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McCrae Landslide

Geochemistry Report

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1. Purpose of this report

Landslides at 10-12 View Point Road, extending downhill to Penny Lane, McCrae, occurred on 5th January and 14th January 2025 causing significant property damage and, in the case of the second event, serious injury to one person. A Board of Inquiry has been established by the Government of Victoria with three objectives, one of which, being to determine the cause(s) of the landslides, is addressed in this report. Whilst the Terms of Reference for the Inquiry refer only to the landslide that occurred on 14th January, there now appears to be consensus amongst the relevant experts that the second landslide was a direct consequence of the first, and in fact this report deals primarily with the landslide that occurred on 5th January.

At this stage of the proceedings there is also a general consensus amongst the experts that the proximate cause of the 5th January landslide was a loss of cohesion in soils located at the top of the slide path caused by an increase in pore pressure due to ingress of shallow groundwater. At present, there is no consensus on as to the source and migration pathway(s) of this groundwater, although there is consensus that some potential sources, such as rainfall, can be discounted.

This report has been prepared specifically to examine aspects of groundwater chemistry in the area around McCrae that may contribute to an understanding of the source of this groundwater and the pathway(s) through which it moved. The key questions that it seeks to answer are:

- did this water originate in whole or in part from the Bayview Road mains leakage, and if not, what other source(s) are likely
- what are the relative proportions of water derived from the available sources that satisfy the requirement for mass balance of chloride in the observed seepage at the head-scarp.

I have been engaged for this purpose by South-East Water, and this report has been prepared in collaboration with SMEC Australia. The opinions presented in this report are, however, my own.

Figures and tabulated data referred to in this report are provided in **Attachments 1 and 2** to this report.

2 Scope

The materials dissolved in groundwater, predominantly but not exclusively in the form of ions, can provide useful information concerning the likely source or sources of the groundwater, and the pathways along which it has travelled. A distinction can be made between ions that could potentially originate from the minerals present within local geological materials and those which cannot, and must therefore be derived from another source. The entire area of interest is underlain by the Dromana Granite, which is a biotite granite containing quartz, greenish orthoclase, perthite, oligoclase and biotite with accessory sphene, zircon, ilmenite and apatite.

3 Origin and Behaviour of Chloride in Groundwater

Seven ions (Cl^-, SO_4^{2-}, HCO_3^-, Na^+, K^+, Ca^{2+} and Mg^{2+}) are commonly present in groundwater at significant concentrations. Of these, chloride ion (Cl^-) is generally regarded as the most useful as a tracer of water origin, movement and mixing because it is highly soluble (and thus unlikely to precipitate due to chemical reaction with other ions or minerals), and does not readily ion-exchange or adsorb to mineral surfaces. Other ions can also be used as tracers, but interpretation is more complex and uncertain. For this reason, in the discussion below, the emphasis is on chloride, with the behaviour of other ions used to add information where this is relevant and adds to understanding of the processes that occurred.

In the absence of anthropogenic sources, chloride dissolved in groundwater within granitic rocks is almost entirely sourced from rainfall, as these rocks do not contain minerals (other than possibly very minor chlorapatite) that include the element chlorine in their structure. The X-ray diffraction (XRD) analyses **(Table 1**) undertaken on samples from the Bayview Road excavation confirm that is the case for materials derived from the Dromana Granite. A set of 30 samples of Melbourne rainwater (Crosbie et al 2012) collected during significant (19-145 mm) rainfall events between June 2009 and November 2001 (**Table 2**) showed a range of chloride concentrations between 1.1 and 28 mg/L with a mean of 6.1 mg/L. Weighted for event rainfall, the mean was 5.6 mg/L. It is possible that average rainfall on the Mornington Peninsula has a slightly higher chloride concentration than that in Melbourne due to the inclusion of some sea-spray when rainfall is accompanied by on-shore winds.

When rain falls on the ground surface, some of it runs off into streams, which, in the case of the Mornington Peninsula, flow quite quickly to the sea. Thus that water, and any chloride that it contains, is lost to the system. Some of the water evaporates from the surface of the soil or rock, or the leaves of trees and other vegetation. That water leaves its chloride behind. Some water infiltrates to the soil and is captured by the roots of vegetation, and transpired by those plants. In that case too, the chloride is left behind in the soil. Chloride left in the soil is eventually dissolved by future, larger or longer rainfall events and carried deeper into the ground, until it eventually reaches the water table. Depending on the climate and vegetation cover, groundwater recharge can be a very small proportion of the total rainfall, but it contains a much higher concentration of chloride than the original rainfall.

Unless significantly fractured, granitic rocks have low to very low permeability, which generally decreases with depth (although fracture zones may be prevalent at specific depths in some systems). Thus, groundwater may take many years, even centuries, to flow from its point of recharge to its discharge location. Therefore, it is important to consider how recharge conditions may have changed over long historical timeframes. **Figure 1** shows the area around McCrae, extending to Arthurs Seat, as captured in a 1939 arial photograph (Geoscience Australia 2025). **Figure 2** is provided for orientation and is an annotated image of the same area dated 2023 (Google Earth). It is clear that in 1939 eucalypt forest similar to that still present on the steeper slopes below Arthurs Seat extended over a larger proportion of the area. The McCrae area was first settled by Europeans in 1844, and it is reasonable to assume that prior to that time eucalypt forest was present over almost the entire area. It is well-established (Barua et al 2021) that groundwater recharge beneath mature forest is substantially lower than recharge beneath cleared land and may be less than 1%, and certainly less than 10% of the mean annual rainfall (780 mm for Rosebud). Thus the chloride concentration in historical recharge may have been as high as 500 mg/L and was certainly >50 mg/L. Chloride ion may be carried through the upper, more transmissive part of a groundwater flow system but then accumulate to high concentrations in deeper zones that have minimal transmissivity.

4 Chloride in the Investigation Area

In this investigation, the groundwater samples with the highest chloride concentrations were obtained from the two deepest bores, WSP_BH04 (3260 mg/L) which is 50 m deep, and SMEC WRC174 BH01 (two samples, 1500 – 1600 mg/L), which is 21.4 m deep. Samples from SMEC BH01 and BH2 (25 m deep and screened in the residual / EW granite had chloride concentrations of 420 and 480 mg/L respectively. All other groundwater samples of which I am aware were obtained from shallower depths and had chloride concentrations less than 330 mg/L.

As shown on **Figure 3**, SMEC BH3 and BH4 were screened across the interface between colluvium and residual soils. Thus the water samples obtained from these bores should be representative of interface groundwater. Chloride concentrations were 100 and 170 mg/L respectively.

A sample of water seepage taken by PSM from the landslide head-scarp on 6 January 2025 had a chloride concentration of 330 mg/L. This sample was obtained from immediately below the assessed point of initial failure and there is consensus, which I have accepted, that it was as representative as is feasible of the pore water at that point. The only other analytes measured on this sample were Electrical Conductivity (EC) and Fluoride.

Subsequently, on 20 January 2025, a water sample (PSM SW5) was obtained from seepage (following rainfall) from the debris pile in Penny Lane resulting from the second landslide. This had a chloride concentration of 240 mg/L. Concentrations of the other six major ions were also measured on this sample; all of these concentrations may have been diluted by the rainfall. It would not be unreasonable to adjust concentrations up by a factor of 1.4, based on the chloride ratio. However, this is unnecessary when only considering ion ratios rather than concentrations.

These are the only two samples of groundwater obtained from the landslide area close to the time of the landslide.

5 Potential Water Sources

A number of potential sources of water were originally identified. As indicated above, some have since been eliminated. Those still being considered are leakage from stormwater drains in Browne Street and View Point Road (but only as a minor component), leakage from the watermain at Bayview Road, garden irrigation and interface groundwater flow, including flow captured and diverted by basement drainage systems.

6 Stormwater Leakage

PSM has estimated the maximum leakage from the Browne Street drain to be 1200 L/day, and assumed that this contributes to interface groundwater flow downgradient. This will be relatively fresh water. Maximum leakage from the stormwater drain in View Point Road (which was replaced about a year prior to the landslide) was estimated to be 400 L/day. I have no reason not to accept these figures.

7 Bayview Road Leakage and Potential Flow Pathways

The Bayview road mains leakage has been described in detail by others. In summary, it began two to three months prior to the landslide occurring, and was repaired on 1 January 2025, four days prior to the first landslide. **Figure 4** (WSP Figure 8.15) shows the estimated rate of discharge (in L/day) during the leak. It can be seen that leakage becomes apparent from about mid-October and increases exponentially until the repair was completed. Total loss was of the order of 37 ML and the ultimate leakage rate about 15 L/s. Evidence has been presented that effectively all the released water could have infiltrated to the ground and service trenches within a short distance from the leak and migrated to the north-west through stormwater drains beneath the Mornington Peninsula Freeway. I accept this. The question then, is what happened to it thereafter.

Three possible pathways have been suggested – one being predominantly through stormwater drains, associated embedment / backfill material and erosion voids, another being predominantly through the embedment material in sewer and other service trenches with some linkage through natural materials where there are gaps in the trench pathway and the third through natural materials, in the latter case predominantly along interfaces between different materials. These potential pathways have been extensively discussed in the reports prepared by WSP, PSM, SMEC and AEA. In my opinion, these pathways are not mutually exclusive; water could have flowed through either or both. The slope of the ground surface between Bayview Road and the landslide site is typically between 9% and 11%; although the average gradient in service trenches will be somewhat lower, as they do not take a direct path, from a hydraulic perspective it is still high. The pathways through natural materials are likely to be along the interfaces between material "layers" – generally degree-of-weathering zones. While the gradients are unknown and likely to be variable, they are also likely to be similar to the land surface gradient. I consider that both pathways are potentially viable.

7.1 Service Trench Pathways

Figure 5 (WSP Figure 8.27) shows a potential pathway through sewer trench embedment identified by WSP, and also discussed by SMEC. I understand that the marked water outbreak on Charlesworth Road near the junction with Coburn Avenue was substantial, with water flowing down the road, and the road surface needing immediate repair. This pathway continues through sewer embedment material around Prospect Hill Road to View Point Road, and along View Point Road. It is my understanding the predominant embedment material in the sewer trenches in this area is a gravel-sized aggregate derived from local weathered granite, which is likely to have similar geochemical characteristics to the granite parent material. As indicated above, samples of embedment material from the sewer excavation on Bay View Road were examined by XRD, with the results provided in **Table 3.** It can be seen that the principal minerals present at concentrations above 1% are Quartz, Sodium Plagioclase, Potassium feldspars, Biotite and Kaolinite, with Calcite present in sand bedding only. I have modelling the reaction of the silicate minerals with SEW mains water and concluded that the extent to which these minerals will dissolve in the likely time available is small.

PSM (Causation Report) indicates a water transmission capacity of 22 to 29 KL/day for this material. PSM has also demonstrated a viable and quite rapid flow path between the sewer trench on View Point Road and the landslide head-scarp using a tracer test. In my opinion there is substantial evidence that this pathway was active at least as far as Coburn Avenue. As discussed below, there is also evidence of freshwater and groundwater impact at 7 Prospect Hill Road. I consider it to be very likely that the sewer embedment material pathway contributed water to the top of the landslide.

Column leaching (LEAF) tests carried out on these samples (**Figure 6**) using mains water showed an initial step increase followed by stability. It is considered that the initial small peaks may reflect the wash-out of fine colloidal material or weakly sorbed ions.

7.2 Groundwater Pathways

Both PSM and WSP indicate that groundwater, and water released from the Bayview mains leak, may have travelled though paleochannels that have been filled with transported soil or colluvium. **Figure 7** shows and explains the regional geology and WSP's conceptual model of the general stratigraphy and groundwater flow are attached as **Figures 8 and 9.** I note that there appears to be some disagreement regarding the presence, or at least the thickness, of residual granite at the head-scarp (**Figures 10 and 11**), but regardless, the model proposed is of groundwater flow at the interface between colluvium and residual or extremely weathered granite. I emphasise that I agree with this model to the extent that it is restricted to interface flow, as shown on **Figure 8**, but not flow through a substantial thickness of colluvium. In my experience, and from what I can observe in the photographs, the colluvium en masse is not likely to be a very permeable material. I think that a hydraulic conductivity of $1x10^{-5}$ m/s would be the most that could reasonably be assumed, and it may well be lower. The cross sectional area of 375 m^2 and consequent flux (discharge) 50% higher than shown in WSP Table 8.2 are also, in my opinion, unrealistic. From a geochemical perspective, it is likely that the colluvium contains a much higher proportion of clay than the either the residual granite of the trench embedment material, and water is thus likely to emerge with a more pronounced Na-Cl signature.

I agree with the process of landscape evolution outlined by WSP, It is possible that the original gully marked on the DEM (**Figure 12**) is present, and that the interface drainage observed at No. 7 Prospect Hill Road is associated with this. The is some sign of disturbance on the marked-up 1939 aerial photo (**Figure 13)** but it is not clear what this represents.

7.3 Irrigation

Many of the properties along View Point Road and Prospect Hill Road have extensive gardens which are irrigated using mains water. WSP examined the domestic water use for the last quarter of 2024 (including but not restricted to irrigation) for the property at 10-12 View Point Road (4000 to 5000 L/day), with 4 View Point Road about 80% and 5 View Point Road about 50% of that figure. Usage may have been higher than average in the days immediately prior to the landslide, given the 30^{o}C+ temperatures. WSP calculated that this use was less than 10% of the 0.1 to 0.2 L/s of water issuing from the head-scarp on 6 January 2025. However, there appears be an error in this calculation. I calculate the 10-12 Viewpoint road usage as 30% to 60% of the measured outflow, with the combined usage being within the range of the outflow estimate.

PSM used a more sophisticated approach and calculated typical daily irrigation volumes of 3400 L/day for 10-12 View Point Road and 2000 L/day for 4 View Point Road (my rounding). These figures are comparable to the WSP volumetric calculation, even though a quite different methodology was used. I have thus decided to include irrigation use in the overall water balance.

7.4 Foundation Drainage

The house at 7 Prospect Hill Road was built on a site that experiences significant problems with groundwater seepage. The site is located at a local topographic low-point, and it seems likely that perched groundwater at the colluvium / residual granite interface lies close to the surface. A passive slotted-pie subfloor drainage system has been installed; it is understood that this discharges to the Prospect Hill Road stormwater drainage system. It seems likely that direct discharge to the service trenches in Prospect Hill Road may also occur. Water collected by the drainage system has been sampled three times since January 2025 with the chloride concentration rising from 81 to 120 and most recently 180 mg/L. This trend is well outside measurement error. It is considered likely that prior to January 2025, water overflowing from the sewer trench entered the system, diluting the groundwater inflow, and that solute concentrations, including chloride, are returning to levels reflecting salinity in the interface aquifer.

7.5 Water Balance

I consider that water from four different sources – water main leakage, garden irrigation, building foundation drainage and direct interface groundwater flow - could have contributed to the flow that was measured emerging from the head-scarp on 6 January 2025. A chloride mass balance in milligrams could be written as follows:

$$C_{hs} V_{hs} = C_{mains}V_{mains} + C_{irrigation}V_{irrigation} + C_{drainage}V_{drainage} + C_{groundwater} V_{groundwater}$$

since the chloride concentrations in each of the potential contributory sources and the head-scarp seepage have been measured, and the infiltration rates are known or can reasonably be estimated.

Mass balance can be achieved with measured concentrations and infiltration rates as follows;

TABLE 4
Chloride Mass Balance

Source	Proportion of total inflow	Chloride concentration	Infiltration Rate	Mass inflow	Head-scarp outflow	Outflow concentration	Mass outflow
	%	mg/L	L/s	mg/s	L/s	mg/L	mg/s
Mains leakage	9%	20	0.014	0.27			
Interface Groundwater	66%	480	0.099	47.5			
Irrigation	15%	20	0.023	0.45			
Drainage	10%	80	0.015	1.20			
Total	**100%**			**49.4**	0.15	330	**49.5**

It can be seen from **Table 4** that a chloride mass balance can be achieved with a relatively low rate of mains water infiltration. Most of the water inflow required to balance the measured outflow by seepage from the head-scarp is derived from interface flow of groundwater.

8 Concluding Comments

This report has reviewed as much of the available data as possible in the space available. Given that limited space (and time) the report has focussed on the key issue of the sources of water available to feed the observed head-slope leakage at the lime of the January 5th landslide, and the relative contributions from these sources required to satisfy a chloride mass balance. I think it likely that that the seepage recorded from the landslide path was a mixture originating from a number of sources. My analysis has found that only a minor contribution from mains water leakage transiting via service trench backfill is required to satisfy a chloride mass balance requirement, with the bulk of the water being sourced from interface groundwater flow. In my opinion, due to the relatively low hydraulic conductivity and limited flowpath thickness available for interface flow, I expect the linear flow velocity to be low, requiring a long transit time. I therefore consider it to be unlikely that this flow originated form the Bayview Road mains leak.

Irrelevant & Sensitive

References

Shovon Barua, Ian Cartwright1, P. Evan Dresel, and Edoardo Daly 2021, *Using multiple methods to investigate the effects of land-use changes on groundwater recharge in a semi-arid area*, Hydrol. Earth Syst. Sci., 25, 89–104, 2021

Crosbie RS, Morrow D, Cresswell RG, Leaney FW, Lamontagne S and Lefournour M 2012, *New insights into the chemical and isotopic composition of rainfall across Australia*. CSIRO Water for a Healthy Country Flagship, Australia.

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TABLES

TABLE 1 HYDRAULIC CHARACTERISTICS						
Medium	**Lithology**	**Condition**	**Porosity[1]**	**Hydraulic Conductivity[2]**	**Nominal Thickness**	**Hydraulic Gradient**
				m/s	m	
Topsoil / subsoil	Silty sand, fine	Unconfined, Generally unsaturated	0.4	**1×10^{-5} to 2×10^{-5}**	variable	_
Trench embedment material[3]	granite-derived gravel	Unconfined aquifer	0.35	1×10^{-4} to 1×10^{-3}	0.5	0.10
Trench embedment material	sand	Unconfined aquifer	0.3	1×10^{-5} to 1×10^{-4}	0.5	0.10
Fill materials	Variable	Unsaturated, or unconfined perched aquifer	0.2	*1×10^{-6} to 1×10^{-3}*	0 to 1.5	_
Colluvium, including channel infill material	Clayey sand and silty sand to sand, with gravel and cobbles	Unconfined; discontinuous; locally saturated at base, forming perched aquifer	0.2 to 0.3	*1×10^{-5} to 2×10^{-3}; locally up to 2×10^{-1}*	0.5 to 2.0	0.10 – 0.12
Residual soils	Clayey sand to sandy clay or silt	Aquitard	0.4	*1×10^{-10} to 1×10^{-7}*	Up to 9.5	0.12
EW Granite	Clayey sand to sandy clay with relict rock fabric	Aquitard	0.2	**1.0×10^{-7} to 2.3×10^{-6}**		0.14
MW to HW Granite	Granite with substantial weathering of biotite and partial weathering of feldspars to clay minerals	Unconfined aquifer	0.2	*1×10^{-6} to 1×10^{-5}*		
Granite	Biotite granite	Hydrogeological basement	0.01	Very low		

Generally present

Locally present

[1] Estimated with reference to Freeze and Cherry 1979 Table 2.4

[2] Estimated with reference to Freeze and Cherry 1979 Table 2.3

[3] Nominal sewer trench width 1m., other services narrower

TABLE 2
Melbourne Rainfall Dissolved Components: Event-Weighted Means

Date	Rainfall	Weighting	pH	H+	EC	EC	Total Alkalinity	F-	Cl-	Br-	NO3-	SO4-	Ca	K	Mg	Na	S	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	P	Pb	Sb	Se	Si	Sr	Zn
	mm		units	M/L	dS/m	µS/cm	meq/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Jun-09	25.8	0.4	6.4	3.98E-07	0.03	30		0.08	5.6	<0.05	<0.05	2.4	0.676	0.201	0.364	3.47	0.74	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.13	<0.05	0.0999
Jul-09	39.6	0.6	6.8	1.58E-07	0.04	40		<0.05	7.5	<0.05	1.7	2.5	0.623	0.155	0.445	4.17	0.713	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.583	<0.05	0.066
Aug-09	41.2	0.7	6.1	7.94E-07	0.03	30		<0.05	5.1	<0.05	<0.05	1.9	0.502	0.183	0.316	2.86	0.502	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.125
Sep-09	71.2	1.1	6.2	6.31E-07	0.03	30		<0.05	4.1	<0.05	<0.05	1.6	0.609	0.139	0.29	2.58	0.464	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.221	<0.05	0.117
Oct-09	22.0	0.3	5.8	1.58E-06	0.06	60		<0.05	10	<0.05	<0.05	4.4	1.38	0.388	0.883	6.59	1.43	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.317	<0.05	0.201
Nov-09	103.6	1.6	6.4	3.98E-07	0.02	20		<0.05	1.1	<0.05	<0.05	1.2	0.571	0.115	0.129	2.11	0.323	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.354	<0.05	0.219
Dec-09	60.2	1.0	6.3	5.01E-07	0.03	30		<0.05	3.1	<0.05	<0.05	1.5	0.809	0.174	0.301	3.26	0.444	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.43	<0.05	0.0728
Jan-10	25.6	0.4	6.1	7.94E-07	0.05	50	0.08	<0.05	11	<0.05	<0.05	3.1	0.813	1.14	0.709	5.1	0.944	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.211	<0.05	0.113
Feb-10	62.8	1.0	6.8	1.58E-07	0.08	80	0.40	<0.05	9.3	0.055	<0.05	1.1	6.24	1.34	0.478	5.04	0.383	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.12
Mar-10	84.8	1.3	5.9	1.26E-06	0.02	20	0.05	<0.05	2.5	<0.05	0.84	1.3	0.377	0.114	0.19	1.28	0.356	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.0641
Apr-10	21.4	0.3	5.5	3.16E-06	0.04	40	0.07	0.06	7.0	<0.05	<0.05	2.1	0.836	0.314	0.673	3.69	0.954	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	0.171	<0.05	0.163
May-10	25.0	0.4	4.7	2.00E-05	0.02	20	0.02	<0.05	2.2	<0.05	<0.05	1.9	0.363	0.163	0.177	0.96	0.612	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.0959
Jun-10	63.4	1.0	4.7	2.00E-05	0.03	30	0.02	<0.05	5.5	<0.05	0.86	2.1	0.233	0.642	0.361	3.52	0.712	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.126
Jul-10	30.8	0.49	4.28	5.25E-05	0.02	22		<0.05	2.0	<0.05	1.0	2.1	0.157	0.1	0.175	1	0.648	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.07
Aug-10	68.2	1.08	4.55	2.82E-05	0.02	23	0.00	<0.05	4.2	<0.05	<0.05	1.7	0.124	0.1	0.249	2.07	0.543	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.102
Sep-10	53.0	0.84	4.80	1.58E-05	0.03	31	0.02	<0.05	6.2	<0.05	0.06	3.2	0.318	0.213	0.393	2.89	0.96	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	0.0717	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.557
Oct-10	144.8	2.29	5.62	2.40E-06	0.01	13	0.04	<0.05	2.2	<0.05	<0.05	1.2	0.207	0.1	0.183	1.14	0.349	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.0888
Nov-10	115.2	1.82	4.95	1.12E-05	0.01	12	0.03	<0.05	1.3	<0.05	0.42	1.2	0.191	0.1	0.113	0.677	0.35	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.256
Dec-10	85.2	1.35	5.29	5.13E-06	0.02	21	0.07	<0.05	3.1	<0.05	<0.05	0.65	1.18	1.11	0.258	1.37	0.299	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.16
Jan-11	89.6	1.4	5.3	5.01E-06	0.0	10	0.04	<0.05	1.4	<0.05	<0.05	0.83	0.196	0.1	0.145	0.742	0.273	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.159
Feb-11	131.4	2.1	5.9	1.26E-06	0.01	10	0.06	<0.05	2.2	<0.05	<0.05	1.1	0.302	0.1	0.211	1.18	0.34	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.107
Mar-11	30.4	0.5	5.8	1.58E-06	0.05	50	0.07	<0.05	7.9	<0.05	<0.05	3.7	0.777	0.127	0.538	4.39	1.26	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	1.04
Apr-11	99.6	1.6	6.2	6.31E-07	0.08	80	0.10	<0.05	18	<0.05	<0.05	4.4	1.12	0.673	1.38	8.66	1.45	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	1.89
May-11	68.4	1.1	5.6	2.51E-06	0.04	40	0.07	<0.05	8.0	<0.05	<0.05	3.2	0.576	0.19	0.54	4.32	1.01	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.616
Jun-11	32.4	0.5	6.8	1.58E-07	0.29	290	1.90	<0.05	28	0.12	<0.05	0.23	30.2	12.5	3.01	13.8	0.707	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	3.26	<0.05	<0.1	<0.05	0.446	0.181	<0.05
Jul-11	37.4	0.6	7.4	3.98E-08	0.10	100	0.49	<0.05	11	<0.05	<0.05	2.9	1.36	2.14	0.73	5.77	0.966	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.219
Aug-11	19.0	0.3	7.1	7.94E-08	0.06	60	0.21	<0.05	5.3	0.07	3.70	3.7	1.26	0.34	0.433	3.03	1.17	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.344
Sep-11	72.1	1.1	5.7	2.00E-06	0.02	20	0.05	<0.05	4.2	<0.05	<0.05	1.7	0.545	0.295	0.329	2.4	0.532	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.182
Oct-11	63.1	1.0	5.4	3.98E-06	0.02	20	0.08	<0.05	2.4	0.05	<0.05	1.5	0.251	0.103	0.179	1.62	0.484	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.121
Nov-11	108.8	1.7	5.9	1.26E-06	0.01	10	0.09	<0.05	1.6	<0.05	0.73	0.46	0.231	0.119	0.161	1.09	0.307	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.1	<0.05	<0.1	<0.05	<0.1	<0.05	0.305
Mean	63.2		5.8	6.12E-06	0.04	43.1	0.2	0.1	6.1	0.1	1.2	2.0	1.8	0.8	0.5	3.4	0.7	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	0.1	<0.1	<0.05	<0.05	<0.05	3.3	<0.05	<0.1	<0.05	0.3	0.2	0.3
Median	63.0		5.9	1.42E-06	0.03	30.0	0.1	0.1	4.7	0.1	0.9	1.8	0.6	0.2	0.3	2.9	0.6	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	0.1	<0.1	<0.05	<0.05	<0.05	3.3	<0.05	<0.1	<0.05	0.3	0.2	0.1
Max	144.8		7.4	5.25E-05	0.29	290.0	1.9	0.1	28.0	0.1	3.7	4.4	30.2	12.5	3.0	13.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.6	0.2	1.9
Min	19.0		4.3	3.98E-08	0.01	10.0	0.0	0.1	1.1	0.1	0.1	0.2	0.1	0.1	0.1	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.1	0.2	0.1
Weighted Mean								**<0.05**	**5.57**	**<0.05**	**0.25**	**1.84**	**1.57**	**0.68**	**0.43**	**3.03**	**0.61**	**<0.05**	**<0.05**	**<0.1**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.1**	**<0.05**	**<0.1**	**<0.05**	**<0.1**	**<0.05**	**0.36**

TABLE 4 X-RAY DIFFRACTION ANALYSIS RESULTS							
	Calcite	Chlorite Group	Kaolinite Subgroup	Mica Group	K-Feldspar#	Quartz	Na-Plagioclase##
Bayview Hand Auger.			1		30	54	15
Bayview Sewer Dig.			5		20	59	15
Bayview Sewer Sand.	14	2	2	5	9	60	8
Bayview 7 March.			2	3	16	69	10
Bayview Sewer Gravel.	<1	4		5	23	50	17

Notes:

- Potassium Feldspar.

- Sodium Plagioclase.

FIGURES

Figure 1: Aerial Photograph of the McCrae Area dated 1939. It can be seen that forest extends across most of the foot-slope

Figure 2: 2023 Google Earth image of the area shown in Figure 1, provided for orientation

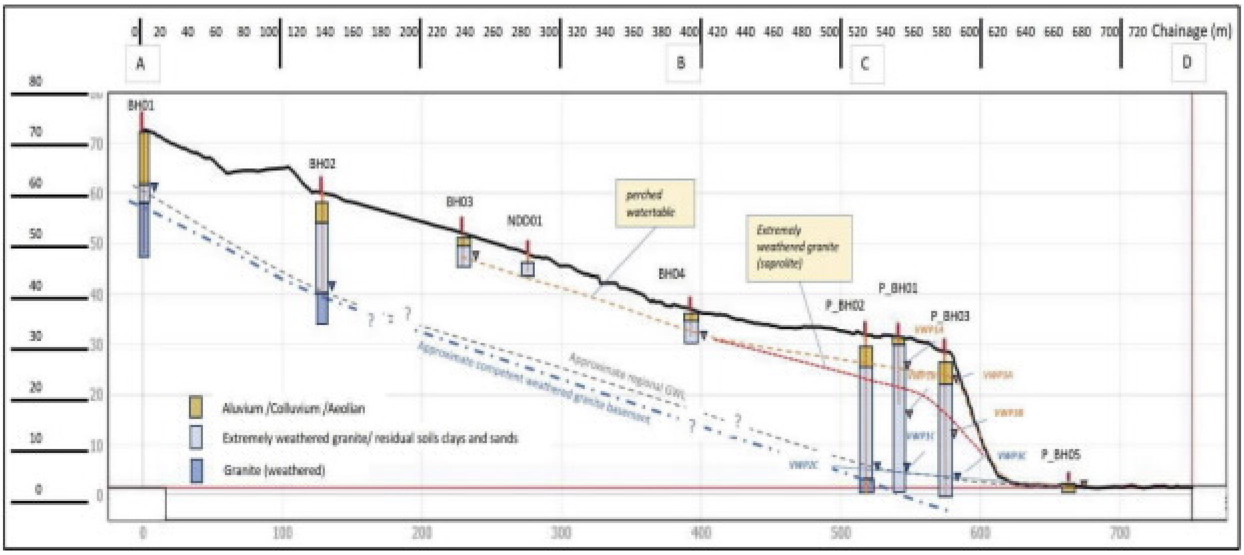


Figure 3: Section drawn approximately along the flowpath shown on Figure 5, showing depth of bores and screened sections in relation to interface flowpath.

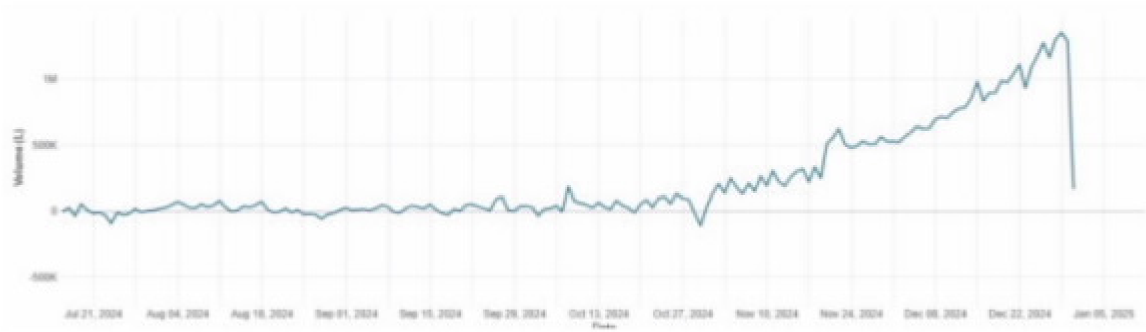


Figure 8.15 Adjusted water balance in McCrae area, July to December 2024 (from SEW.0001.0001.0746).

Figure 4: Rate of Outflow from SEW Bayview Road Water Main

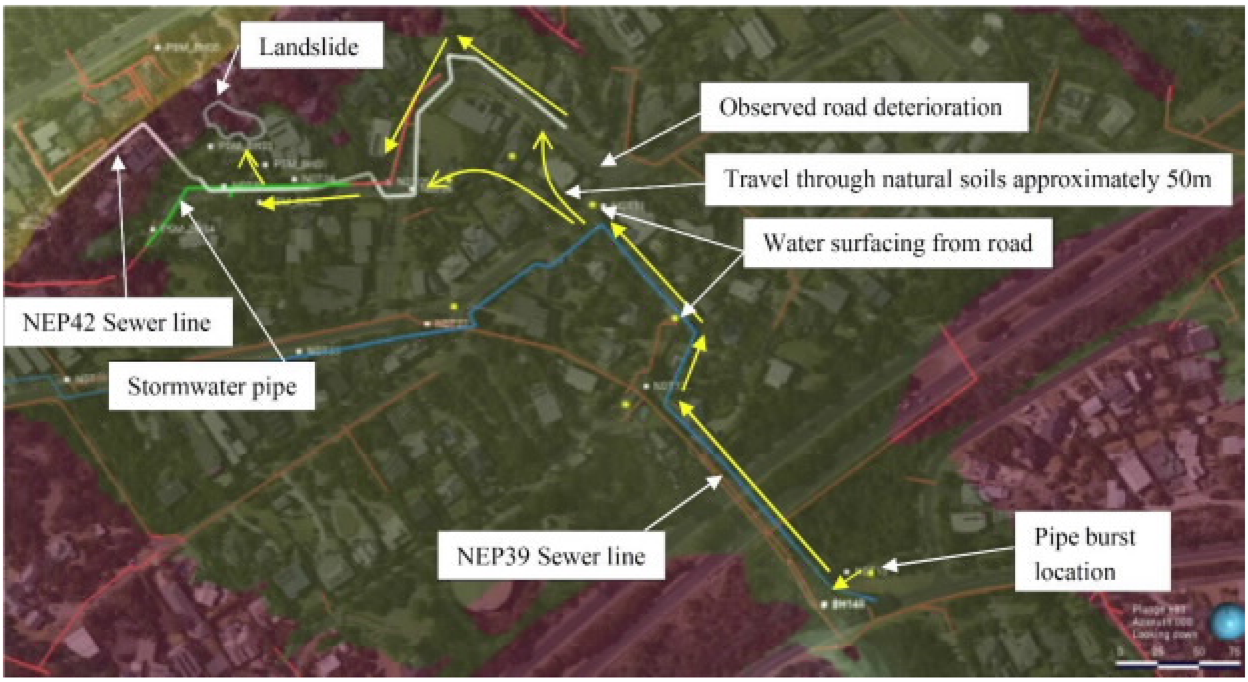
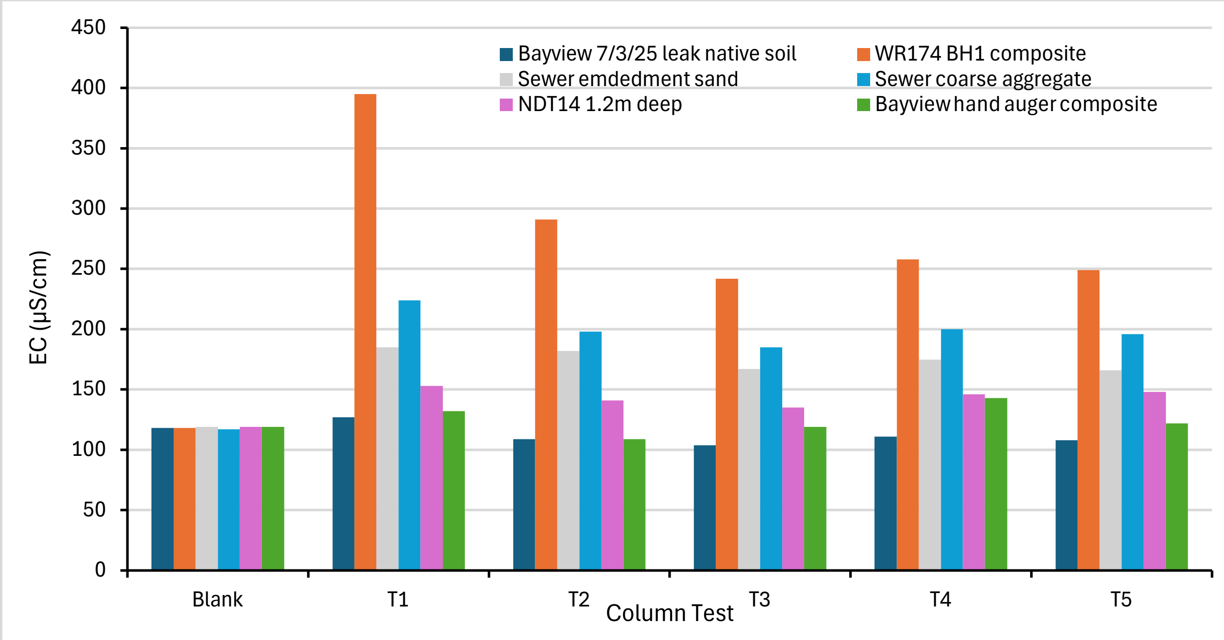


Figure 5: Flow Pathways through Sewer Embedment Material



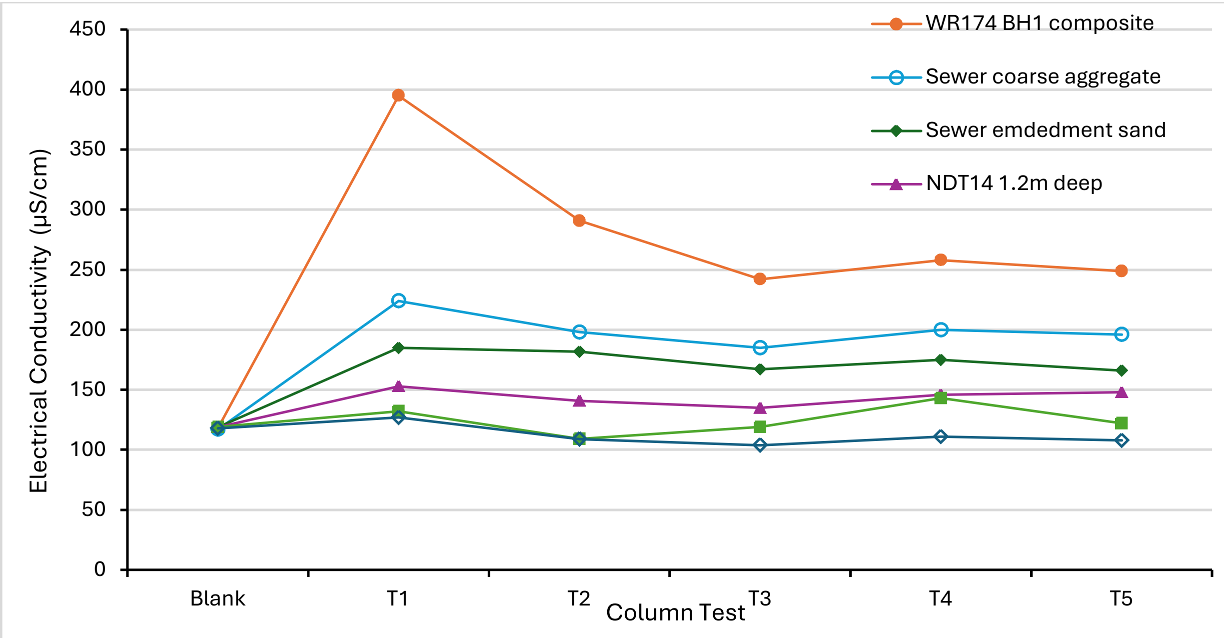
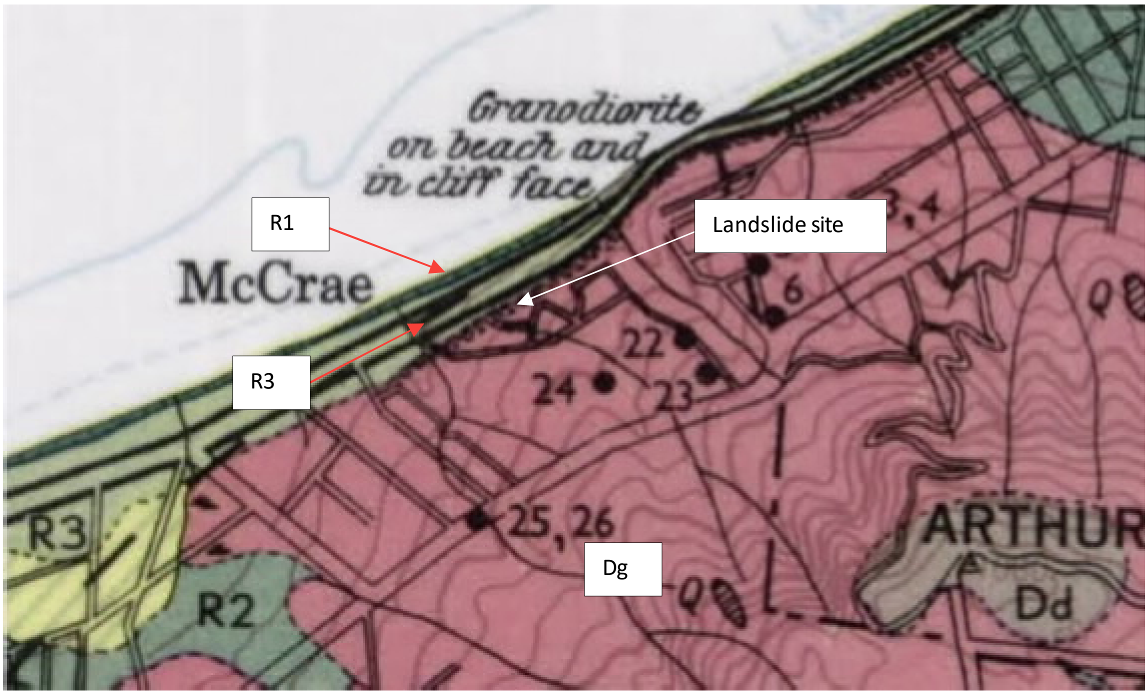


Figure 6: Leaf Tests

Figure 7: Geology

The Devonian-age Dromana Granite extends from Arthurs Seat to the escarpment. Holocene coastal deposits to the north-west between the scarp foot and the coast. The Selwyn Fault trends parallel to and beneath or somewhat to the north-west of the scarp.



a. R1: Holocene[6] age coastal deposits, comprising siliceous sand, shell beds.

b. R3: Holocene age raised coastal deposits, comprising siliceous and calcareous sand, shell beds, guano (Mud Islands).

c. Dg: Devonian[7] age granodiorite, referred to as Dromana Granite since 1988. The term granite is used in this statement to reference the Dromana Granite.

The Dromana Granite is described as a biotite granite: greenish, medium-grained, equigranular granite containing quartz, greenish orthoclase, perthite, oligoclase and biotite with accessory sphene, zircon, ilmenite and apatite; intruded by dykes of porphyry and aplite. (REF). Above the granite, there is a typical weathering profile that progresses upwards through highly then extremely weathered granite to residual granite soils and, locally, colluvial soils and fill materials.

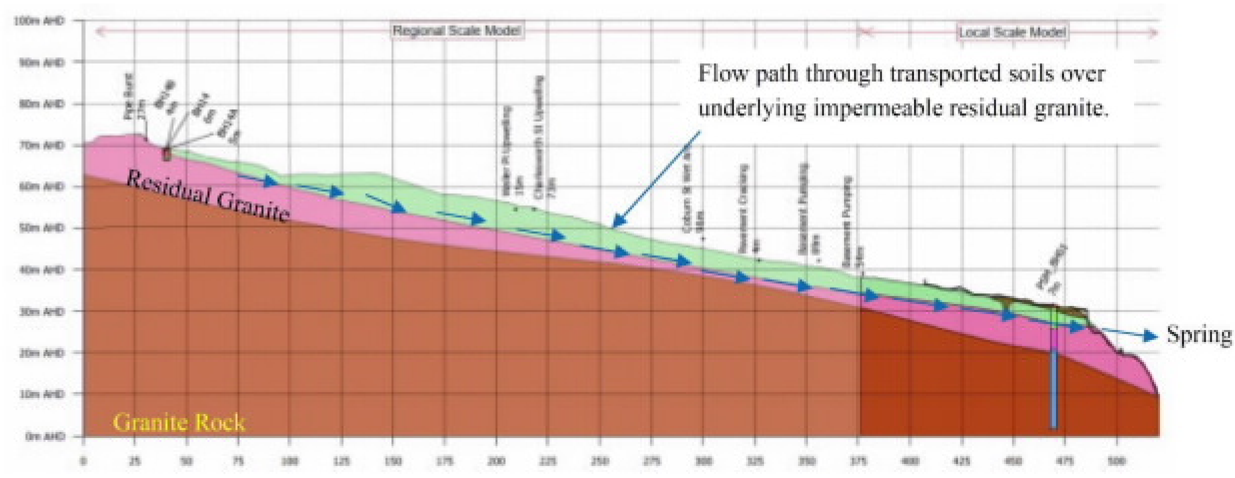


Figure 7.7 Conceptual hydrogeological sketch. Showing natural flowpaths between the foot of Arthurs Seat at The Boulevard and the McCrae Escarpment.

Figure 8: WSP Regional Conceptual Model showing Drainage at the Colluvium-Residual Granite Interface

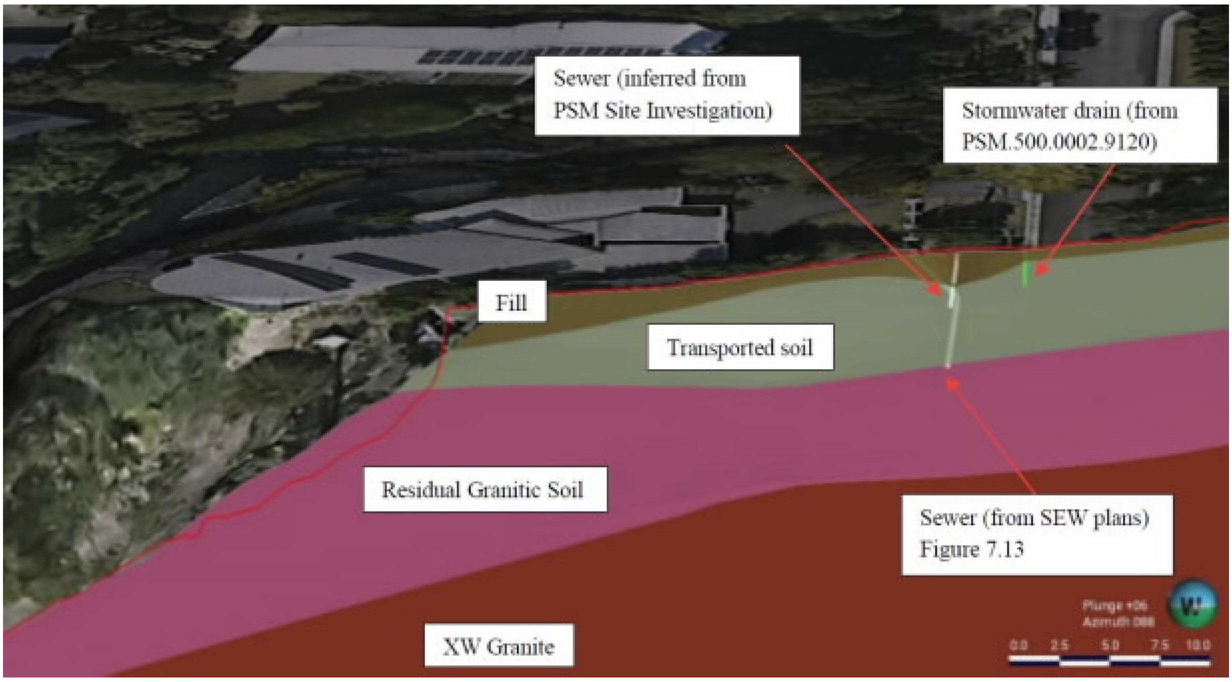


Figure 9: WSP Local Conceptual Model

Figure 10: (Figure 6.1 from WSP Causation Report) Photograph showing layer structure in head-scarp

Figure 11: PSM Photograph of head-scarp, the EW granite seen in the right foreground, suggests that interface groundwater flow may be locally on an EW Granite interface, rather than on a residual interface.

Figure 12: Gully Erosion

The land surface falls towards the north west, from an elevation of approximately 310 m AHD at Arthurs Seat to about 10 m AHD at the top of the escarpment at McCrae. From the base of the scarp below Arthurs Seat to the top of the coastal escarpment at McCrae, the land surface falls quite evenly at a gradient of 0.13, easing to 0.10 then 0.09 north of the freeway. This slope is cut by a number of north-west to north trending gullies, some of which are partially or completely infilled with colluvium.

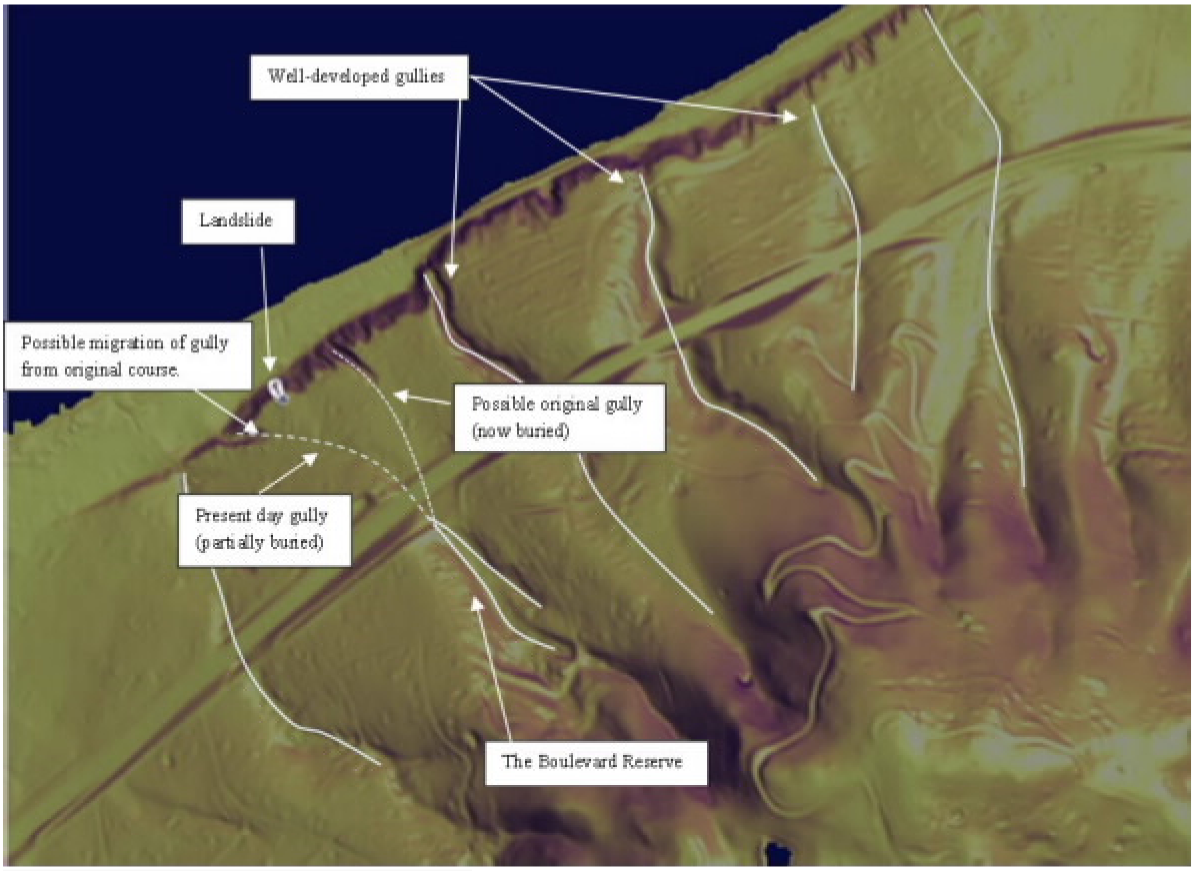


Figure 6.5 from WSP Causation Report

There seems to be no evidence for the "possible original gully" on the 1939 AP and its presence would be inconsistent with the otherwise vet even spacing of the gullies, capturing equivalent drainage volumes.

It is likely that the gully beds have a similar overall slope to that of the land surface, with locally steeper sections.

Figure 13 – 1939 Photograph marked up with location of Bayview Road leak, and landslide, also highlighting gully.