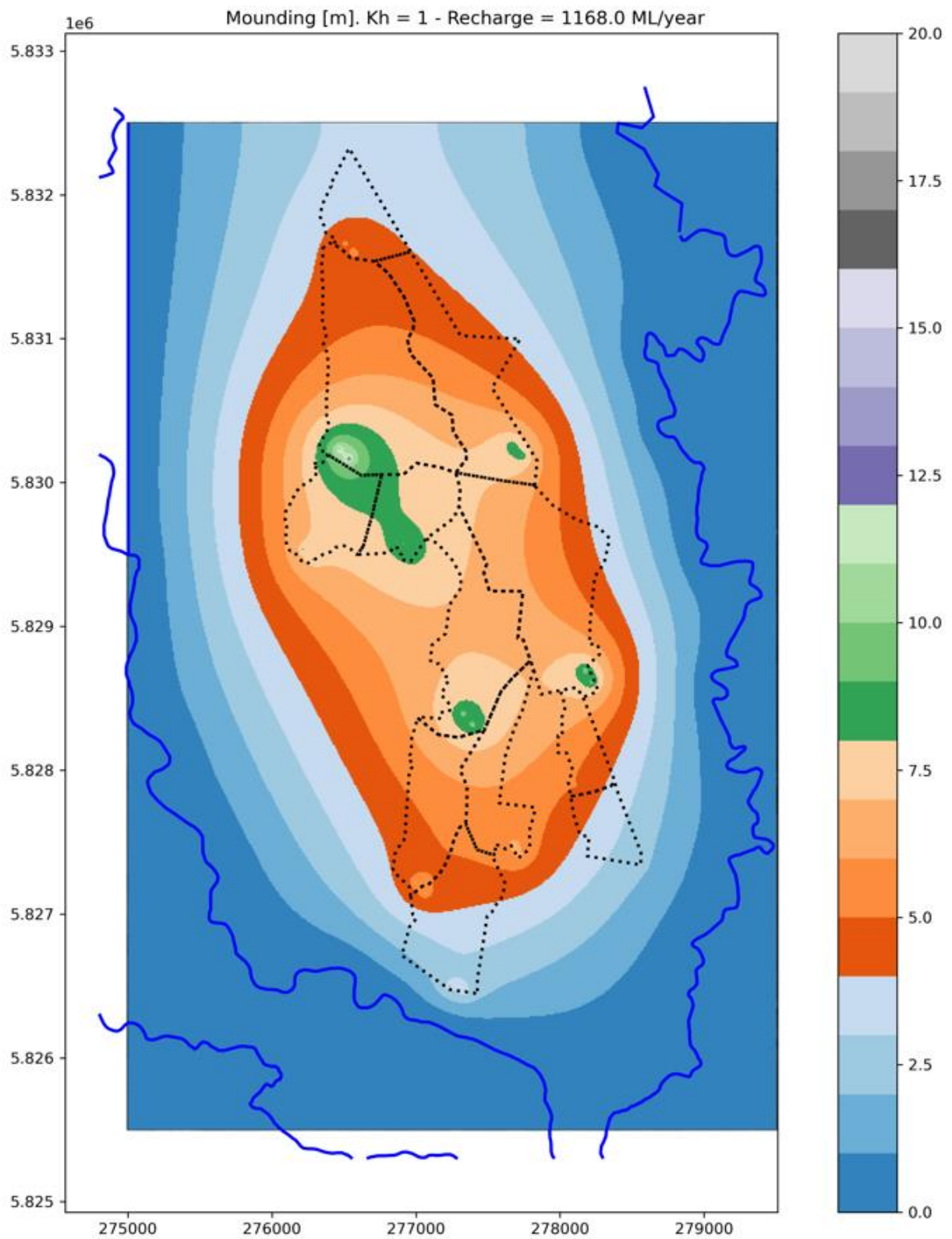


Figure 22. Zones of breached ground surface from mounding for Assessment 2.

Assessment 2b: Multiple injection bores at each injection site

The individual bore capacity may provide a limit to maximum injection rates, which would mean a larger pond storage is required as a buffer between maximum surface water flows and injection. A secondary Assessment 2 has been run to assess whether mounding changes when multiple bores are used at each injection site. The injection rates and bores numbers are provided in Table 17 below and results in Figure 23 and Figure 24. A bore spacing of 100 m was applied at sites with multiple bores. This assessment shows that multiple injection bores produce similar mounding effects across the catchment.

Table 17. Injection rates and bore numbers requirement by sub-catchment for Assessment 2b

Sub-catchment	Sub-catchment area [ha]	Modelled stormwater injection rate [ML/yr]	Number of bores
1	26	58	2
2	103	219	2
3	65	142	2
4	33	73	2
5	30	68	2
6	92	183	2
7	59	131	2
8	41	92	2
9	47	105	2
10	34	76	2
11	17	10	1
12	17	10	1
Total		1,168	22

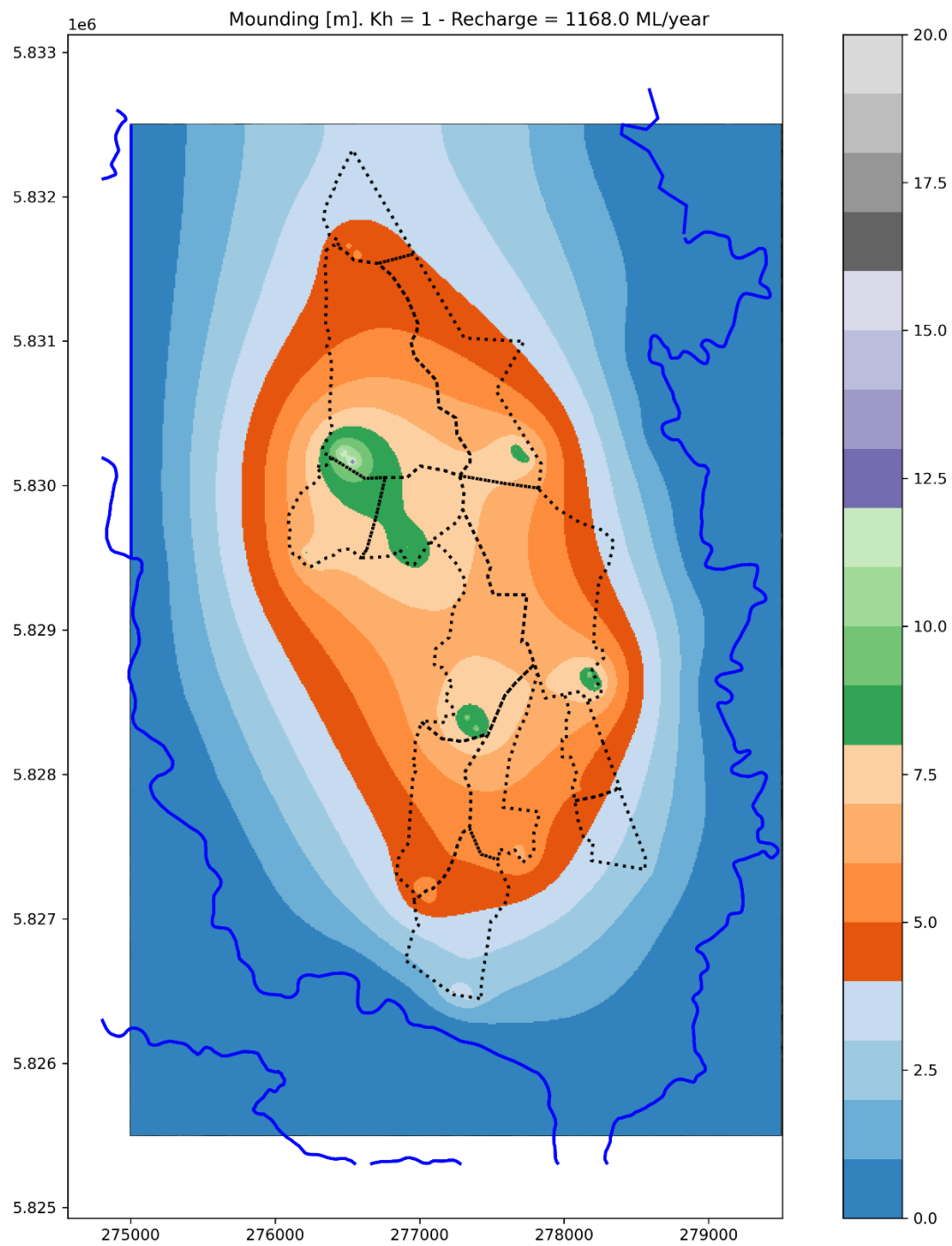


Figure 23. Calculated steady state mounding from the 22 injection wells (Assessment 2b).

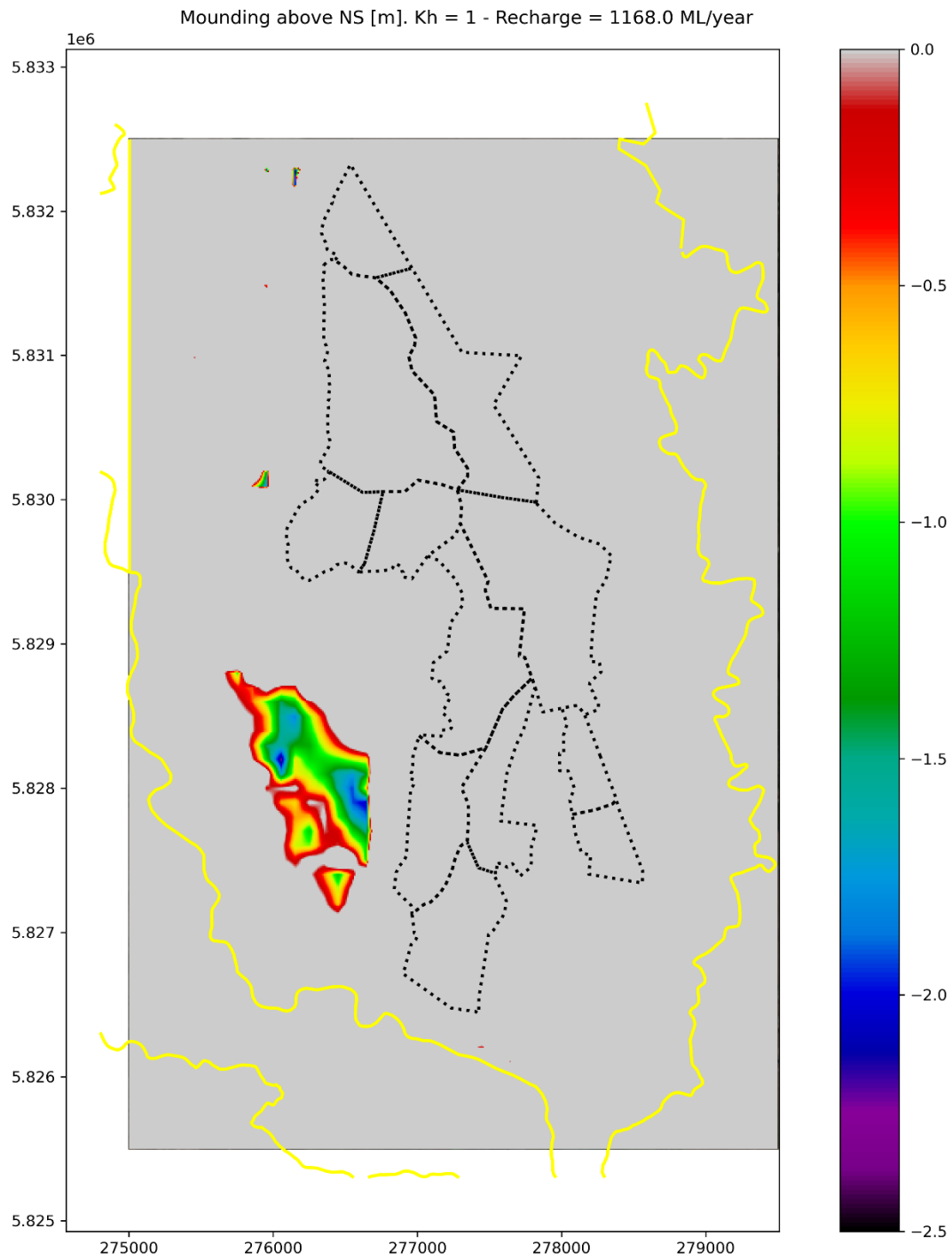


Figure 24. Zones of breached ground surface from mounding for Assessment 2b.

Assessment 3: Preliminary feasibility of alternative injection well arrangement

This scenario consists of 6 injection bores accounting for a total injection rate of 1,079 ML/year. The location of the injection wells is illustrated in Figure 25 and the individual injection rates provided in (Table 18). The rates were provided by Alluvium based on surface water modelling across the plateau sub-catchments, including transfer from less suitable catchments to more suitable catchments in terms of injection feasibility (as per Assessment 1).

The resulting mounding from the 6 injection bores is shown in Figure 26. The calculated mounding reaches over 20 m at bore 6, but with mounding much reduced in the north of the plateau due to the lack of injection in this location.

The areas where the watertable breaches the ground surface is shown on Figure 27. This figure indicates that the injection rate at bore 6 is higher than the capacity of the aquifer unsaturated zone can accept, with the watertable outcropping at the bore location. The modelled injection rate is around 20 L/sec, which appears to be above the aquifers capacity assuming a 1 m/day hydraulic conductivity. This is a relatively conservative hydraulic conductivity assumption and therefore bore capacity may be underestimated. A simple analysis has been undertaken to assess proposed maximum injection rates for the bores across the plateau. Assuming a hydraulic conductivity of 1 m/day and a high specific yield of 0.1 to account for the unconfined nature of the aquifer, a maximum injection rate of 10 L/sec is recommended at this stage of the assessment.

The other areas of outcropping watertable are in the southwest. The outcropping watertable in the northwest (in the location of the quarry) is less, with only a small spot of shallow outcropping occurring.

Table 18. Injection rate requirement by sub-catchment for Assessment 3

Sub-catchment	Sub-catchment area [ha]	Modelled stormwater injection rate [ML/yr]
1	26	-
2	103	-
3	65	-
4	33	-
5	30	-
6	92	685
7	59	-
8	41	203
9	47	97
10	34	73
11	17	10
12	17	10
Total		1,079

*Annual injection volumes in this table are based on MUSIC modelling outputs in section 3.

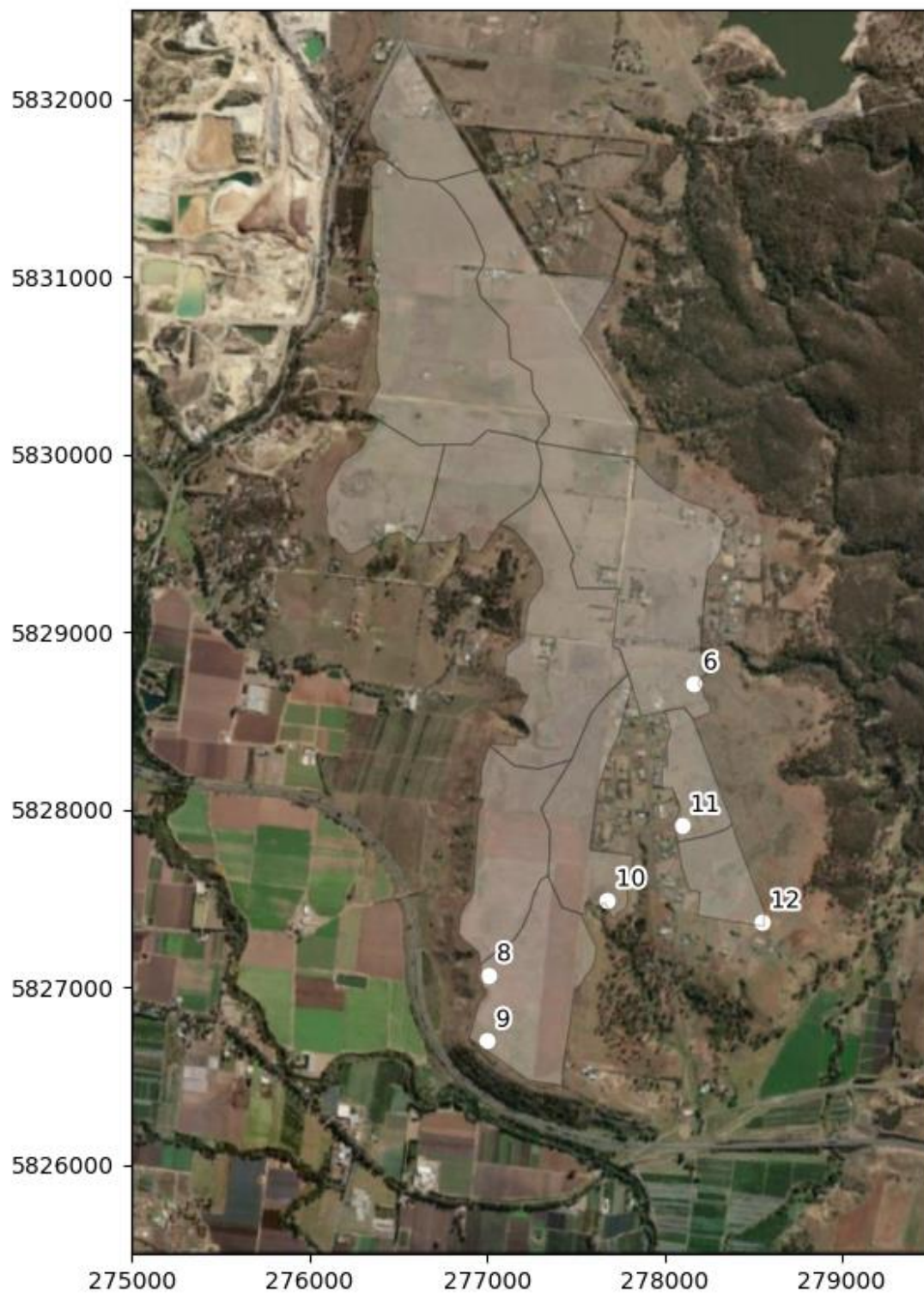


Figure 25. *Injection well locations for Assessment 3.*

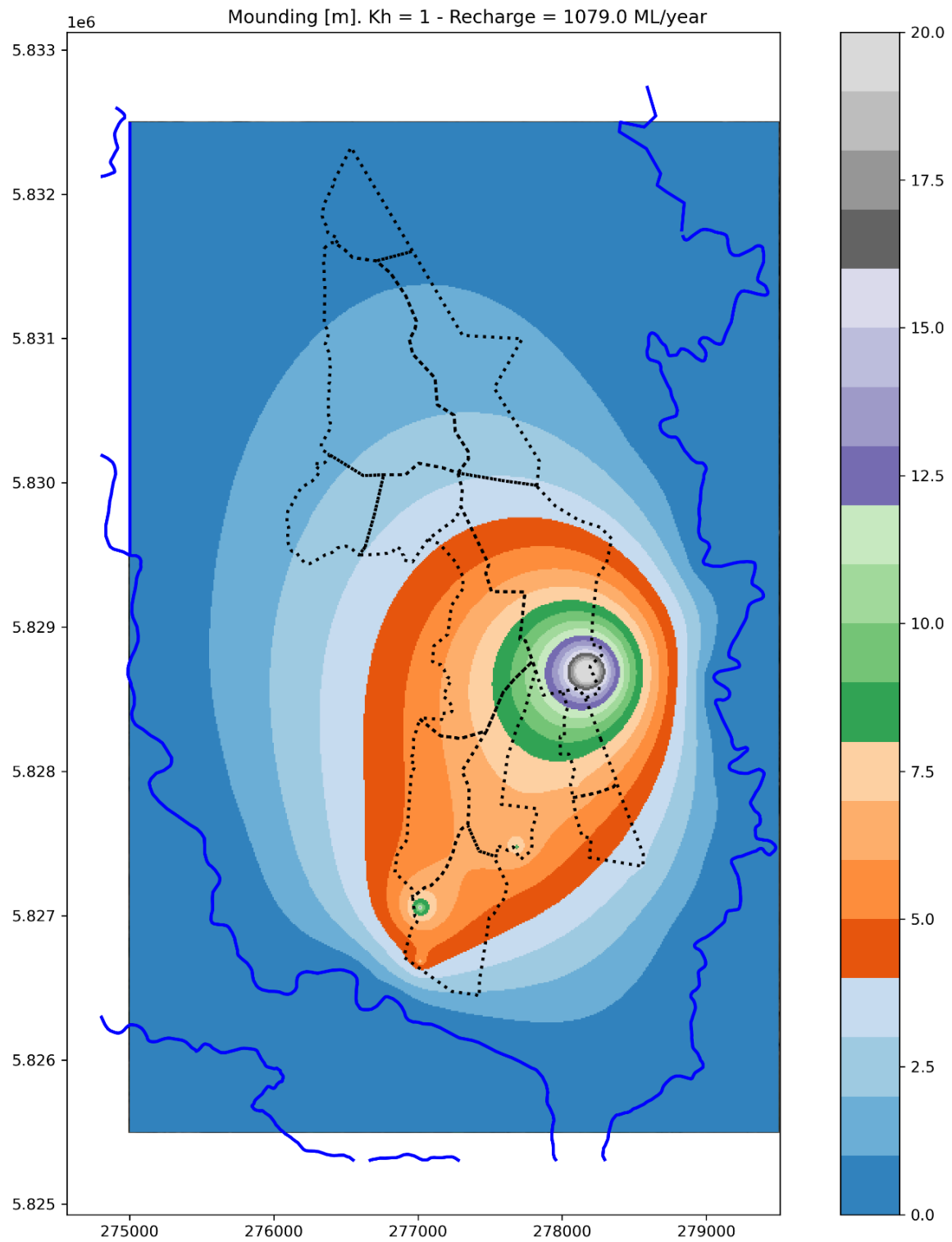


Figure 26. Calculated steady state mounding from the 6 injection wells (Assessment 3).

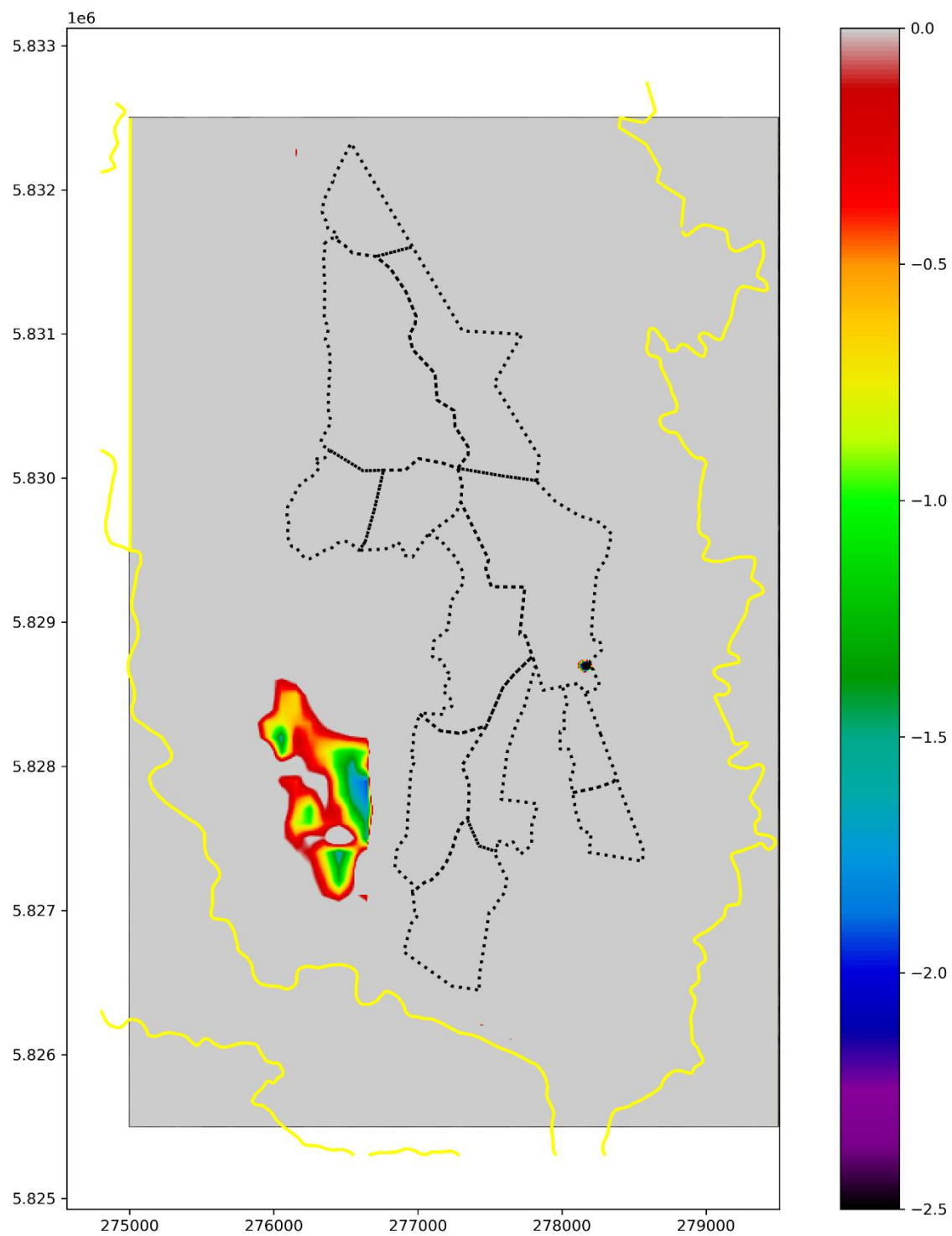


Figure 27. Zones of breached ground surface from mounding for Assessment 3.

Assessment 3b: Alternative well arrangement – multiple injection bores at each injection site

Assessment 3 shows that individual bore capacity limits the maximum injection rate a bore can achieve without causing overtopping at the bore site. A secondary Assessment 3 has been undertaken to understand the effects of splitting the injection rate between multiple bores. The injection rates and bores numbers are provided in Table 19 below and results in Figure 28 and Figure 29. The results indicate that splitting the injection rate between bores does not lower the overall mounding and there is still an overtopping effect in Catchment 6. This is likely due to the bore spacing of 100 m not being sufficient to avoid superimposition of the mounding. The degree of overtopping is less than when one injection well is used.

Table 19. Injection rate and bores number requirement by sub-catchment for Assessment 3b

Sub-catchment	Sub-catchment area [ha]	Modelled stormwater injection rate [ML/yr]	Number of bores
1	26	-	-
2	103	-	-
3	65	-	-
4	33	-	-
5	30	-	-
6	92	686	3
7	59	131	2
8	41	92	2
9	47	105	2
10	34	76	2
11	17	10	1
12	17	10	1
Total		1,100	13

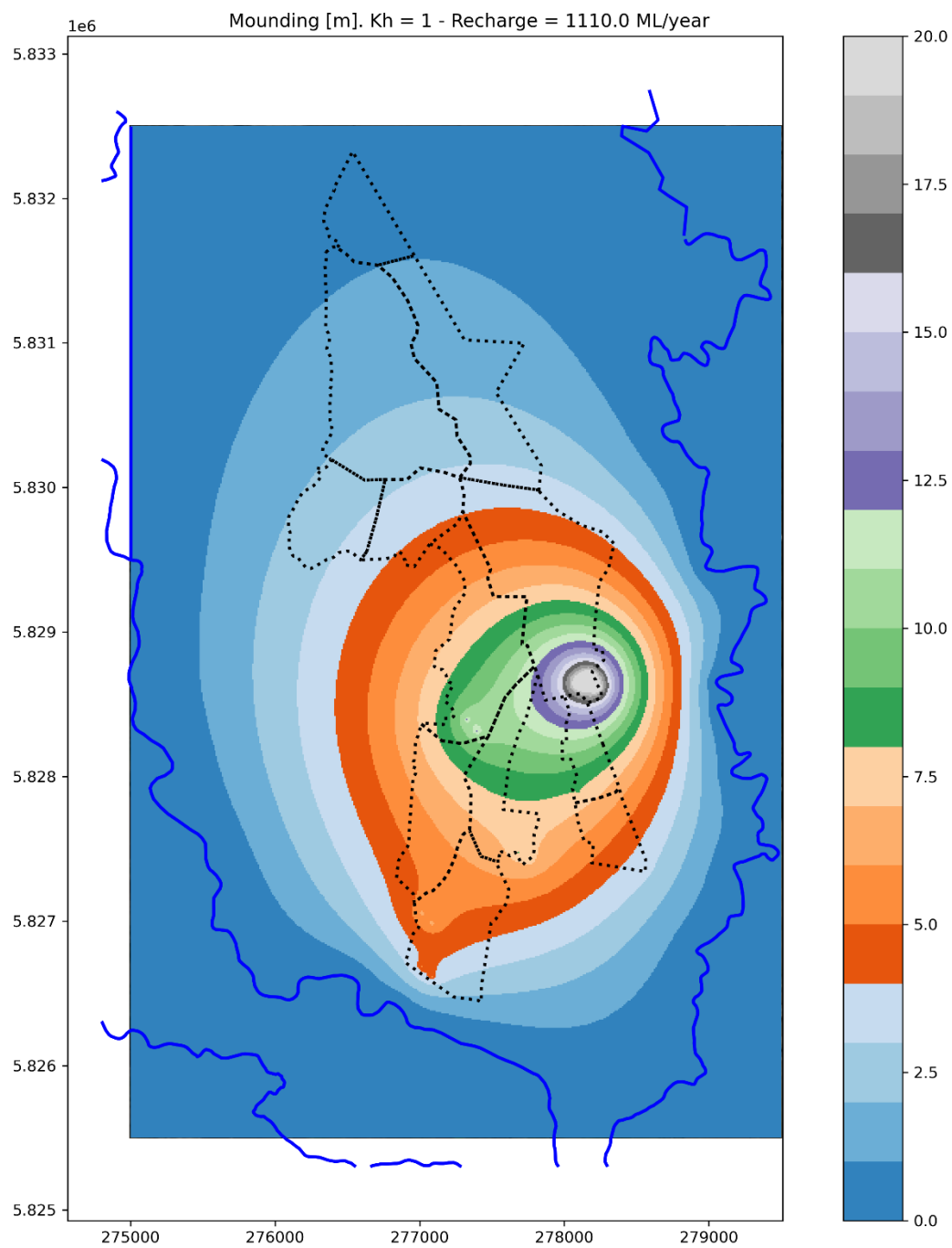


Figure 28. Calculated steady state mounding from the 13 injection wells (Assessment 3b).

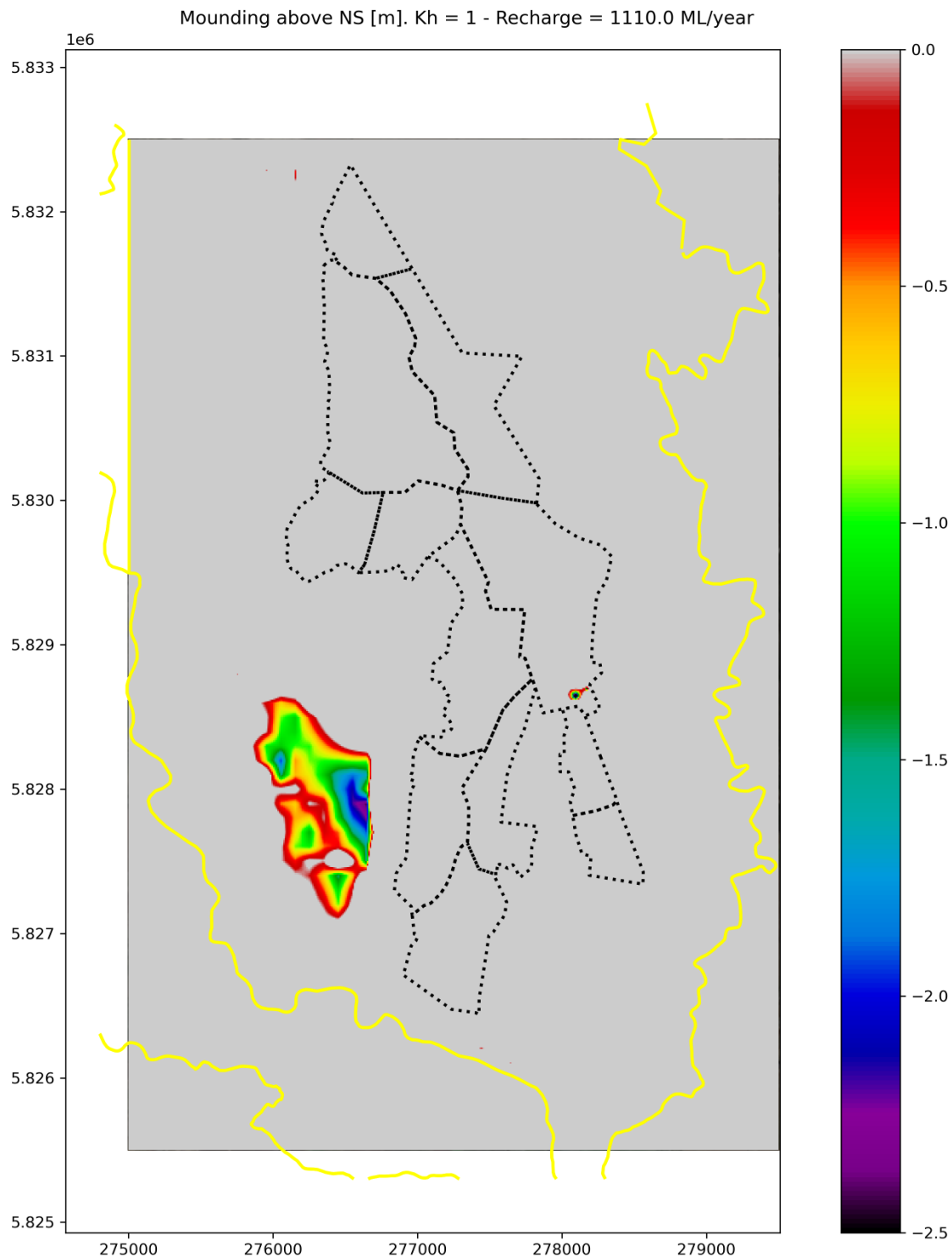


Figure 29. Zones of breached ground surface from mounding for Assessment 3b.

Sensitivity of results to horizontal hydraulic conductivity

The horizontal hydraulic conductivity of the Werribee Formation used in the above modelling has been set at 1 m/day. A conservative value was chosen given the lack of site specific data and the uncertainty associated with this parameter. There is limited local data to inform this parameter, however in Werribee values of 3 to 8 m/day (Stuyfzand & Osma, 2019) were established from pumping tests and injection trials (this is in an area of thick, confined Werribee Formation) and regional literature values include 5 to 15 m/day (Leonard, 2006) and 0.1 to 100 m/day (Dalhaus et al., 2004). As can be seen from these values, there is a large degree of uncertainty associated with this parameter.

To assess the sensitivity of the model results to horizontal hydraulic conductivity, Assessments 2b and 3b were run with a hydraulic conductivity of 2 m/day. The results are shown in Figure 30 and Figure 31 and indicate a degree of sensitivity, with mounding reduced beneath the plateau and limited outcropping of the watertable in the valley floor. These results highlight the importance of further work to understand the site specific characteristics of the Werribee Formation prior to feasibility level assessment.

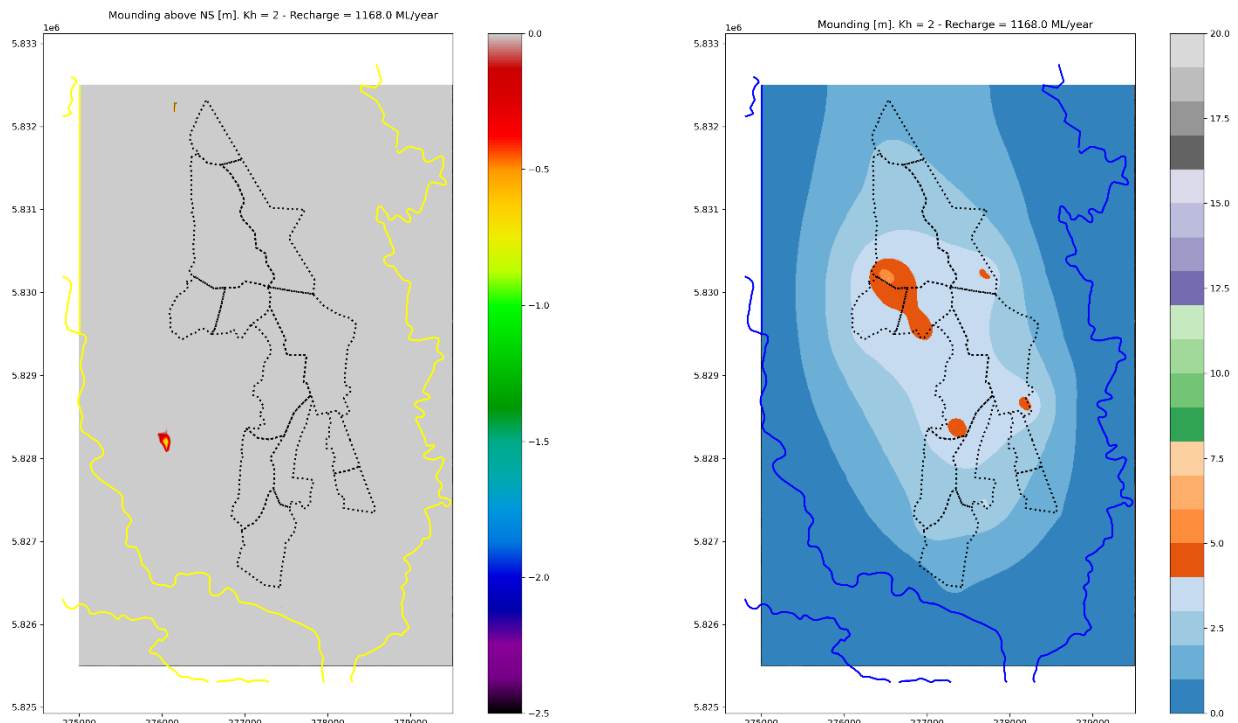


Figure 30. Scenario 2b run with a horizontal hydraulic conductivity of 2 m/day.

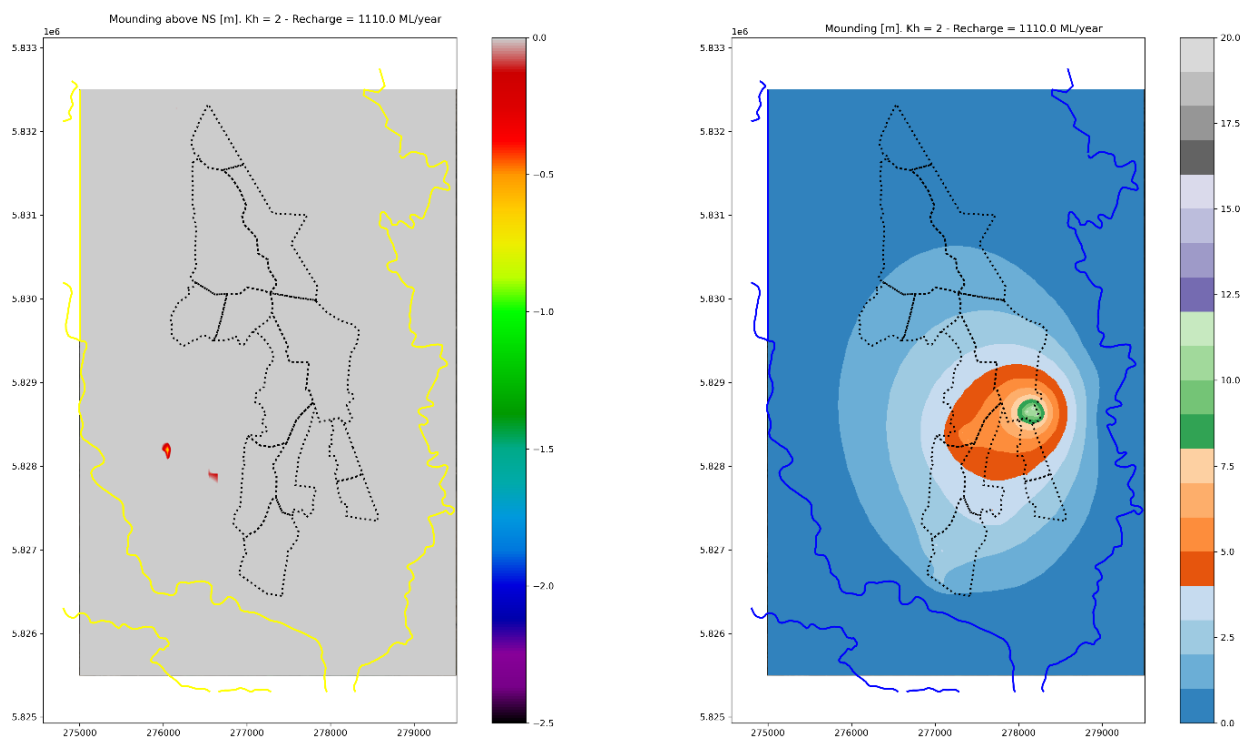


Figure 31. Scenario 3b run with a horizontal hydraulic conductivity of 2 m/day.

Groundwater modelling conclusions

The modelled assessments indicate the following:

- The optimisation assessment indicates that the south-east side of the plateau is more suitable for injection than the northern side. This is a consequence of the pinching out of the Werribee Formation to the north, the shallow water table along the south-west area and the presence of the quarry in the west, where water table is near or at the base of some pits.
- The assessment of the 12 injection wells indicate that the mounding of the water table could reach ground surface in several places to the west of the plateau (outside of the Merrimu PSP area). However, the assessment is conservative, and therefore is an overestimation of what is likely to happen and not indicative of the injection option being outright unsuitable. The pre-feasibility model results indicate that the pursuit of this option should be made with some caution, requiring a refined assessment to predict the aquifer response to injection more accurately.
- The assessment of the 6 injection wells (surface water transferred between catchments) shows that there is a limit to the rate of injection that one bore can accept (roughly 10 L/sec based on a simple analytical method). This assessment shows that by transferring water to the south of the plateau, outcropping of the watertable to the north (in the location of the quarry) can be avoided. However, there is still watertable outcropping to the southwest.
- Assessment 2b and 3b indicate that splitting the total injection volume between multiple bores may allow for greater maximum injection rates per catchment, meaning that smaller storages may be a feasible option.
- An assessment of the sensitivity of the model results to horizontal hydraulic conductivity indicate that the results are sensitive, and the initial results (presented in this report) are a conservative assessment. Understanding the site specific qualities of the Werribee Formation (thickness, extent and hydraulic conductivity) is key for any ongoing assessments of feasibility.
- One of the key limitations to this assessment is the use of the Statewide Depth to Watertable map, which, based on the drilling results, is inaccurate across the plateau.

5 Overall implications for stormwater management in the Merrimu PSP area

This section considers the overall implications the surface water and groundwater modelling results have on feasible locations for stormwater infrastructure. Additional studies are needed to more tightly define the conceptual stormwater asset layout, and the approach for stormwater injection to be employed (see section 6) in the Merrimu PSP area. Those more detailed studies can be used to determine injection well arrangement and number of bores at each injection site. The groundwater assessment indicates the occurrence of some off-site impacts (using the conservative modelling etc) which occur to the south-west of the Merrimu PSPS area. However, we have identified the following implications for stormwater management from the groundwater assessment:

- Disposing of stormwater via infiltration at injection sites across the plateau has the potential to lead to groundwater mounding that expresses at the land surface in an off-site location (i.e. outside the PSP area). The main affected area is the floodplain of the Lerderderg River to the south-west of the plateau and is shown in Figure 22.
- Groundwater modelling indicates that a uniform setback distance from the escarpment edge for all stormwater infiltration assets is not necessary. Instead, areas on the plateau where groundwater mounding has the potential to be high and to express at the surface should be avoided. Some sections of the escarpment also fall within the mounding-prone areas, but much of the escarpment does not and is much less prone to groundwater mounding expressing at the surface.

Considering the combined groundwater and surface water modelling results, we have summarised considerations for the DSS design below. Assuming an injection well arrangement where injection of stormwater occurs within each sub-catchment and multiple bores at each injection site (2 bores at each site for sub-catchments 1-10 and 1 bore at each site for sub-catchment 11), the land take for the stormwater management assets across the plateau (expressed as a proportion of the sub-catchment areas) is estimated to be 3.4% higher compared to the business-as-usual approach. Future investigations as part of feasibility assessment should look at optimising the storage pond volume and footprint requirements further which in turn will depend on developing better understanding of the specific qualities of the Werribee Formation (thickness, extent and hydraulic conductivity).

Based on asset sizing requirements for this pre-feasibility study, a conceptual layout for the stormwater management assets has been developed (see Appendix B). The investigation has assumed that each asset location would consist of a combination of three asset types:

- Stormwater treatment wetland
- Storage pond for collection of treated stormwater from the treatment wetland with injection by gravity into the Werribee formation using bores
- Retarding basin.

Given the requirement to retain 99 % of the average annual developed stormwater runoff volume, there will be times when the storage pond receives untreated stormwater (e.g. when treatment wetland design flows are exceeded). It is important that this forms part of future investigation on the implications for groundwater quality, and refinement to the stormwater management strategy undertaken if needed.

6 Pathway forward

The Phase 3 investigations summarised in this report have used a combination of surface water modelling and groundwater modelling to identify areas of the Merrimu PSP area where disposing of stormwater via infiltration has the potential to trigger mounding of the water table that is high enough for groundwater to express at the surface. The modelling has also identified areas within the PSP where disposal of stormwater via infiltration is far less likely to cause mounding of the water table that results in groundwater being expressed at the land surface.

The groundwater modelling undertaken in this project is at a pre-feasibility level, having adopted a range of simplifying assumptions. These simplifying assumptions have been used where the relevant model input data is either unavailable or where employing such assumptions was necessary to identify the envelope of water table elevations, i.e. the groundwater modelling established, at a high level, what areas of the PSP area are or are not likely to be suitable for disposal of stormwater via infiltration. These assumptions create uncertainty in the model outputs (the predicted areas of water table mounding). The groundwater modelling is conservative, using a horizontal hydraulic conductivity for the Werribee Formation at the low end of estimates for this formation. Higher hydraulic conductivity values result in less mounding and less outcropping of the watertable in the valley floor.

Future investigations can be used to reduce the uncertainty in the groundwater model output. The updated modelling results can then be used in conjunction with surface water modelling results to decide whether disposing of stormwater via infiltration to groundwater is a feasible management option for the DSS. This decision could be made once the areas suitable for infiltration are defined with more certainty, or once the possible asset layouts arising from that updated modelling are developed. Whether infiltration alone, a combination of infiltration and disposal via the tributaries draining the plateau is adopted will depend on:

- which tributaries are suitable for any stormwater outfall and the scale of any engineering works required to prevent erosion in those tributaries.
- the feasibility of disposing of stormwater at suitable injection locations on the plateau (i.e. movement of flows between catchments to avoid triggering mounding).
- Whether sensitive vegetation mapped along the tributaries that would receive stormwater runoff (assuming not all stormwater is disposed of via infiltration) would be adversely impacted by the new flow regime imposed on the tributaries. Note that this consideration is eco-hydrological rather than geomorphic alone.

6.1 Recommendations for future investigations

We have summarised the nature and scope of the future investigations that can reduce the uncertainty described above. Future investigations have been prioritised so that investigations that are relatively fast, low cost and leverage the existing modelling are undertaken before more detailed investigations or those that rely on the output of updated modelling. The recommended future investigations are:

1. A combined geomorphic and engineering investigation to assess the erosion potential and possible mitigation works at the likely outfall locations on tributaries draining the plateau. These geomorphic and engineering-feasibility investigations recognise that:
 - a. the condition of no additional flow to tributaries may not be possible to implement for all sub catchments (for example because disposal via infiltration has an upper limit that requires alternative management for some sub-catchments).
 - b. Some of the tributaries are already eroding and their current condition is unlikely to be an acceptable outcome from a public safety, amenity or waterway health standpoint.
 - c. If suitable works can be used to mitigate erosion potential, then disposing of some stormwater via outfall to tributaries provides flexibility in scheme design.
2. Assessment of the suitability of potential outfall locations detailed in Figure 20 for their suitability as constructed waterways (given the investigations in 1). Many of these outfalls (which would be co-located with injection wetlands/bores) discharge onto the steep escarpment face. Eliminating

unsuitable outfall locations would be the first step in progressing the preferred stormwater management option. When combined with the groundwater modelling results for this project, identifying candidate sites for outfall would provide clear guidance for DSS layout design. Assessment of potential outfall sites should consider:

- a. Whether flow will be appropriately channelized across the escarpment face.
 - b. The thickness of soils, basalt and the Werribee formation both at the head of the escarpment and across the escarpment face. These assessments should aim to determine how these soils will respond to intermittent runoff. This is essentially a localised geomorphic and geotechnical study.
3. A more detailed assessment of the environmental values and sensitivity of receiving waterways. Assuming some stormwater is disposed of by increased delivery to tributaries that drain the escarpment, a more detailed assessment of the ecological impacts of increased flows will be required. By ecological impacts we mean the sensitivity of vegetation to the new flow regime imposed on the tributaries and the resulting impacts on any instream habitat that the vegetation and particular geomorphic form supports. The surface water modelling used in this project can be used as the basis for such modelling, combined with some targeted field visits and a review of previous ecological and geomorphic value mapping undertaken in Phase 1 investigation (Alluvium, 2019).
4. A cultural heritage management plan for the site will need to explicitly consider whether any proposed outfall sites are suitable from a cultural heritage perspective. Both cultural values likely to be directly impacted by excavation and works at the outfall as well as those receiving environments (the plateau escarpment and waterways receiving stormwater flows) will need to be considered. This cultural heritage assessments should be undertaken once a preferred approach for stormwater management has been adopted (i.e. injection or some combination of injection and BAU disposal), but before the exact location of outfalls is chosen (so that culturally sensitive sites can be identified and the design updated to avoid these impacts wherever possible).
5. Field work to map the limit of the Werribee Formation to the north of the plateau, and refinement of the existing Victorian Aquifer Framework isopach map of the Werribee Formation thickness across the Merrimu plateau and surrounding area. This geological mapping will be used to update the boundary conditions of the existing groundwater model to better represent the Merrimu PSP area.
6. Development of a conceptual understanding of the potential risk related to mounding within the Boral quarry to the west of the PSP area (see Figure 1). These investigations include establishing how groundwater is currently managed in the quarry. This conceptual understanding can also be used to update model boundary conditions in the model, to more accurately predict the likelihood of mounding and possible off-site impacts of stormwater injection at the quarry.
7. Complete an injection test at GW03 to estimate the transmissivity (and hydraulic conductivity) of the Werribee Formation at this location. This will be used to update parameters within the existing model.
8. Development of a refined groundwater model incorporating:
 - a. A larger model domain including the full course of the Lerderderg River on the western side of the plateau.
 - b. Inclusion of improved conceptualisation for boundary conditions of the Werribee Formation (extent and thickness) and the quarry.
 - c. Develop a calibrated model representing groundwater flow in the Werribee Formation (to represent the aquifer, not just the mounding in relation to the state-wide depth to water table map). The model should integrate estimates of rainfall recharge and evaporation for a better assessment of mounding impact. This approach would also overcome the lack of accuracy of depth to water table maps used in the assessment.
9. Optimising land take by determining the number of injection bores possible at each site which in turn will reduce storage pond volume and footprint requirements. This will depend on developing better understanding of the specific qualities of the Werribee Formation (thickness, extent and hydraulic conductivity).

Each of the investigations above reduces some of the uncertainty in the existing groundwater model and in turn on lake take requirements. An iterative approach may be best, in which the likelihood of mounding is re-assessed after each of the above investigations are undertaken and a more certain picture emerges.

7 References

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8 Appendix A – RORB sub-catchments

The following figures show the delineation of sub-catchment 1 to 11 in existing (pre-developed) and developed condition.

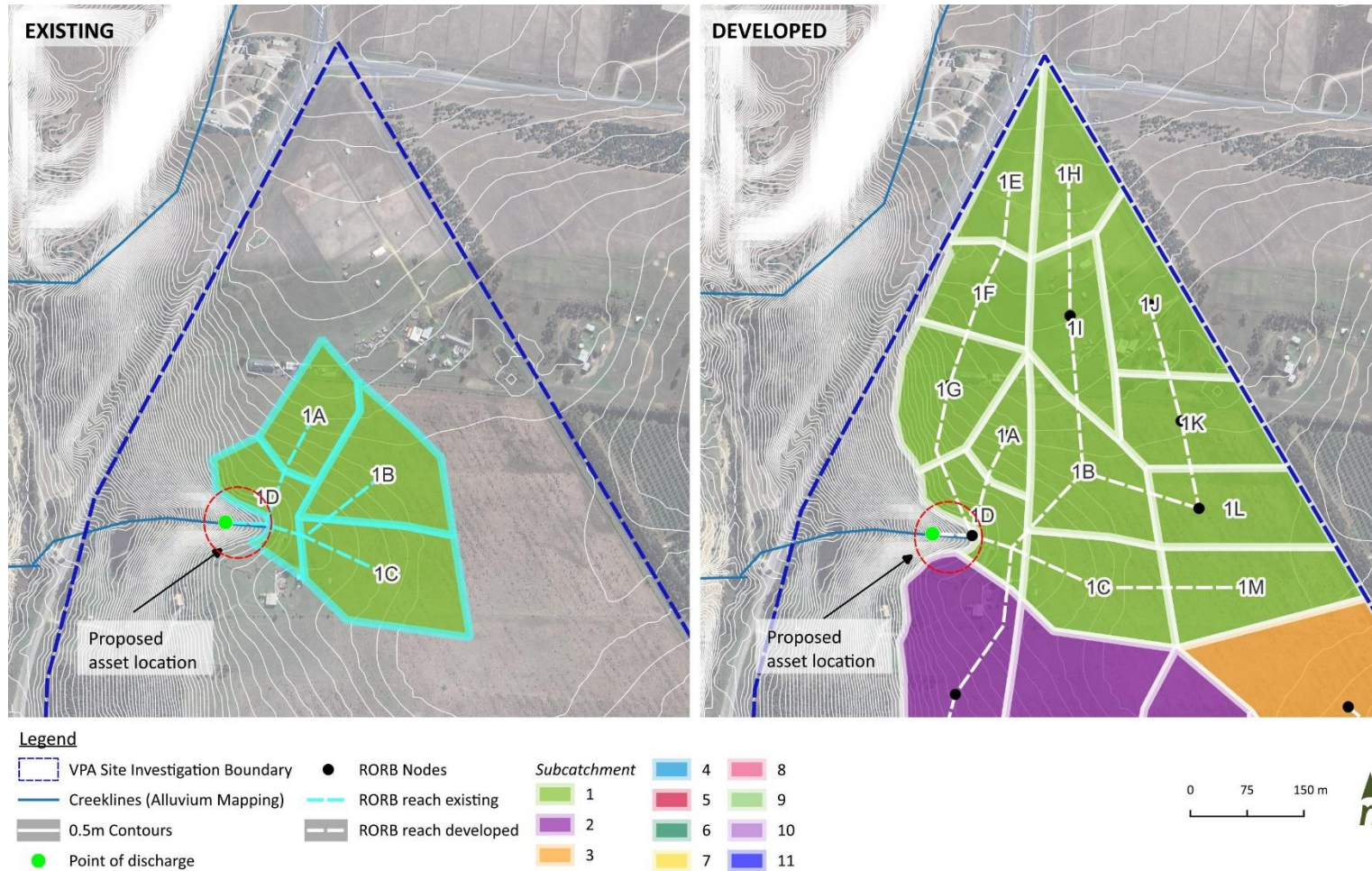


Figure 32. Sub-catchment 1 existing and developed RORB delineation

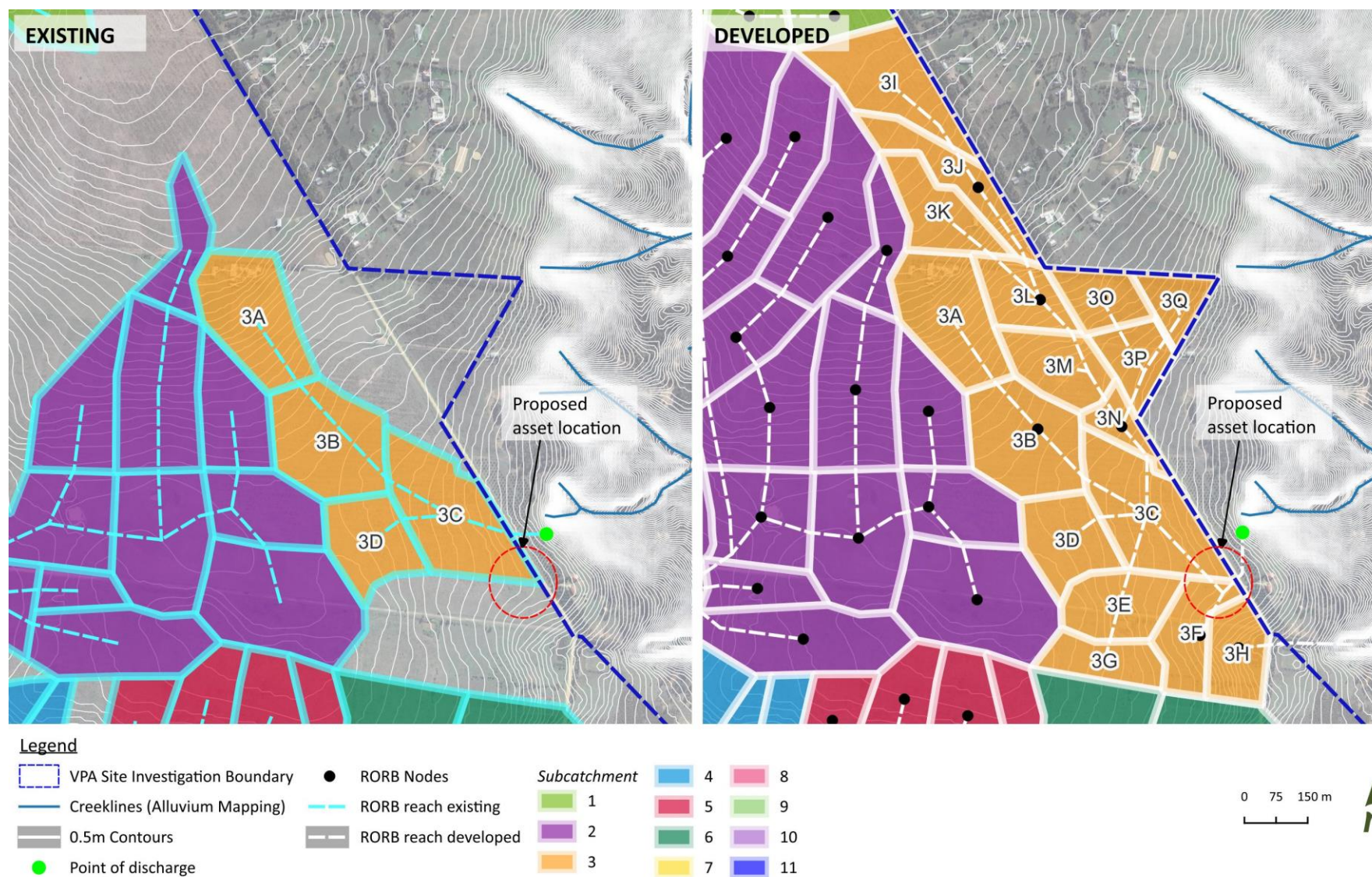


Figure 34. Sub-catchment 3 existing and developed RORB delineation

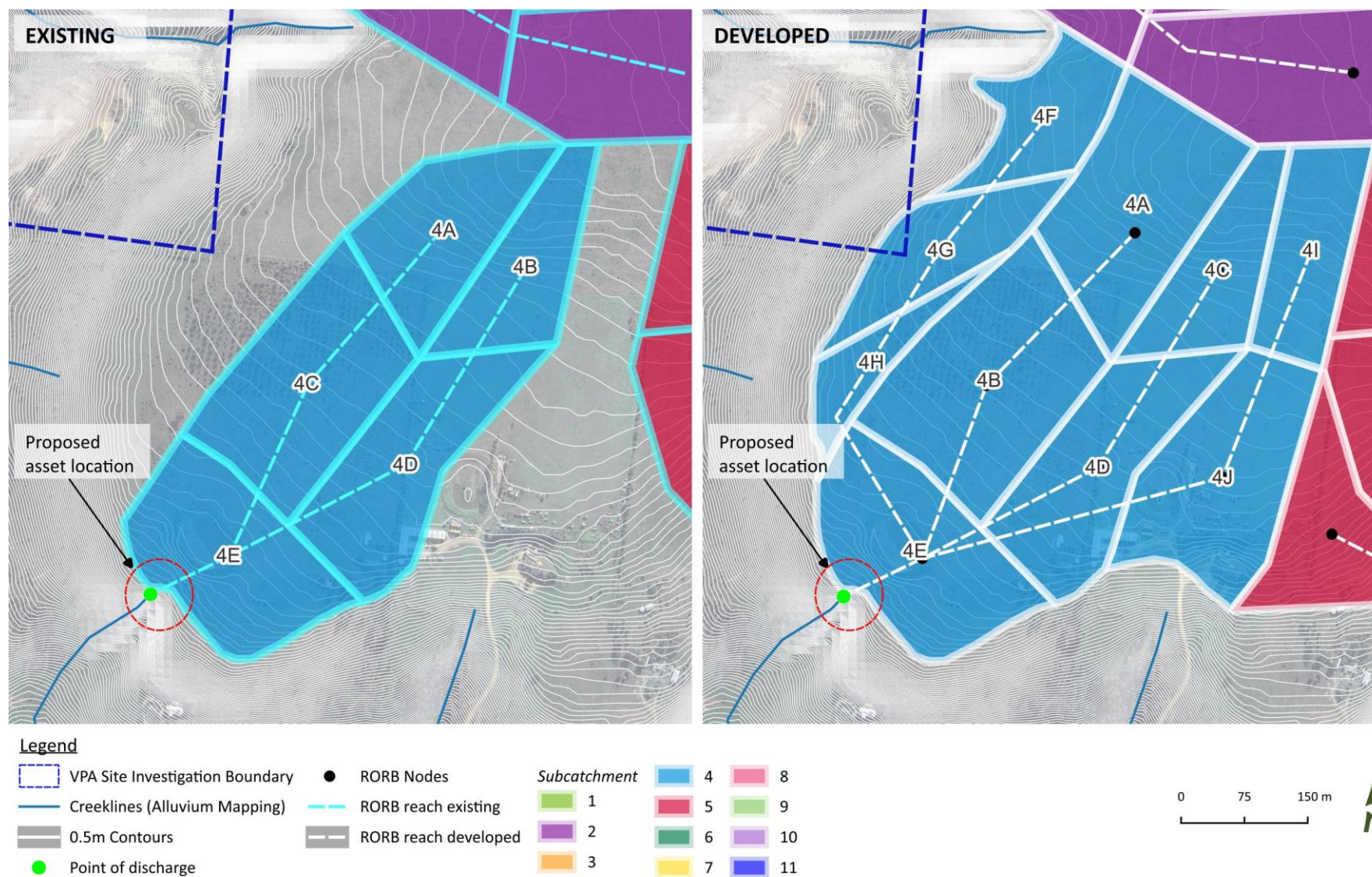


Figure 35. Sub-catchment 4 existing and developed RORB delineation.

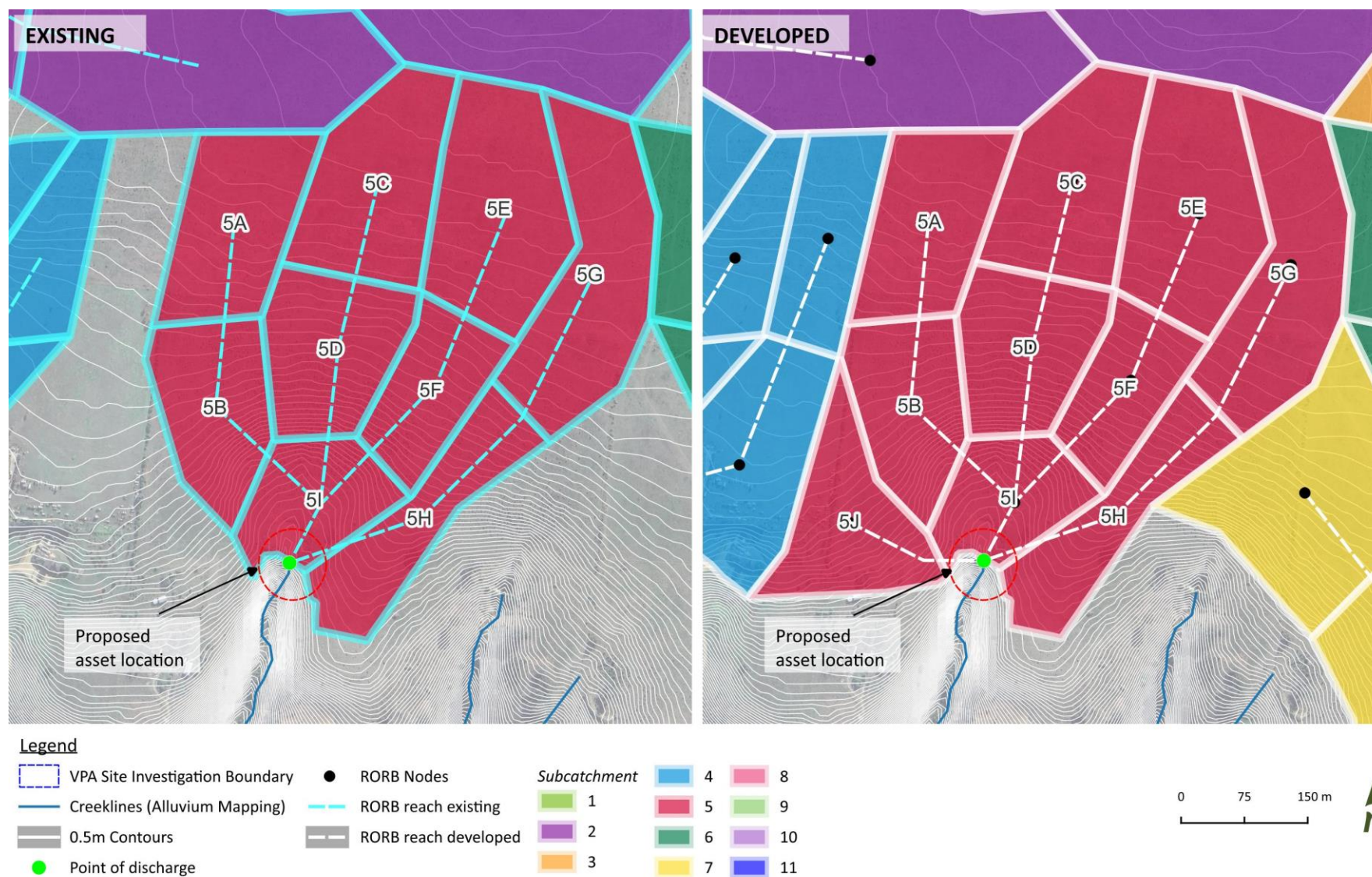


Figure 36. Sub-catchment 5 existing and developed RORB delineation.

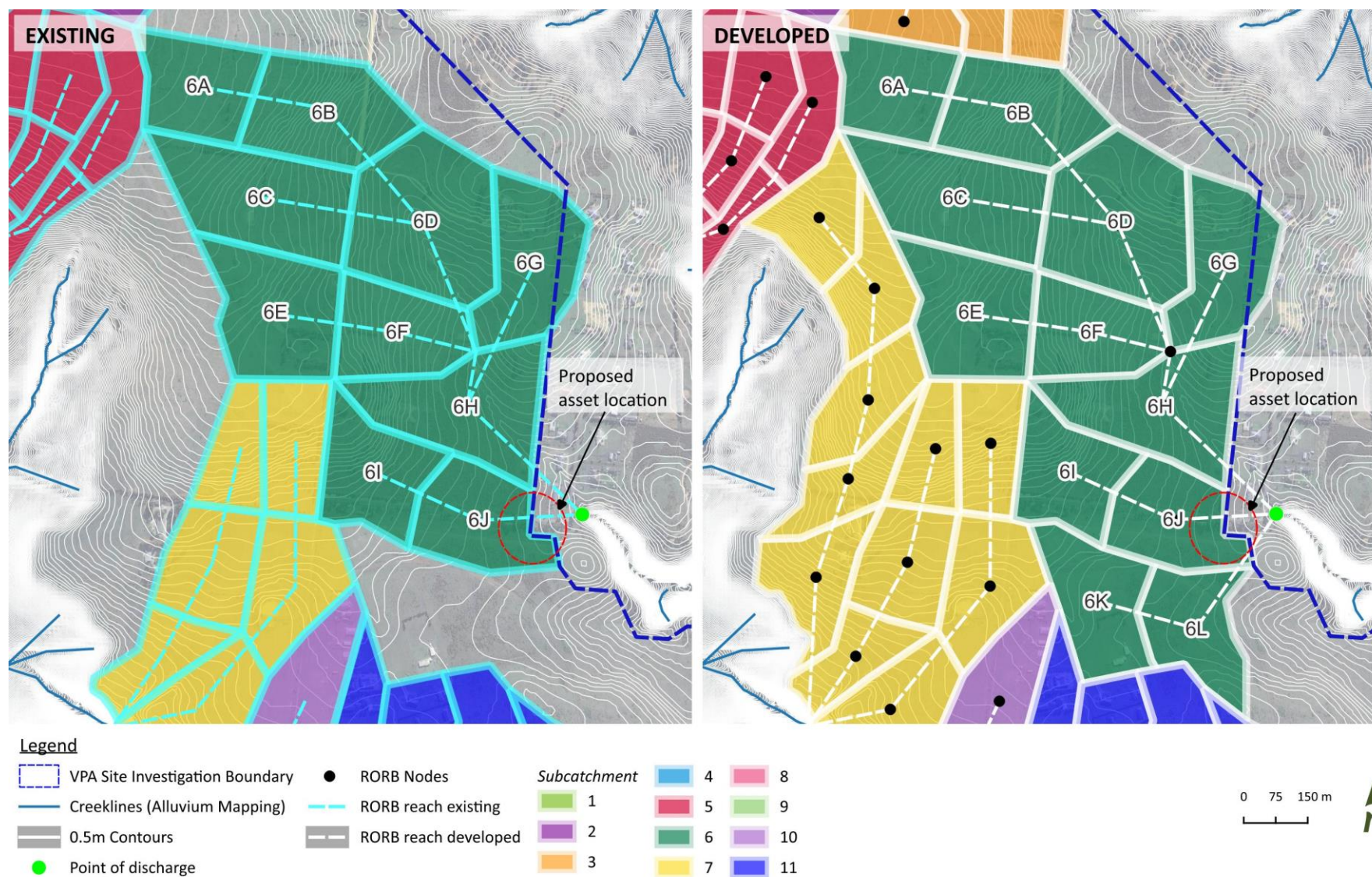


Figure 37. Sub-catchment 6 existing and developed RORB delineation.

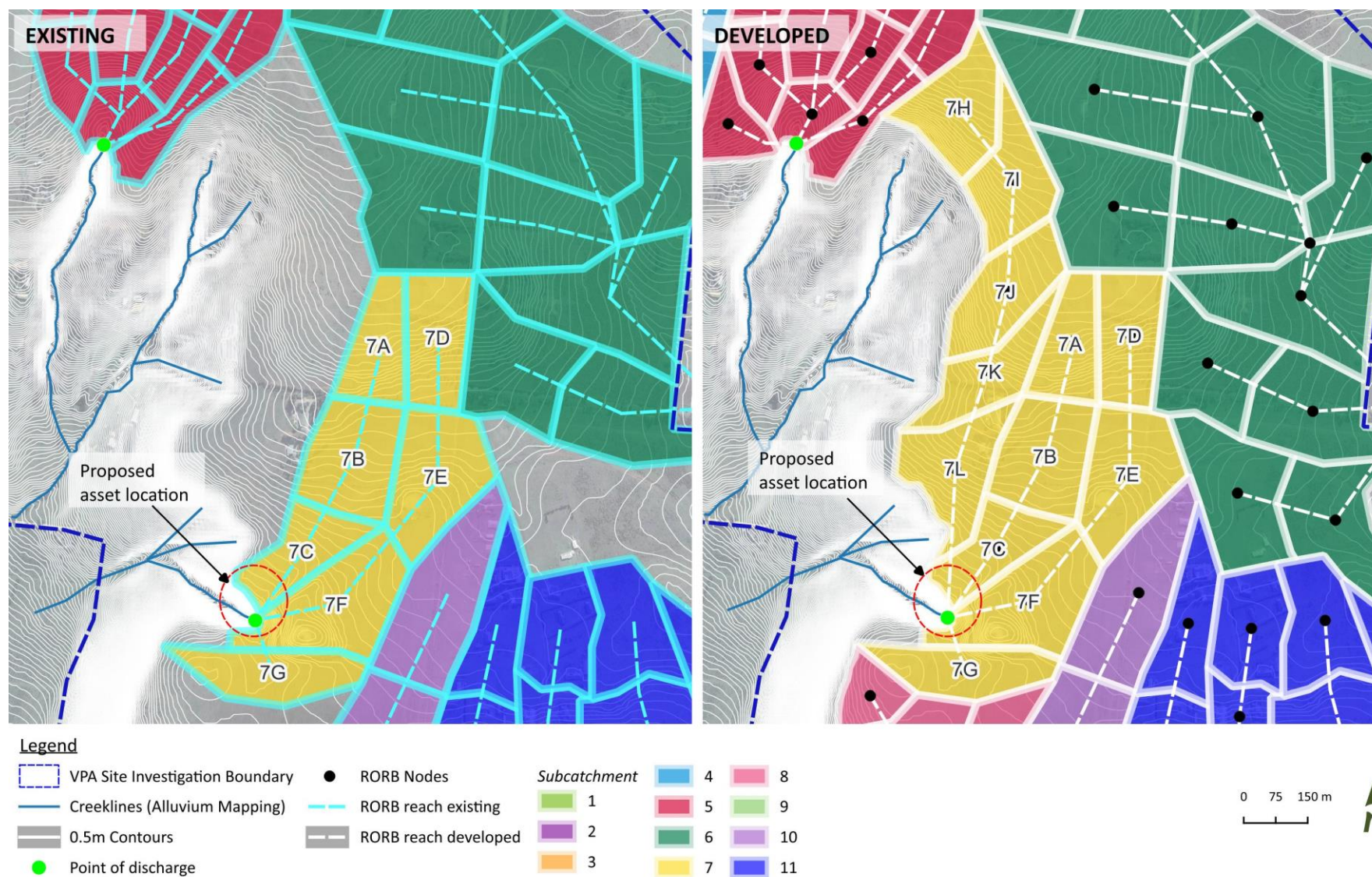


Figure 38. Sub-catchment 7 existing and developed RORB delineation.

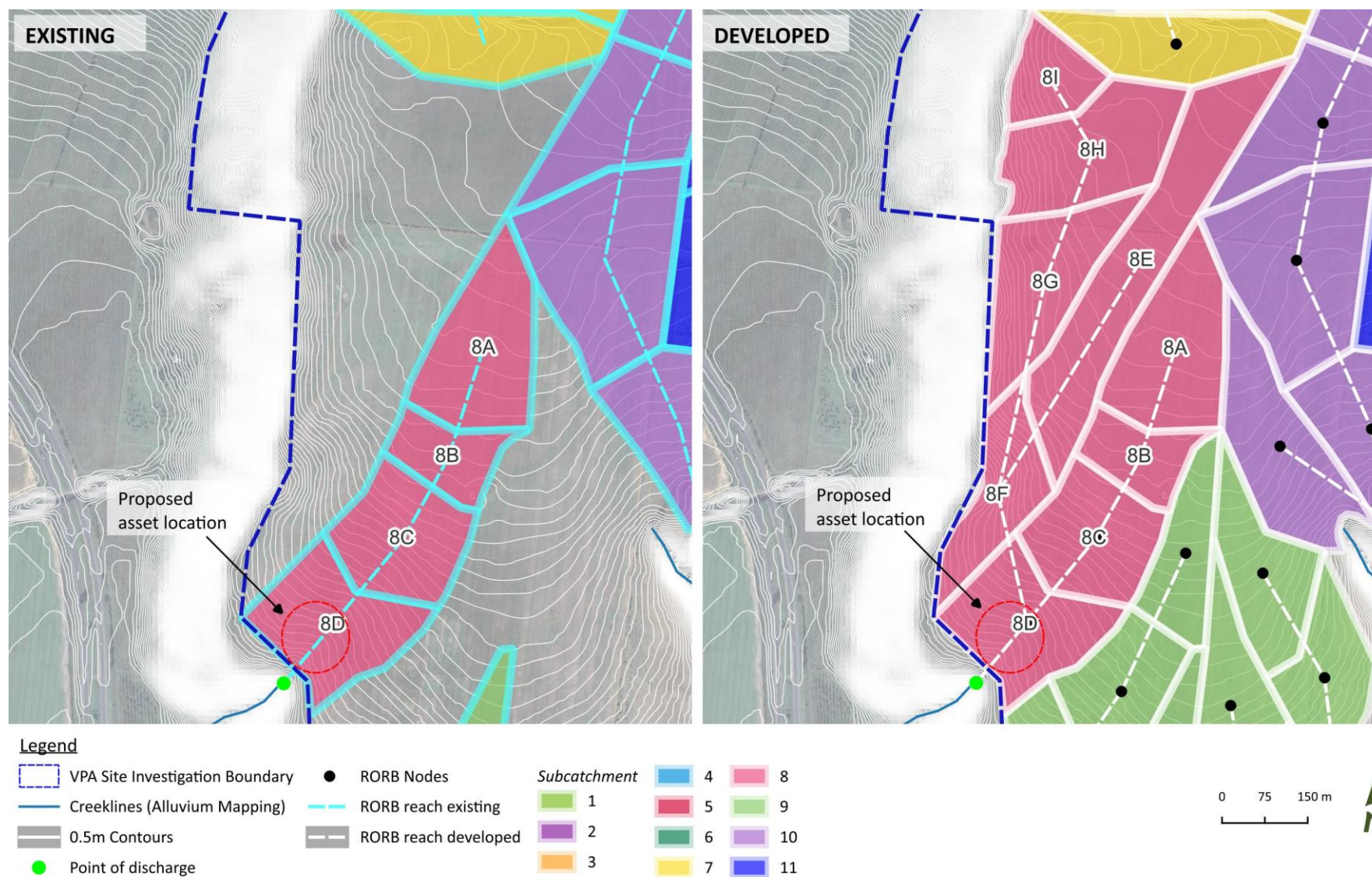


Figure 39. Sub-catchment 8 existing and developed RORB delineation.

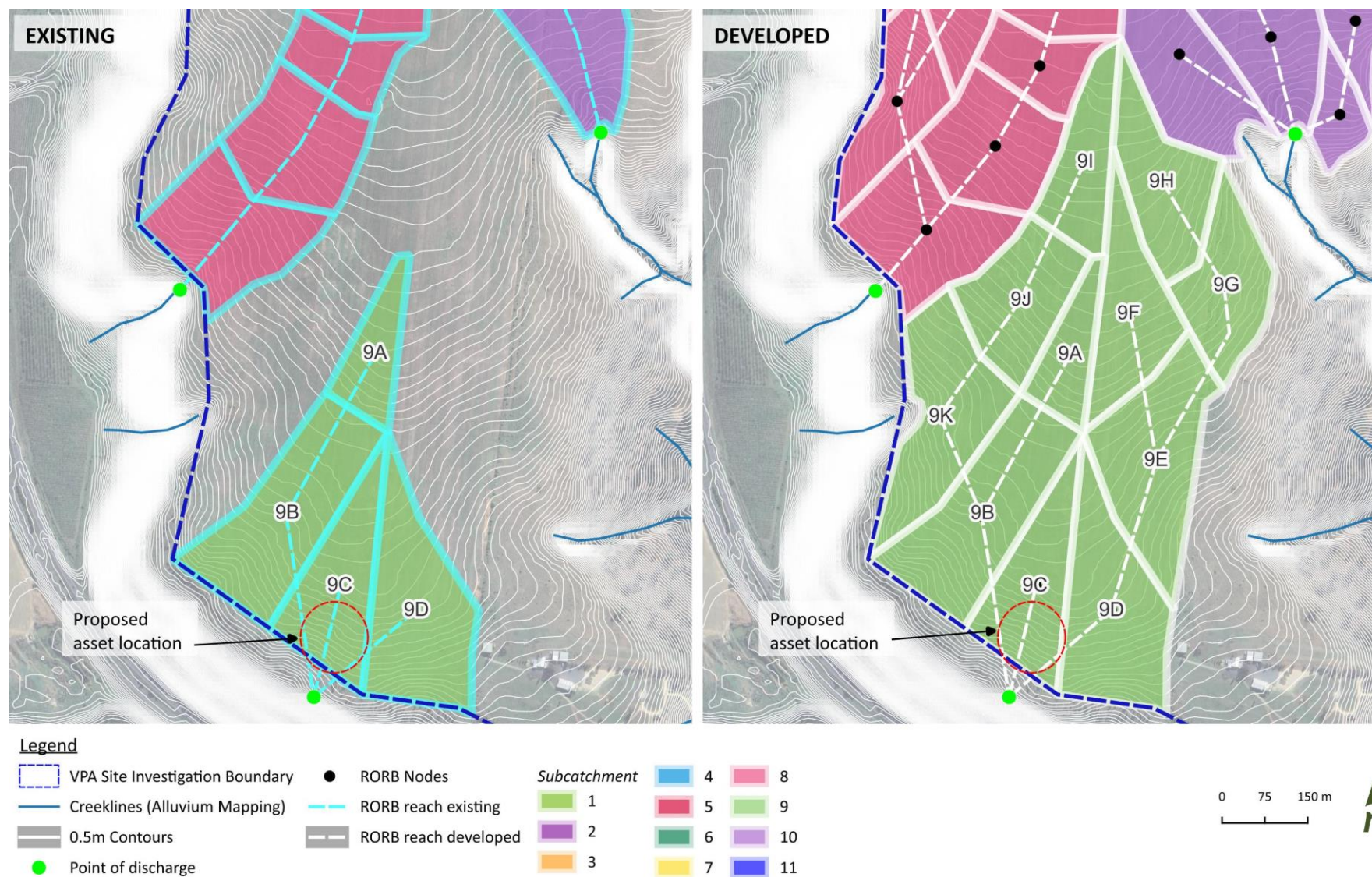


Figure 40. Sub-catchment 9 existing and developed RORB delineation.

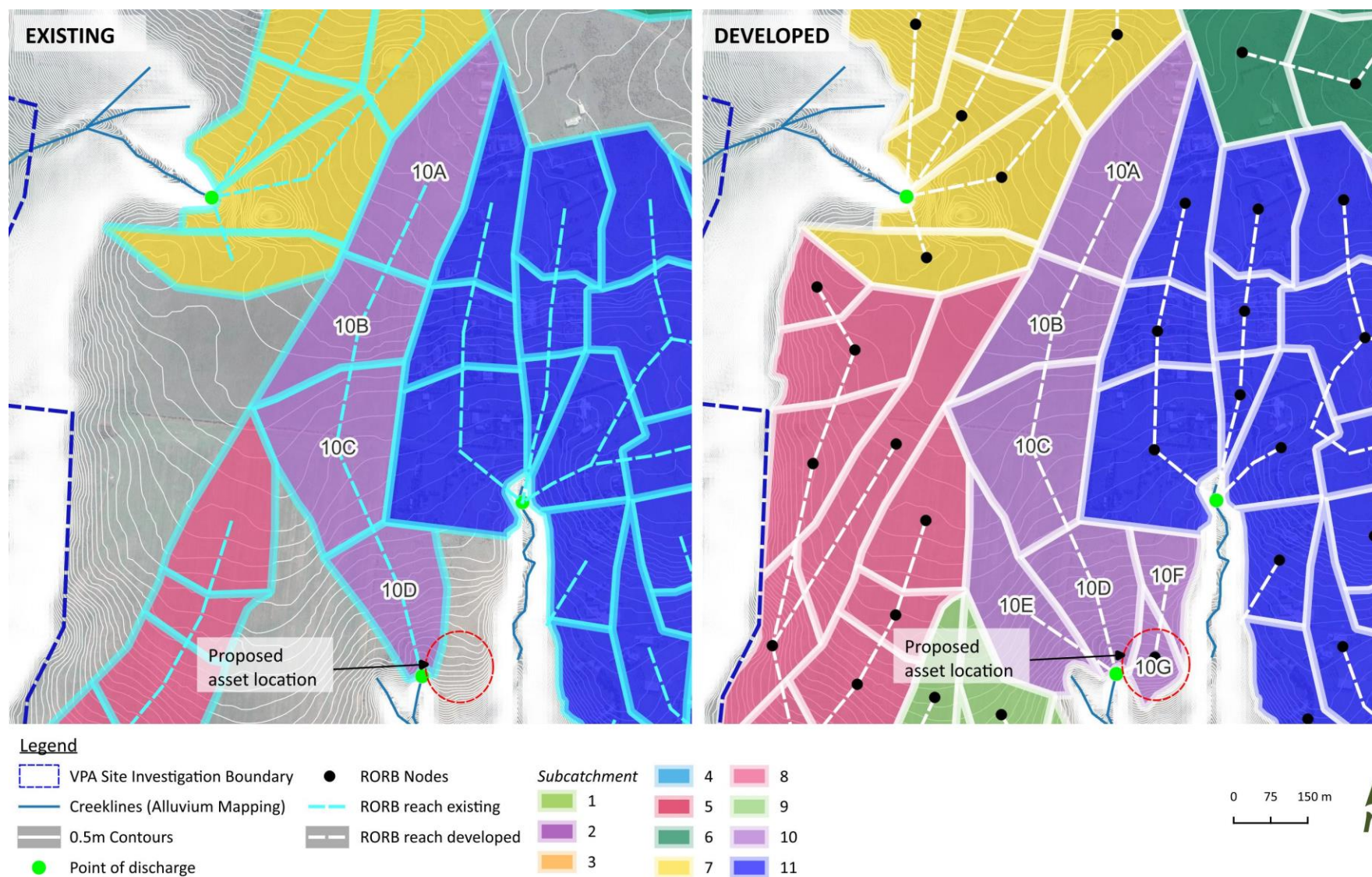


Figure 41. Sub-catchment 10 existing and developed RORB delineation.

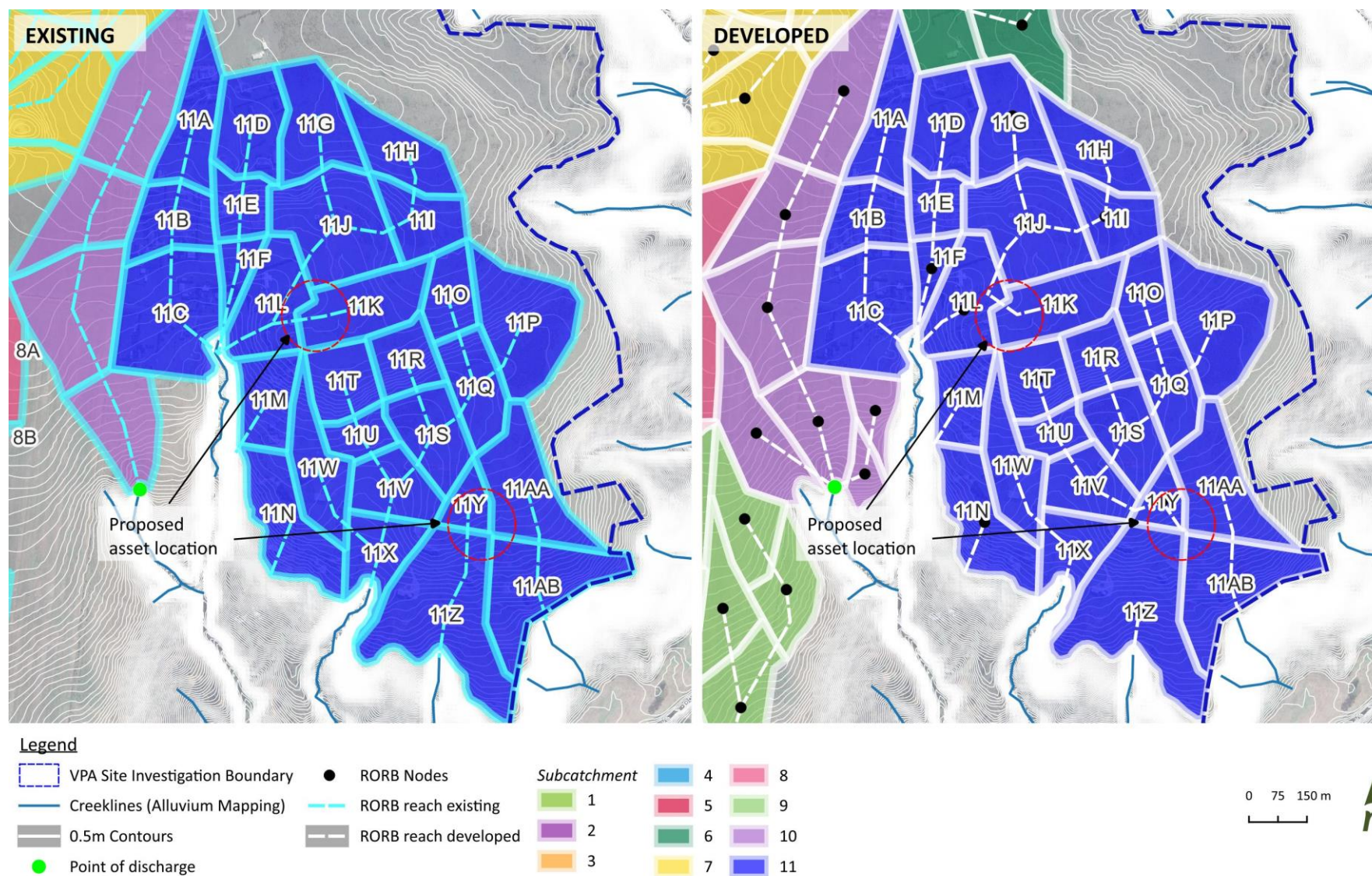
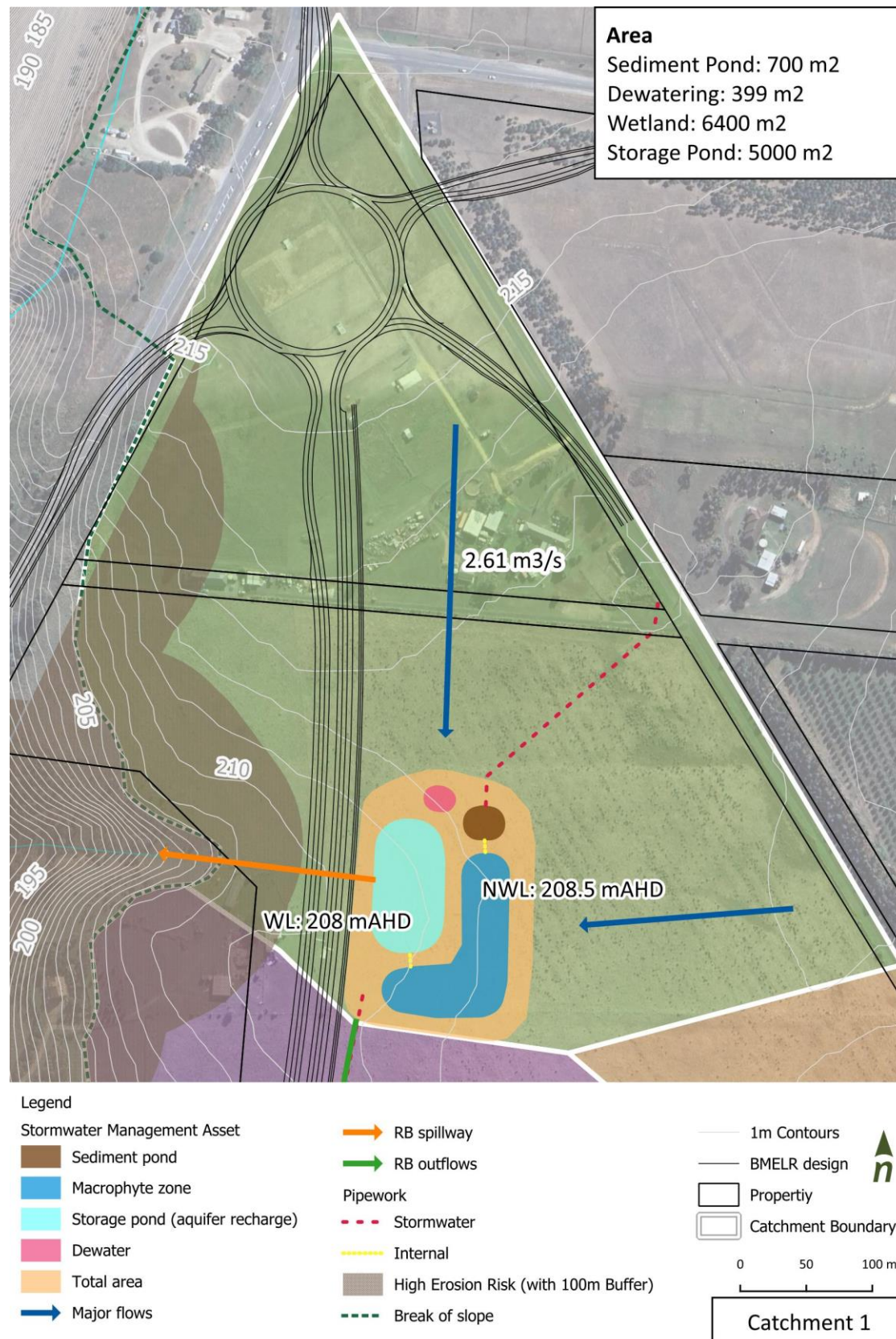


Figure 42. Sub-catchment 11 existing and developed RORB delineation.

9 Appendix B – Conceptual Asset Layout



* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 43. Sub-catchment 1 stormwater management asset design

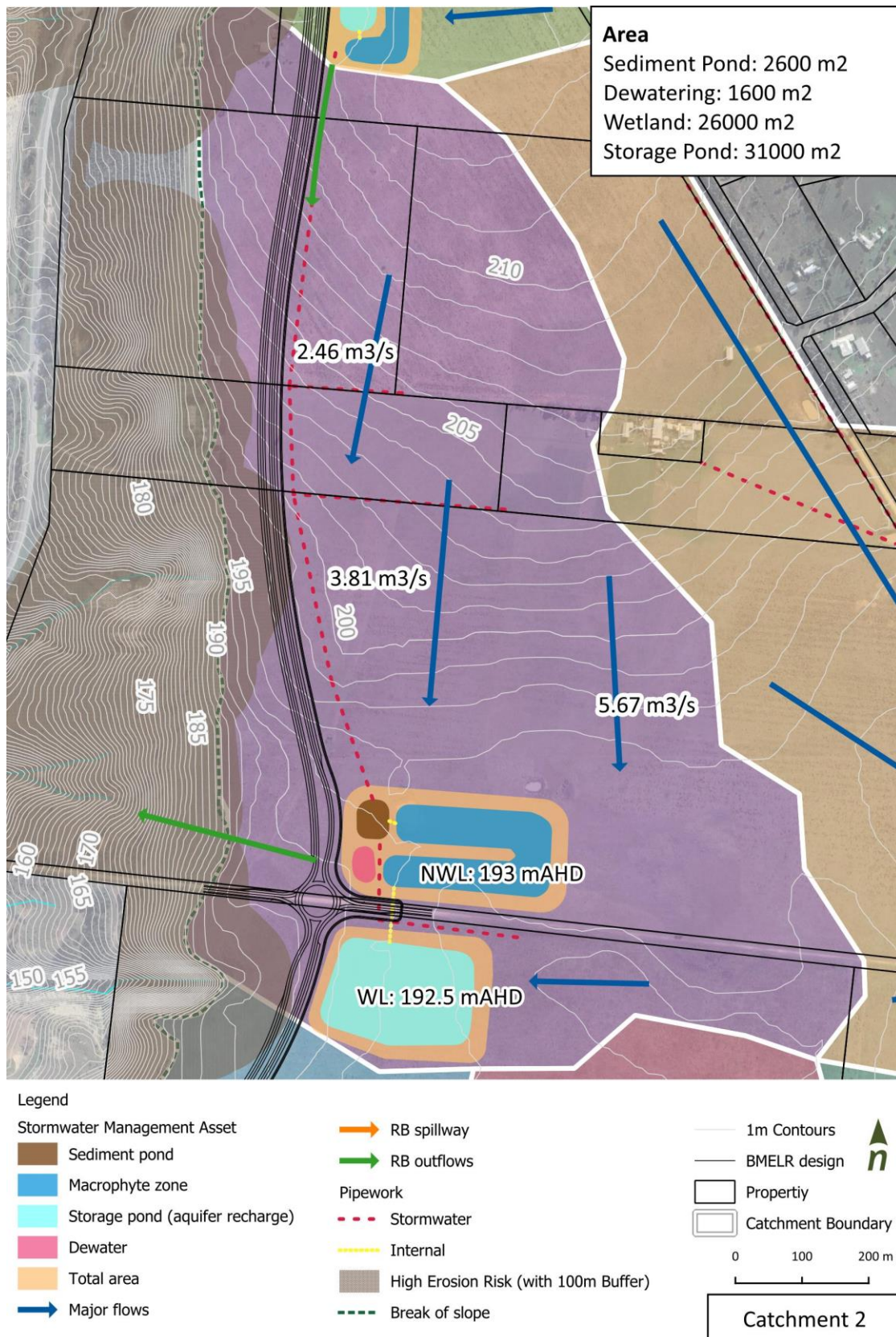
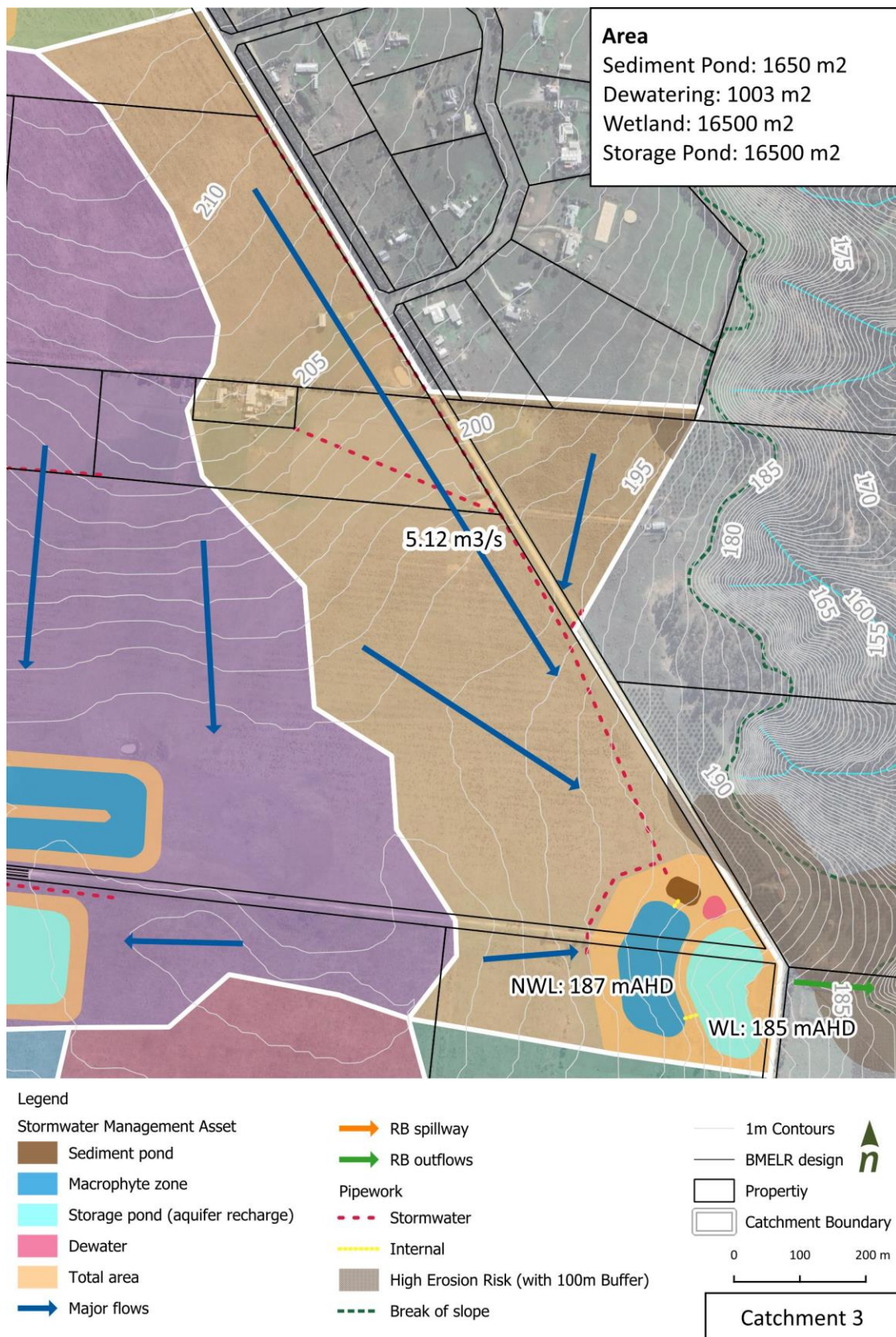
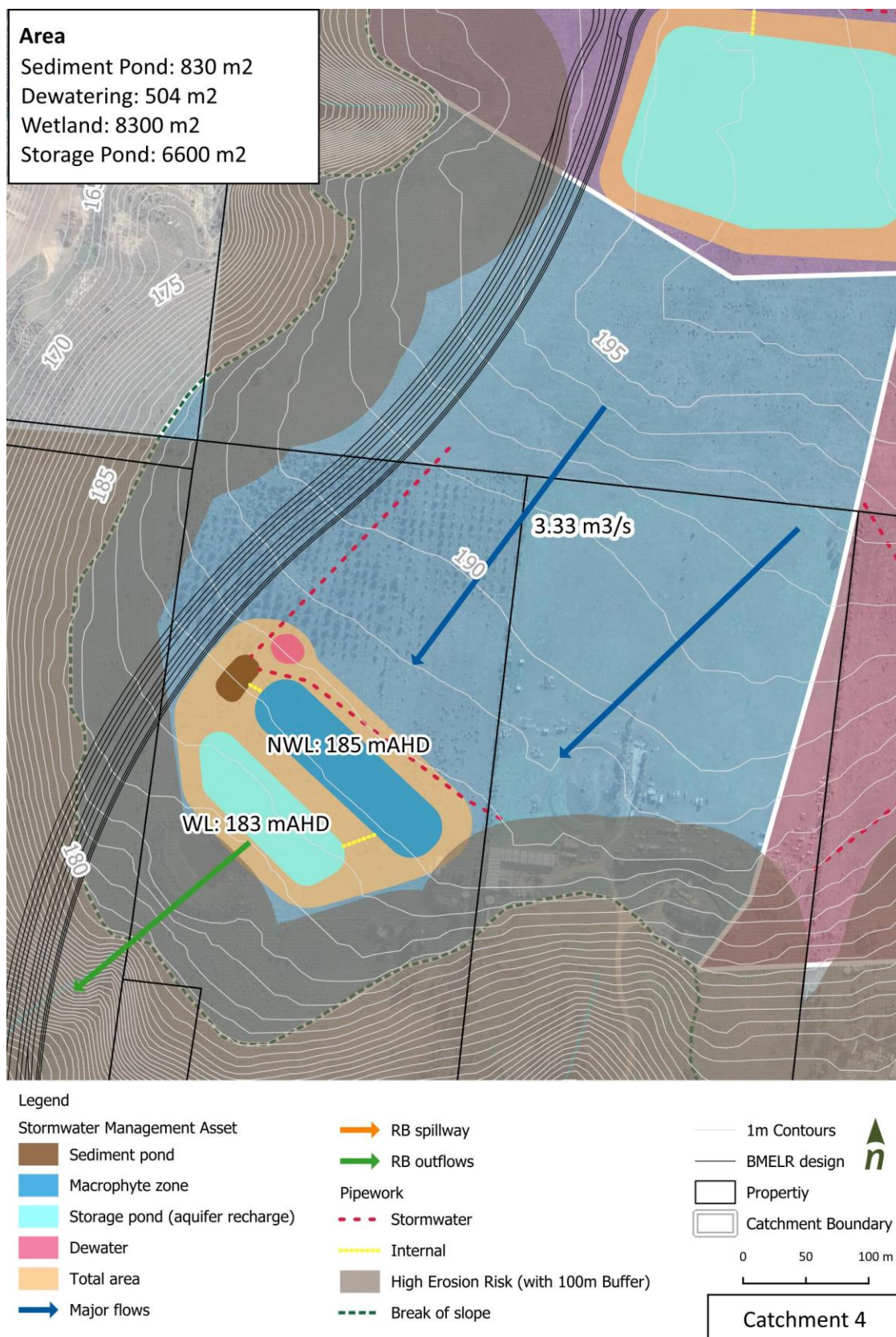


Figure 44. Sub-catchment 2 stormwater management asset design



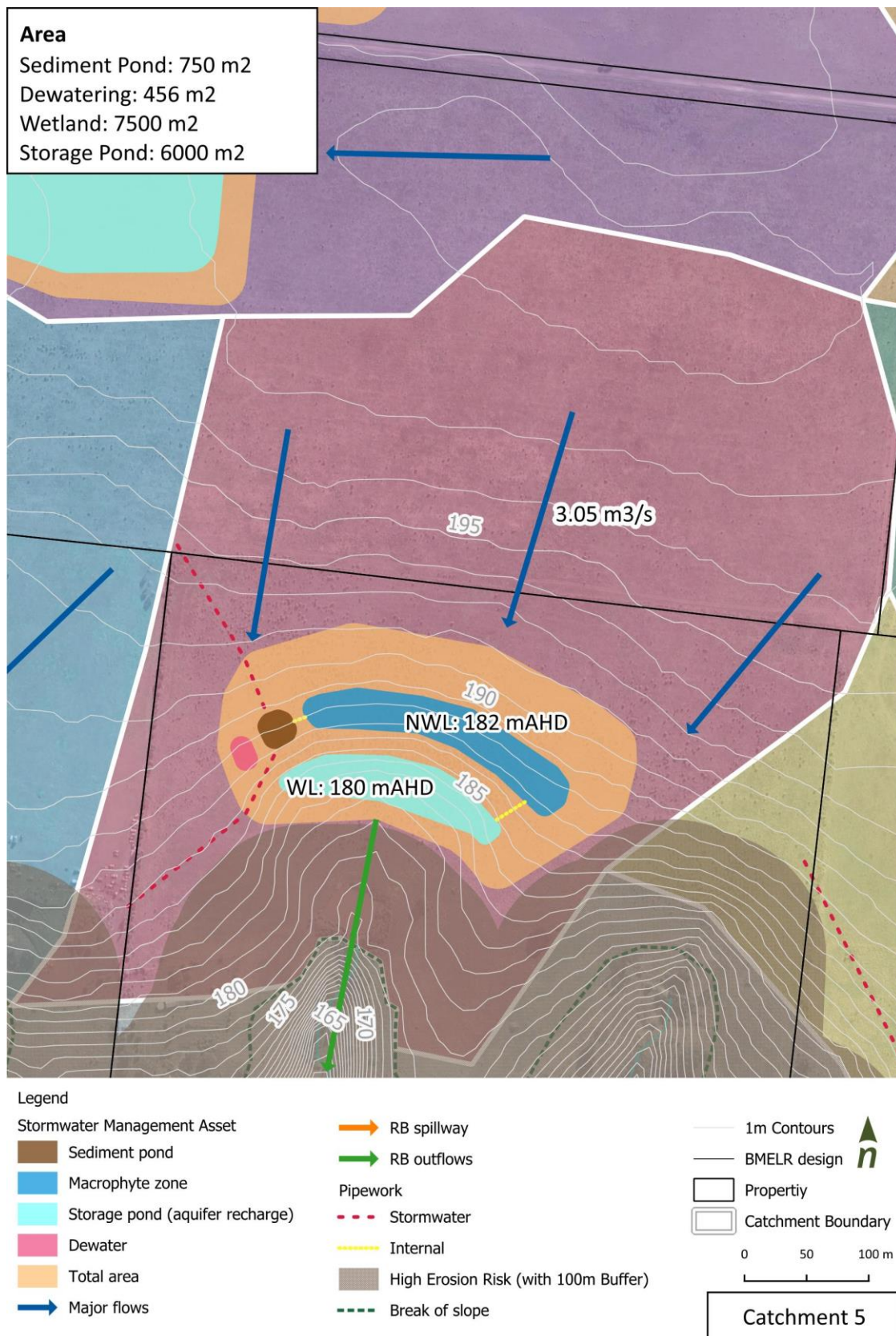
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 45. Sub-catchment 3 stormwater management asset design



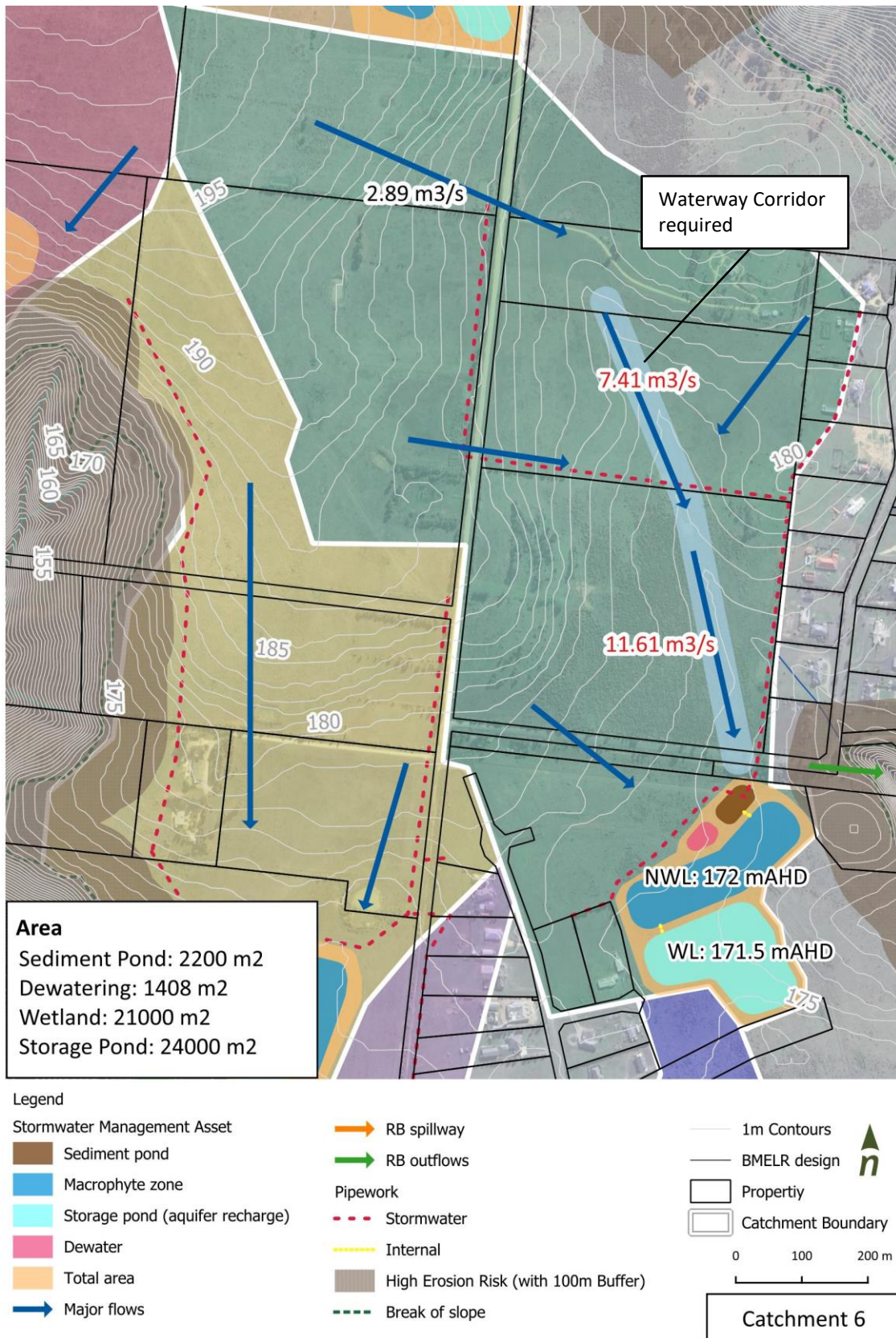
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 46. Sub-catchment 4 stormwater management asset design



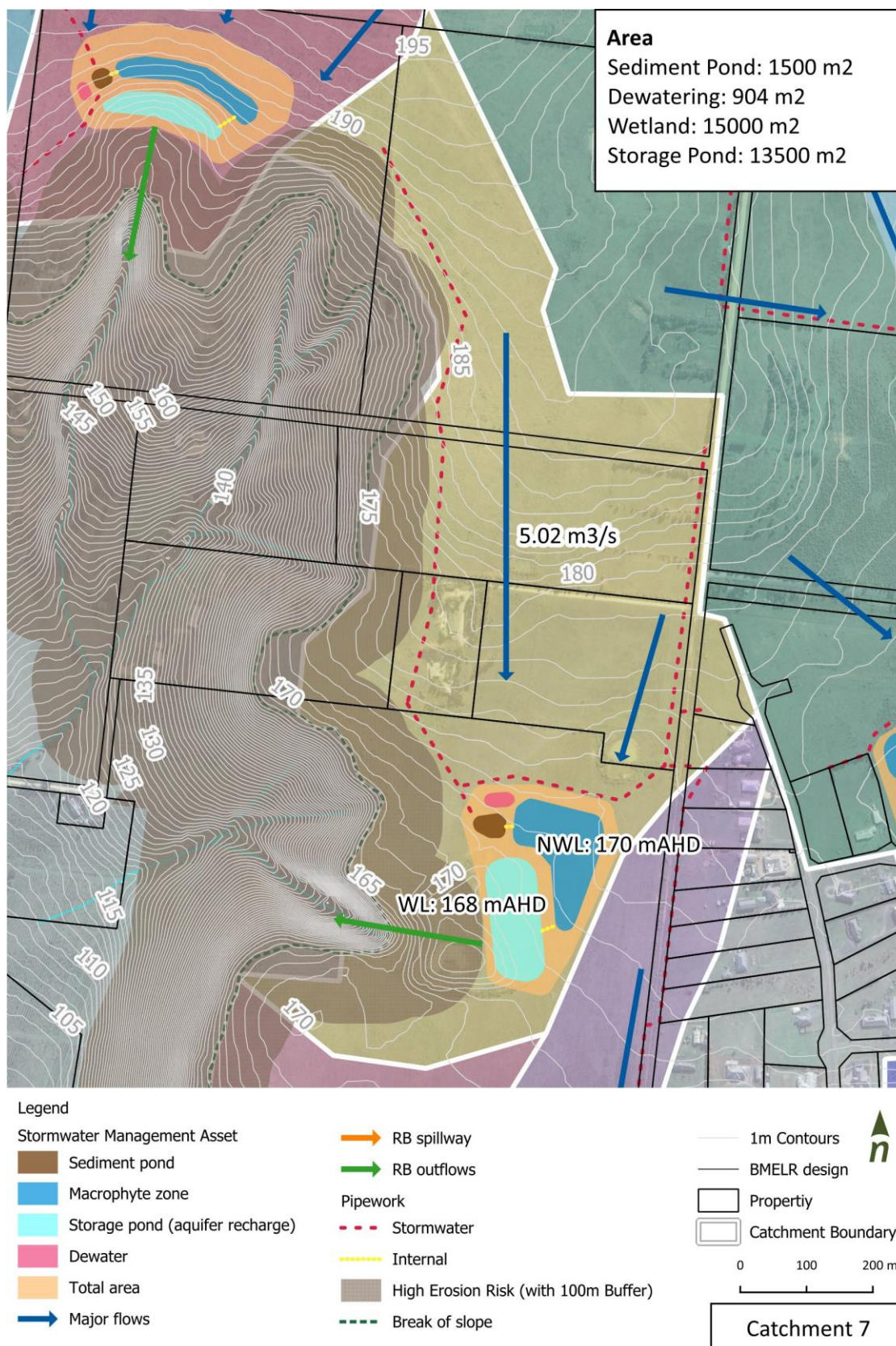
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 47. Sub-catchment 5 stormwater management asset design



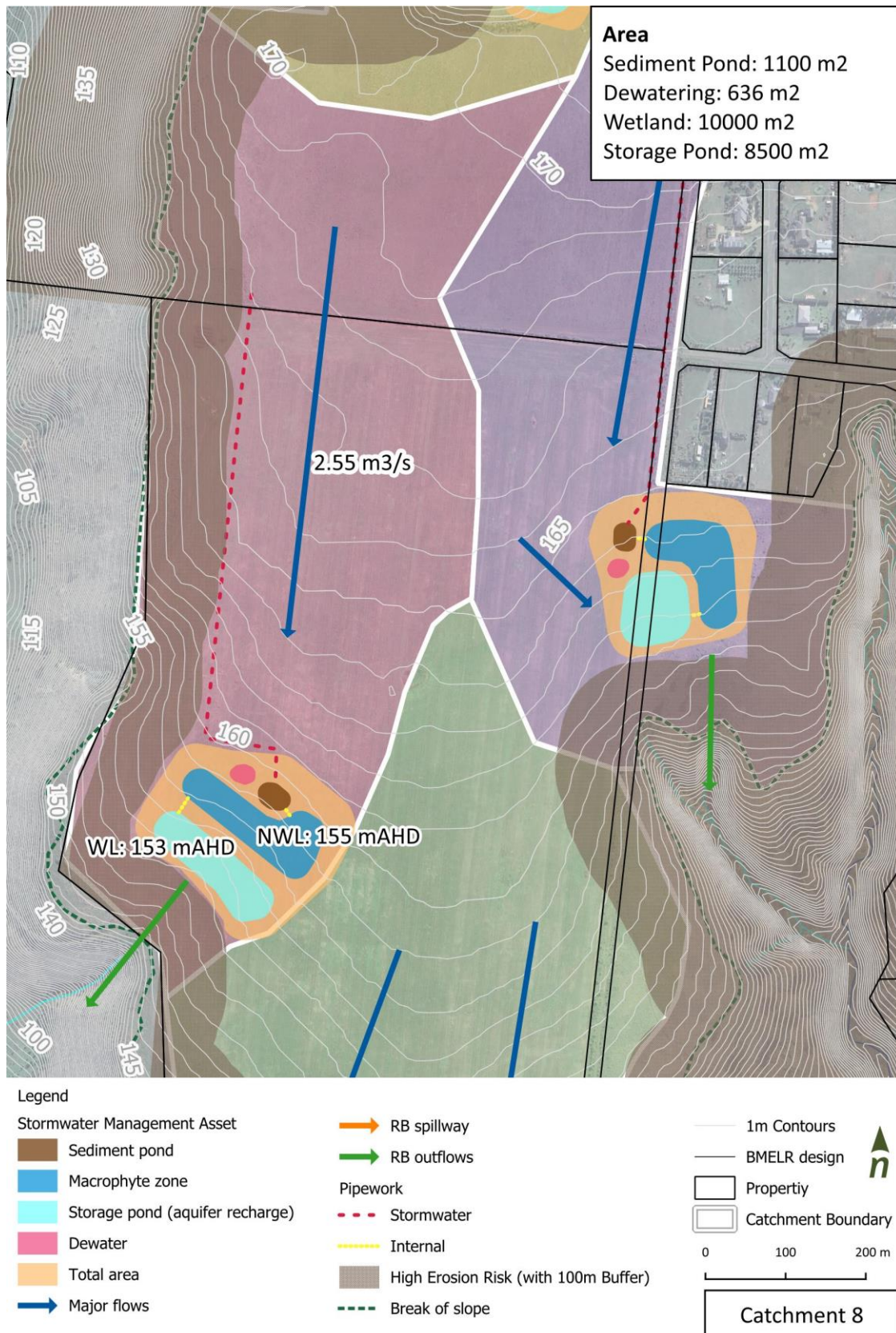
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 48. Sub-catchment 6 stormwater management asset design



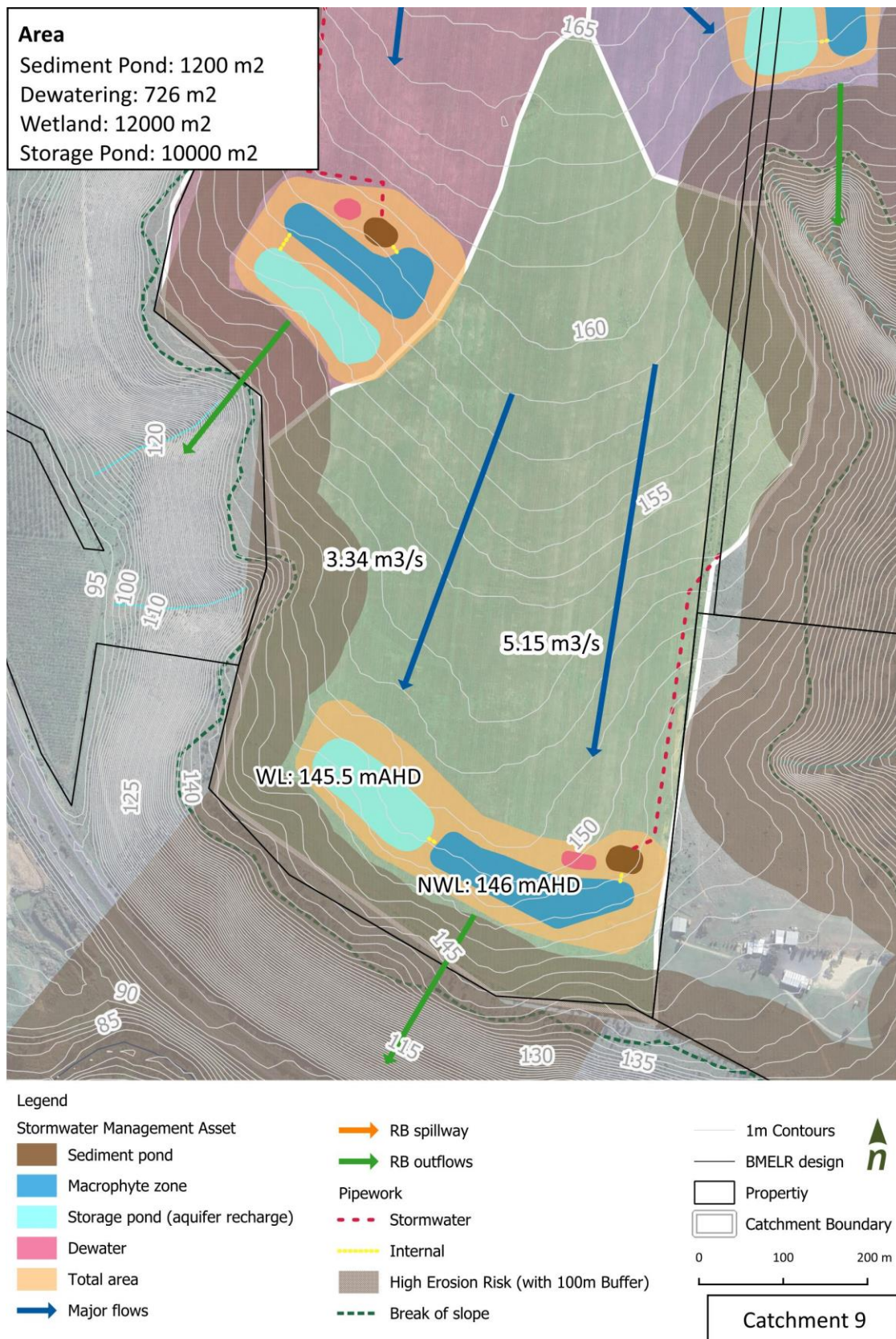
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 49. Sub-catchment 7 stormwater management asset design



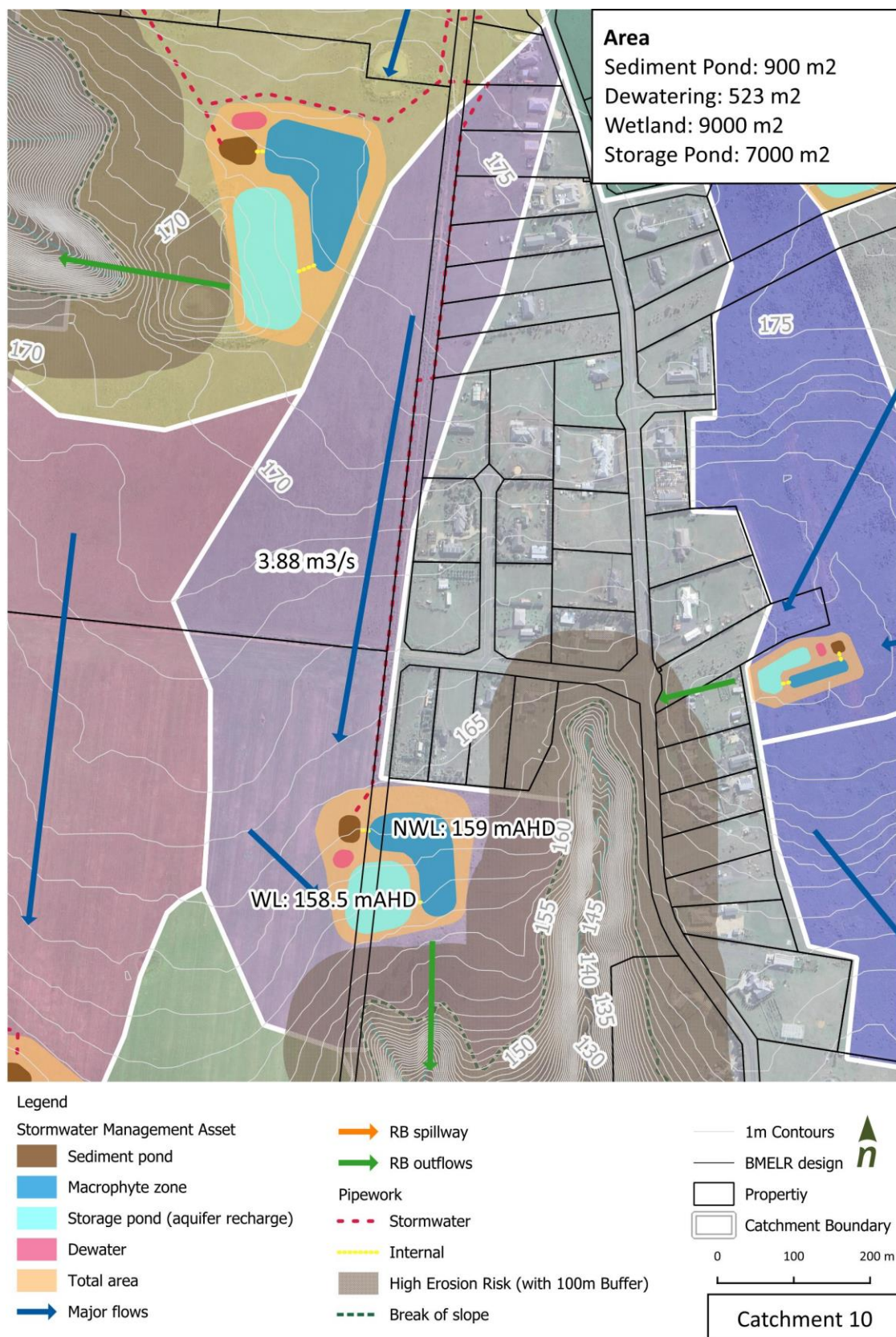
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 50. Sub-catchment 8 stormwater management asset design



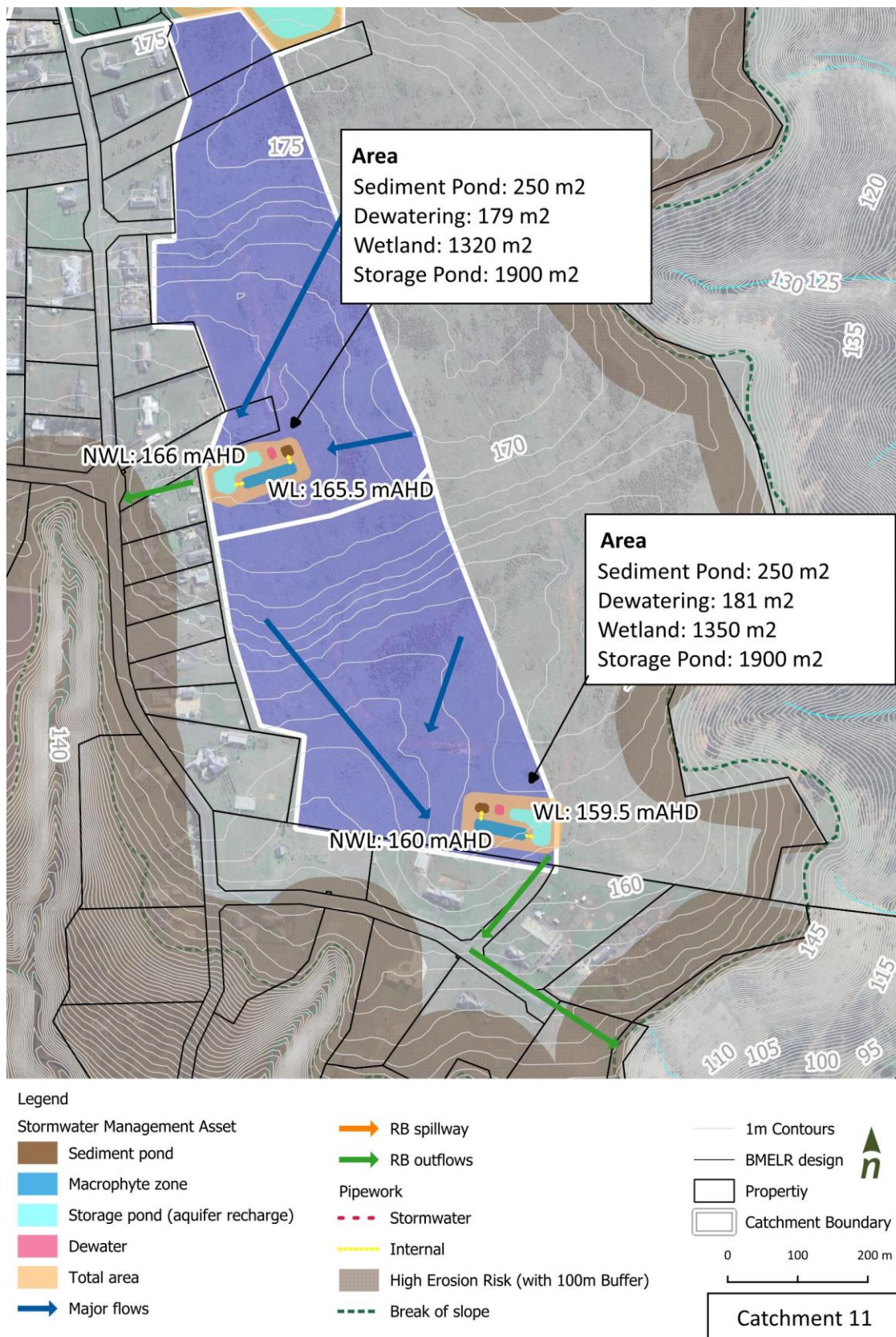
* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 51. Sub-catchment 9 stormwater management asset design



* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 52. Sub-catchment 10 stormwater management asset design



* Note: Refer to WSP (2023) for "High Erosion Risk (with 100 meter buffer)"

Figure 53. Sub-catchment 11 stormwater management asset design

