BEFORE THE COMMISSION
APPOINTED BY THE OTAGO REGIONAL COUNCIL

UNDER	the Resource Management Act 1991 (RMA)
IN THE MATTER	Of an application by Dunedin City Council for resource consent being processed with reference RM20.280
BY	**BIG STONE FORESTS LIMITED, ŌTOKIA CREEK AND MARSH HABITAT TRUST AND SOUTH COAST NEIGHBOURHOOD SOCIETY INC** **Submitter**

STATEMENT OF EVIDENCE OF DAVID IFE

DATED 6 MAY 2022

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STATEMENT OF EVIDENCE OF DAVID IFE

Introduction

1. My name is David Ife. I am a Senior Principal Hydrogeologist with EHS Support Pty Ltd. I specialise in hydrogeological assessment and landfill management.

Qualifications and Experience

2. I hold a Bachelor of Science (Hons) and a Master of Applied Science (Hydrogeology) and I am a member of the International Association of Hydrogeologists

3. I have over 48 years' experience in hydrogeological assessment, waste management, salinity, catchment management and water resources development and for the last 28 years I have provided consulting services to designers and operators of landfills and other waste management facilities throughout Australia and in Taiwan, Singapore, Indonesia, Georgia and India.

4. Some of my work experience which is relevant to this application is as follows:

   a) Hydrogeological assessments, landfill gas risk assessments, rehabilitation planning and aftercare management plans for landfills around Victoria, including Boral Western Landfill, Smythesdale, Eaglehawk, Colac, Dooen, Wyndham, Tyabb, Rye, Maddingley (Bacchus Marsh) and closed landfills at Heatherton Park, Rowan-Spring Road, Keilor, Cathies Lane, Llewellyn Park.

   b) During 2017 – 2018 Technical Director with AECOM for a geo-environmental and geotechnical study of a former landfill in Singapore that is now used for multiple recycling operations.

   c) In 2018 – 2019 Technical adviser for the Sambirejo Landfill hydrogeological study in Indonesia. The site is a former landfill comprising lamp glass waste and is to be re-developed as a soccer pitch for the local community.

d) Preparation of Works Approval application for Cosgrove 3 landfill in Shepparton.

e) Hydrogen sulphide management study at Woodlawn Bioreactor landfill.

f) Investigation of hydrogeological characteristics of a site for the development of a long-term containment facility in Nowingi, Victoria involving drilling and testing of 40 boreholes, the carrying out of hydraulic testing and the assessment of impacts of potential leachate seepage on groundwater quality and the environment.

g) Waste management study for BP BTC in Georgia to locate a site and develop a concept design for an EU-compliant landfill facility to accept non-hazardous wastes from BP Operations in Georgia associated with construction and maintenance of the BTC Pipeline.

h) Inspection of hazardous waste treatment facility and landfill in Kaosiung, Taiwan and the development of construction QA/QC and Inspection and Testing Procedures for the ongoing management of the facility.

i) Woodlawn bioreactor landfill – provision of ongoing advice in relation to leachate and landfill gas management and water balance studies.

j) Hydrogeological analysis of the Woodlawn open cut mine and development of a proposal to convert the mine to a solid waste landfill for municipal waste from Sydney. Presentation of evidence before a Commission of Inquiry concerning the hydrogeological integrity of the site and the security of the site with respect to potential for leachate migration.

k) Preparation of an EES for the Werribee prescribed waste landfill. The project involved the design of a landfill to receive prescribed waste and the modelling of leachate seepage rates and solute transport through various liner configurations to assess the impacts of each option on groundwater quality.

l) Training staff in Himachal Pradesh in the development of a waste management strategy for industrial waste in the Baddi – Barotiwala Industrial Area, under an AusAid project in India.

m) Hydrogeological study and conceptual design of a proposed landfill at Highbury in Adelaide SA. The project involved designing a putrescible waste facility that would not adversely impact on the beneficial uses of the environment. The protection of groundwater was a key consideration at this site.

n) Training of Chinese hydrogeologists in Beijing at the China Australia Research Institute into Mine Waste Management (CARIM) in the use of groundwater models for assessing the impacts of contaminated leachate from tailings dams on groundwater and surface water quality. The training involved the use of SEEP/W, CTRAN/W, MODFLOW, PM for Windows and SURFER computer codes.

Expert witness code of conduct

5. Although not necessary in respect of council hearings, I can confirm I have read the Expert Witness Code of Conduct set out in the Environment Court’s Practice Note dated 1 December 2014 and agree to comply with it. I have complied with the Code of Conduct in preparing this evidence and I agree to comply with it while giving oral evidence before the hearing committee. Except where I state that I am relying on the evidence of another person, this written evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed in this evidence.

Scope and Structure of Evidence

6. My evidence will address the following matters within my areas of expertise:

    a) Does the site accord with present landfill siting criteria?

    b) Are the leachate management arrangements adequate to protect adjacent wetlands?

    c) Will the proposed development present an unacceptable risk to ecological values of the adjacent wetlands?

    d) Is the Landfill Management Plan adequate and appropriate for a facility of this size and scope?

Previous Reports Reviewed to Prepare Statement

7. I have reviewed the following reports and materials in preparing my evidence:

    a) Application appendix 2 – General arrangement

    b) Application appendix 3 – Landfill concept design report

    c) Application appendix 4 – Concept design plans

    d) Application appendix 8 – Groundwater report

    e) Application appendix 12 – Amended landscape mitigation plan

    f) Further s92 response – Draft landfill management plan

    g) Further s92 response – Final ORC response 5 Aug 2021

    h) Further s92 response – Updated alternative assessment 5 Aug 2021

    i) Original s92 response – Beca site selection assessment 1992

    j) Tonkin&Taylor Technical review to inform notification decision – Groundwater Report

k) Tonkin&Taylor Technical review to inform notification decision – Design Report

l) Wasteminz Technical guidelines for disposal to land – Project Team draft (Aug 2018)

m) UNEP – Technical guidelines on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfill

n) Statements of Evidence of Anthony Kirk, Dr Mark Stirling and Samantha Webb, 19th April 2022

Siting and Design Basis

8. The location of the site is shown in Figure 1 of the Landfill Concept Design Report. It is owned by Dunedin City Council and is bounded to the north and west by forestry land and to the northeast by farmland. The landfill footprint covers 18.6 ha. There are some smaller blocks of land containing residential dwellings and forestry in the vicinity also.

9. Guidance on landfill siting and design is provided in a number of references internationally, but in the New Zealand context three guideline references are considered relevant – Centre for Advanced Engineering (CAE) Landfill Guidelines (2000), WasteMINZ Technical Guidelines for Disposal to Land – Project Team draft (WasteMINZ, 2018) and the EPA Victoria Best Practice Environmental Management – Siting, design, operation and rehabilitation of landfills (BPEM, 2015).

10. I have compared the relevant criteria from these guideline documents in **Table 1**.

11. The guidelines all recognise the importance of a number of siting criteria including geology, seismic hazard, groundwater conditions, surface water and protection of environmentally sensitive areas from potential contaminant migration.

12. The WasteMINZ guidelines are only in draft status and have not been formally adopted/endorsed by MfE..

13. The only endorsed/adopted guidelines are the old CAE Landfill Guidelines, but they are generally acknowledged as being out of date. However, the CAE guidelines have a good section (Section 4.13) on construction QA/QC.

14. I consider that the guidelines are sufficiently similar to provide a basis for review of the Smooth Hill landfill application. Although they were prepared 22 years ago, the CAE guidelines are still relevant and many criteria are replicated in the draft WasteMINZ guidelines. The draft WasteMINZ guidelines provides "technical guidance relating to the siting, design, operation and monitoring of landfills in New Zealand,

based on local and international experience" and BPEM provides more detailed guidance on siting and design of landfills, also based on local and international experience.

15. BPEM siting requirements include consideration a number of screening requirements that include, but are not limited to, consideration of groundwater and surface water conditions, geology, buffer distances and ecological conditions. Since there is much overlap with the draft WasteMINZ guidelines and the CAE guidelines, the application for the Smooth Hill landfill will be regarded in the context of the draft WasteMINZ guidelines and BPEM will only be referenced where specific items need to be expanded.

16. The landfill will receive municipal solid waste and is therefore classified as a Class 1 Landfill under the draft WasteMINZ guidelines.

17. The draft WasteMINZ requirements for Class 1 landfills, which accord with the CAE guidelines, include:

    - a rigorous assessment of siting constraints, considering all factors, but with achieving a high level of containment as a key aim;
    - engineered environmental protection by way of a liner and leachate collection system, and an appropriate cap, all with appropriate redundancy;
    - landfill gas management; and
    - a rigorous monitoring and reporting regime

18. The proposed layout of the landfill is shown in **Figure 1**.

19. The landfill will receive 60,000 tonnes/year over the 40 year life of the facility and its footprint at closure will be 18.6 ha with a total capacity of 3.3 Mm^3 (gross) and 2.96 Mm^3 (net).

Table 1 Comparison of Landfill Siting and Design Criteria

Criterion	CAE (2000)	Draft WasteMINZ (2018)	BPEM (2015)
Landfill siting	• Sites should be identified and ranked on the basis of geology, hydrogeology, surface water hydrology, stability, topography and compatibility with surrounding land use.	• Good natural containment preferred • A number of possible locations should be identified and rated according to a number of criteria including geology, hydrogeology, hydrology, topography.	• Identification of candidate sites and ranking on the basis of landfill type, groundwater, buffer distances, geology, flora and fauna, surface water, land ownership. • Valley fill landfills are to be avoided as they have inherent environmental problems such as unstable slopes, water infiltration and leachate seepage
Geology and site stability	• High permeability substrate undesirable • Karst undesirable • Consider suitability for construction materials such as clay for construction • Avoid seismically active areas	• Avoid active faults • Avoid karst areas	• Avoid sites within 100m of a fault displaced in the Holocene period (10,000 to 12,000 years BP) • Assess stability in karst areas • Consider the shrink/swell characteristics of the substrate • Assess the suitability of local materials for liner construction
Hydrogeology	• Drinking water aquifers undesirable • Consider depth to water table, location of recharge areas, distance to water users, sensitivity of water users, water quality • Consider effects of failure on groundwater	• Avoid drinking water aquifers	• Avoid areas of potable groundwater • Avoid groundwater recharge areas • Avoid Groundwater Supply Protection Areas • Avoid sites below the regional water table • Municipal (type 2) landfills to be located 2m above the water table
Hydrology	• Flood plains undesirable • Water supply catchment undesirable • Gullies with significant water ingress undesirable	Avoid • Floodplains • Water supply catchments	• Sites to be located 100m from surface waters • Avoid high-value wetlands • Avoid land liable to flooding

Criterion	CAE (2000)	Draft WasteMINZ (2018)	BPEM (2015)
	• Estuaries, marshes and wetlands undesirable • Avoid sensitive ecosystems	• Estuaries, marshes and wetlands	
Environmentally sensitive areas	Avoid • Significant wetlands • Significant areas of native bush • Recognised wildlife habitats • Areas where release of contaminants could severely affect fish/wildlife/aquatic resources	Avoid • Significant wetlands • Significant areas of native bush • Recognised wildlife habitats • Areas with sensitive fish/wildlife/aquatic resources	• Design to minimise impacts on ecology
Liner design	Three designs considered acceptable: • Single clay liner 900mm thick compacted in layers 150mm thick with a permeability not exceeding 1 x 10^{-9} m/sec • Composite liner comprising flexible membrane 1.5mm thick overlying 600mm of clay with a permeability not exceeding 1 x 10^{-9} m/sec • Composite liner comprising flexible membrane 1.5mm thick overlying a geosynthetic clay liner (GCL) with a permeability not exceeding 1 x 10^{-11} m/sec overlying a 600mm compacted subbase with a permeability not exceeding 1 x 10^{-8} m/sec	Type 2 composite liner: • Leachate drainage material, with underlying cushion geotextile to protect the geomembrane • FML of 1.5 mm HDPE geomembrane • Geosynthetic clay liner (GCL) of minimum 5 mm thickness and with k < 1 x 10^{-11} m/s • 600 mm of compacted cohesive soil clay with k < 1 x 10^{-8} m/s • 300 mm of compacted cohesive soil with k < 1 x 10^{-9} m/s	Type 2 landfill to use best available technology to control seepage to an amount not exceeding 10 L/ha/day. Liner to comprise: • Subbase • Clay or geosynthetic clay liner • Clay to be at least one metre thick with a hydraulic conductivity less than 1 x 10^{-9} m/sec • Geomembrane and protection layer • Drainage layer/leachate collection system • Geotextile

Criterion	CAE (2000)	Draft WasteMINZ (2018)	BPEM (2015)
Final capping / cover	If the final cover is to minimise infiltration of water into the waste, then the following is typically used: • 600mm vegetation layer (k<1 x 10^{-7} m/sec) • 300mm filter layer • 300mm biotic barrier layer • 300mm drainage layer • Flexible membrane layer (1 – 1.5mm thick) • 600mm com[acted clay layer	Enhanced Minimum: • 150mm topsoil • 300mm growth media layer • 600mm compacted soil (k<1 x 10-7 m/sec • Intermediate cover	Indicative landfill cap Performance – 75% of the anticipated seepage rate through the liner that meets best practice requirements • 1000mm soil • 600mm low permeability clay • 300mm earthen cover
Construction QA/QC	Considerable detail on QA/QC procedures and ASTM test methods	Testing requirements but no reference to ASTM methods	Detail on clay liners, geomembranes, GCLs and geotextiles in Appendices B, D, E and F respectively

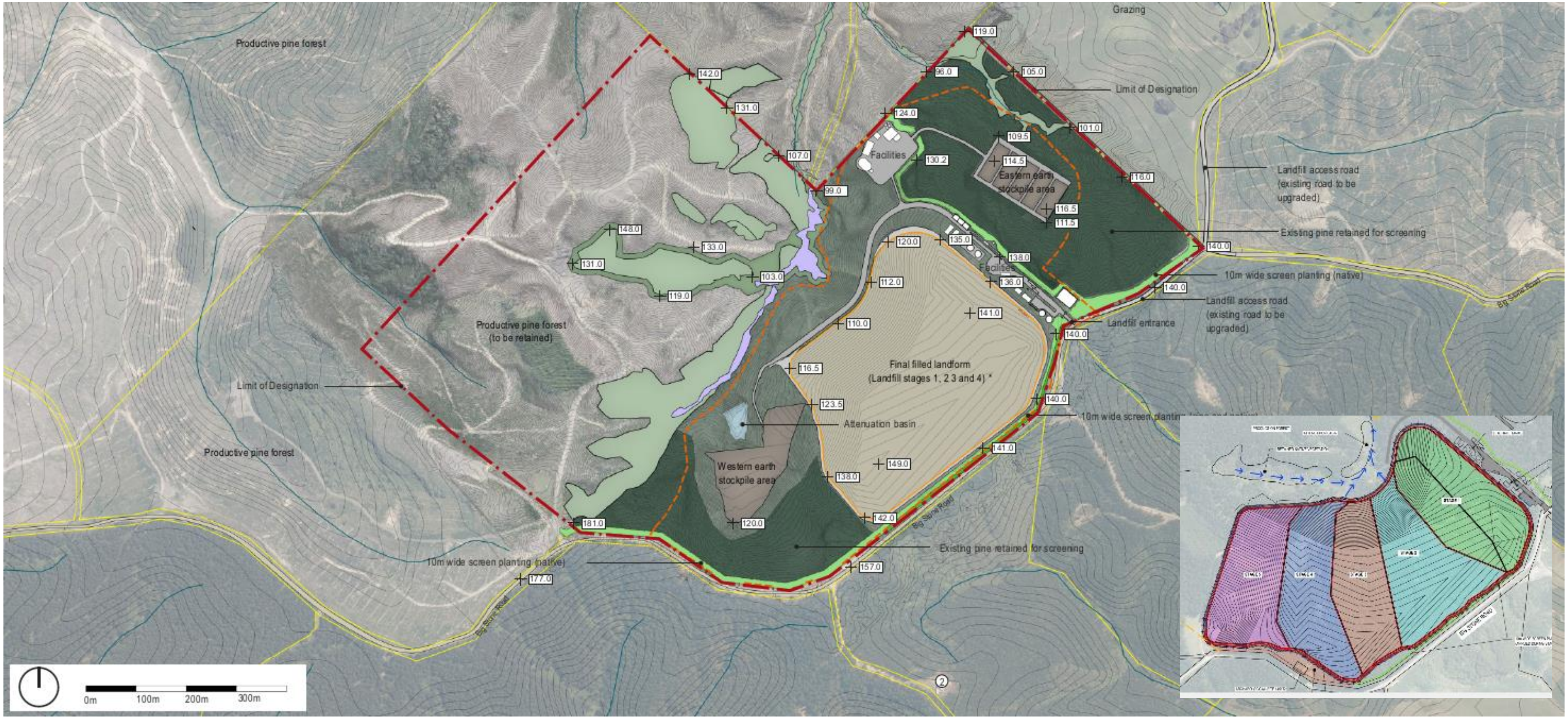


Figure 1 Smooth Hill Landfill – Proposed layout (from Dunedin City Council, 2021)

Does the site accord with present landfill siting criteria?

Geology

20. The geological map of the site is shown in Figure 4 of the Landfill Design Concept Report.

21. The dominant geological unit underlying the site is Henley Breccia overlain by up to 5m of topsoil. The topsoil comprises loess between 1.25 and 4.1m bgl.

22. I consider that the basement geology of schist and breccia would not pose problems but the overlying Tertiary and Quaternary deposits, with higher permeabilities, may be an issue.

23. The breccia is overlain by several metres of loess, alluvium and colluvium. The loess has been reworked in the colluvium and is proposed in the concept design to be the main source of material for liner and capping. I consider that the suitability of loess could be an issue for two reasons. Firstly it is dispersive and reactive and would therefore require treatment before being used. Generally calcareous deposits are not advisable as liner materials because of their reactive nature. Secondly the geotechnical testing of hydraulic conductivity found values in the range 5×10^{-10} to 3×10^{-8} m/sec. The standard to be achieved for liner and capping systems is normally 1×10^{-9} m/sec – so in many cases the loess would not meet the criterion in its natural state.

Hydrogeology

24. Two phases of intrusive site investigation were undertaken in 2019, with ten boreholes and eleven test pits advanced between May and June, and an additional five boreholes and 15 bulk samples collected from a number of shallow test pits between October and November 2019.

25. Bore locations are shown in **Figure 2**.

26. Thirteen of the boreholes were installed as monitoring wells, with ten being constructed as two nested wells. A number of shear vane tests were undertaken in the test pits and samples were collected for geotechnical laboratory analysis.

27. In the alluvium/colluvium where the landfill is to be mainly developed, groundwater levels appear to be very close to surface (refer Figures 7 and 8 in Groundwater Report - Appendix 8).

28. Water table levels are within 2m of surface in bores BH01A, BH01B, BH02A and BH02B.

29. The Statement of Evidence of Anthony Kirk states that the deep groundwater system in the Henley Breccia does not provide baseflow to any streams and that it discharges directly to the ocean whereas the shallow groundwater system is linked to surface water in the Ōtokia Creek catchment. However, his cross section C (Figure 2 of his evidence) shows that groundwater levels in the deep and shallow bores at BH01 are similar, suggesting a degree of hydraulic connectivity between the two aquifer systems at the creek level.

30. The Groundwater Report (Appendix 8) provides groundwater quality information in Table A5 (Appendix A). The table compares analyte concentrations with ORC (2016) Schedule 16A Discharge Thresholds for Discharge and ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

31. Nitrate-N exceeded the Otago threshold of 1.0 mg/L in BH01A, BH03A, BH03B and BH201 and the NH4-N threshold of 0.2 mg/L was exceeded in BH02B, BH03B, BH04B, BH201 and BH211.

32. I have compared the same set of analysis results against NZ Drinking Water Standards and the results are presented in **Table 5** with exceedances highlighted in yellow.

33. The comparison shows that, apart from elevated concentrations of iron and manganese, the groundwater is potable.

34. If potability is defined on the basis of Total Dissolved Solids (TDS), with a threshold of 1200 mg/L, all bores apart from BH4B would be classified as being potable.

35. Constructing a landfill in an area of drinking water quality is not desirable and is considered a constraint under the WasteMINZ Guidelines, particularly considering the facility will be a municipal landfill which is liable to generate more biologically active leachates and persistent organic pollutants (POPs). Although the closest active groundwater consent is located 5.7km from the site (Appendix 8 Groundwater Report, Section 2.3), high quality groundwater resources should be protected regardless of current usage and particularly because of the connectivity between groundwater and surface water systems as occurs in the Ōtokia Creek catchment.

Seismic Hazard

36. Seismicity and seismic risk are important considerations in the Dunedin region since the city has experienced a significant earthquake (magnitude 5) on 9 April 1974 and the region is seismically active.

37. The Akatore Fault is close to the proposed site, as shown in **Figure 3** and it is classified as an active fault (Taylor-Silva et al (2020)).

38. The fault is a Holocene fault that has been active over the last 10,000 years – most recently 1,000 and 700 years before present. The fault runs subparallel with the coast and is located about 3.5km southeast of the site.

39. Results of a study on the palaeoseismology of the Akatore Fault, Taylor-Silva et al (2020) indicated that for “seismic hazard assessments in nearby Dunedin, it is prudent to assume that the high rates of recent earthquakes will continue into the immediate future on the Akatore Fault”.

40. The USEPA Resource Conservation and Recovery Act (RCRA) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities (1995) indicate that a new MSW landfill “may not be located within 200

feet (60 metres) of a fault that has experienced displacement in the Holocene time" while the Victoria BPEM indicates that sites within 100 metres of a Holocene fault should be avoided.

41. The Statement of Evidence of Mark Stirling indicates that a Probabilistic Seismic Hazard Analysis (PSHA) should be conducted as a condition of consent as part of the detailed design process. Dr Stirling also indicates that he is confident that PSHA "will show the Akatore Fault will to be the dominant contributor to seismic hazard at hazard levels greater than the 10% in 50 years (475 year return period) level used in the NZ Loadings Standard". At the site itself, however, he indicates that direct fault displacement is likely to be extremely low. I agree with this observation.

Site Setting

42. I understand that the site for the landfill was selected on the basis of an alternative site assessment conducted by Beca Steven in 1992. This document compared the Smooth Hill site with another ten possible locations and provided a ranking for each based on permeability and attenuation capability of underlying formation, complexity of groundwater system and distance to environmentally sensitive areas. I consider that this ranking system is now invalid since it had no data on which to classify the hydrogeological conditions and assigns a low rating to "expected complexity of groundwater system", it applies a low rating to proximity to environmentally sensitive receptors and it didn't consider seismic risk in the ranking process.

43. On the basis of the draft WasteMINZ guidelines, appropriate landfill siting requirements that are relevant for the Smooth Hill landfill are:

- The landfill should not be sited in an area underlain by drinking water quality aquifers;
- The landfill should not be sited on active faults;
- The landfill should not be sited in significant wetland areas or areas of recognised wildlife habitats or sensitive fish/wildlife/aquatic resources.

44. The landfill site is located in an area of significant topography – with slopes between 4% and 25% and the proposed landfill is essentially a valley fill.

45. According to BPEM valley fill landfills are to be avoided as they "have inherent environmental problems such as unstable slopes, water infiltration and leachate seepage."

46. Valley fill landfills are more prone to issues of contamination arising as a result of high stormwater flows causing runoff to breach diversion drains, flow into the active cell and merge with leachate.

47. The surface water catchment area is 1.5 km^2 and the Ōtokia Creek catchment is 27 km^2.

48. To the north of the site the series of wetlands, connected by defined watercourses, continue at least as far as the culvert beneath McLaren Gully Road. It is noted that the watercourse connecting the wetlands appears to be perennial or likely to have surface water present all or most of the year. However, during dry periods such as that over the 2020/2021 summer, surface water flow ceases as far downstream as at least the culvert, and surface water retreats to occasional isolated pools where water is impounded.

49. The guidelines indicate that siting should consider the availability of construction materials for lining, cover and capping. The site is underlain by unconsolidated sediments including alluvium in the gullies (sand, silt and gravels) and loess across most of the site to depths between 1.25 and 4.1m and comprising non-plastic to low-plasticity silt, with varying amounts of clay, fine sand and gravel.

50. Loess is a wind-blown sediment and the samples from the site were found to be dispersive, with permeabilities between 3×10^{-8} and 5×10^{-10} m/sec. These characteristics are not suitable for landfill liner construction without treatment. According to the concept design report treatment with 2.5% lime resulted in a non-dispersive material but permeability may still be an issue. The statement of Samantha Webb

confirmed that lime treatment did improve dispersivity of the lime stabilised loess.

51. The low plasticity nature of loess is also an issue for construction of liner and capping and, according to the statement of Ms Webb, laboratory testing showed that lime treatment only caused a nominal increase in plasticity in lime stablised soils from the site.

52. The draft WasteMINZ guidelines provide a number of hydrogeological issues that should be considered in landfill siting, including depth to water table, groundwater quality, distance to water users, location of aquifer recharge areas, seeps or springs and connection with sensitive water uses.

53. The site is underlain by high quality groundwater and at the lower slopes of the cells the water table is close to the bases of the landfill, requiring a groundwater underdrain to be incorporated into the design.

54. In terms of stability, the Smooth Hill site is located close to the Akatore Fault. The design document indicates that a site-specific seismic hazard assessment is not required because risks can be mitigated through “liner design and leachate management practices” and published recurrence interval data.

55. The presence of the Holocene faults in the area, including the Akatore Fault and the susceptibility of the region to seismic events (refer Seismic Hazard section and Dr Stirling’s statement) indicates to me that a significant seismic hazard exists and that a site-specific seismic hazard assessment should be conducted for this facility before consent is issued.

Conclusions on Suitability of Siting

56. The site selection process used to select the Smooth Hill site for landfill development is 30 years old and is considered out of date and not appropriate in the context of the knowledge that now exists for the site.

57. An assessment of the site of the proposed Smooth Hill landfill against the draft WasteMINZ siting requirements (refer Table 4-1, WasteMINZ, 2018) is provided in **Table 2.**

58. In consideration of these factors, my view is that the site is certainly not perfect for development of a landfill and presents a number of challenges that need to be carefully considered and managed. Groundwater quality, seismic hazard, proximity to environmentally sensitive receptors and the location of the proposed facility in a valley are factors that would not give the site a high rating if an alternative site assessment had been carried out.

Table 2 Assessment of site against WasteMINZ constraints criteria

Technical Constraints	Class 1 Landfill Requirements	Smooth Hill Landfill
Site stability and seismicity	Geothermal areas	Not present
	Karst areas	Not present
	Active faults and seismic hazard	1.8km from fault line along McLaren Road (Beca, 1992) The Akatore Fault is a Holocene fault that has been active over the last 10,000 years – most recently 1,000 and 700 years before present. The fault runs subparallel with the coast and is located about 3.5km southeast of the site. Dunedin experienced a significant earthquake (magnitude 5) in 1974 and the Akatore fault is close to the proposed site and has been seismically active over the last 10,000 years.
Hydrogeology	Drinking water aquifers	On the basis of salinity, groundwater quality is suitable for potable supply.
	Depth to water table	Water table levels within 2m of surface in bores BH01A, BH01B, BH02A and BH02B
Surface hydrology	Flood plains	Not on floodplain but in a valley that may be at risk of stormwater runoff incursion during high rainfall events

Technical Constraints	Class 1 Landfill Requirements	Smooth Hill Landfill
	Water supply catchments	Not in designated water supply catchment
	Estuaries, marshes and wetlands	Wetland areas are present in adjacent property
Environmentally sensitive areas	Significant wetlands	Wetland areas are present in adjacent properties – Ōtokia Swamp 3.4km north west of the site and Lower Ōtokia Creek Marsh approximately 7.6km north east of the site.
	Inter-tidal areas	Not present

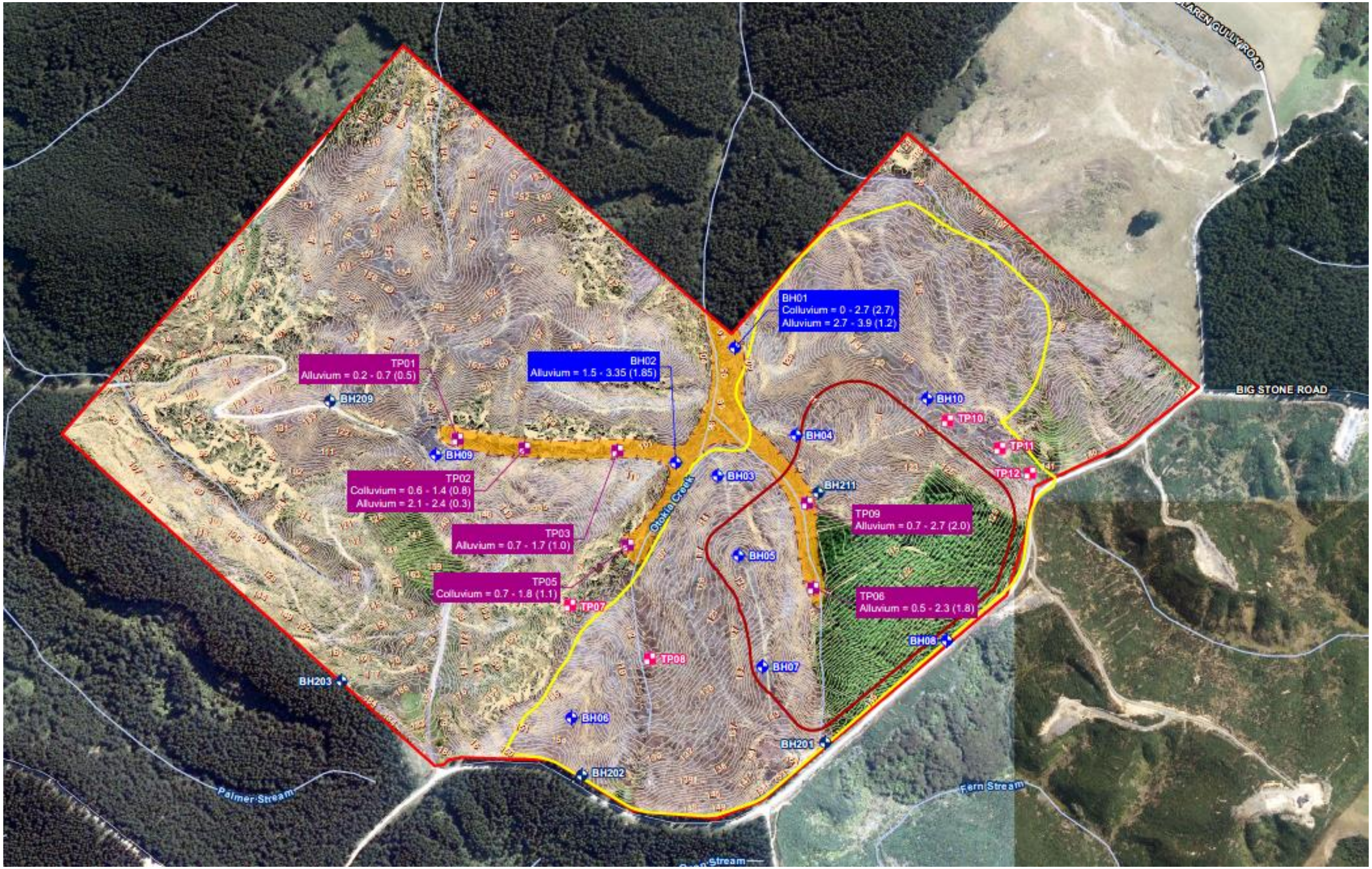


Figure 2 Bore locations (after GHD, 2021)

Are the landfill design and leachate management arrangements appropriate?

59. In respect of this question, I have considered the design elements and the potential for adverse environmental impacts posed by the facility.

Design Elements

60. This is a Class 1 (municipal) landfill – so Appendix B of the draft WasteMINZ guidelines on Design is applicable.

61. If a Type 2 liner is adopted based on the draft WasteMINZ guidelines, the design would include:

- Leachate drainage material, with underlying cushion geotextile to protect the geomembrane
- FML of 1.5 mm HDPE geomembrane
- Geosynthetic clay liner (GCL) of minimum 5 mm thickness and with k < 1 x 10^{-11} m/s
- 600 mm of compacted cohesive soil clay with k < 1 x 10^{-8} m/s
- 300 mm of compacted cohesive soil with k < 1 x 10^{-9} m/s

62. Testing of the prevailing soils on site which comprise non-stabilised loess achieved permeabilities of less than 3 x 10^{-8} m/sec. These results indicate that appropriate permeabilities could be achieved to meet most of the design metrics but the Design report also states that the loess is dispersive and would require stabilisation with lime.

63. On the basis of the draft WasteMINZ guidelines the proposed liner system options are broadly appropriate, but the application makes no indication of which will be adopted – the concept design report says this will be considered in the detailed design phase. Mr Kirk's subsequent statement indicates that that there will only be FML on 1 x 10^{-9} m/sec clay on the slopes whereas an FML and GCL will be constructed on the base but with 1 x 10^{-8} m/sec clay. I consider that it is on the base, where the head of leachate is most likely to build up, that clay with a permeability of 1 x 10^{-9} m/sec clay is required.

64. BPEM indicates that a liner system should comprise low permeability clay and a geomembrane suitable to control seepage to an amount not exceeding 10 L/ha/day. To achieve such a low seepage rate would require a 1000mm thick clay liner with a hydraulic conductivity of 1 x

10^{-9} m/sec overlain by a GCL and an intact HDPE geomembrane of 2mm thickness with a hydraulic conductivity of 1 x 10^{-14} m/sec. This liner system is a significantly higher standard than the proposed design.

65. The concept design indicates that the groundwater seepages in the shallow groundwater system located within the bottom of gullies on the site may be exposed during excavation to base grade levels. To reduce the impact of shallow groundwater seepages and springs the design has moved the "toe of the landfill uphill from the areas of wetland at the northern edge of the site…" (Sec 3.15).

66. In Sec. 3.15 the design also states that "To control groundwater beneath the landfill, a network of subsoil drains will be constructed beneath the lining system to alleviate groundwater pressures and provide sub-liner drainage protection under all stages of the landfill development."

67. The concept design states that the final capping layer will meet the draft WasteMINZ guidelines for a Class 1 landfill and will follow the "Enhanced Minimum Final Cover Design" requirements.

Suitability of Loess for Liner Construction

68. The evidence of Samantha Webb indicates that laboratory testing of soil samples from the site was focussed on two aspects – the suitability of loess for use as a low permeability liner and the suitability of weathered Henley Breccia for use as a structural engineered fill.

69. The testing showed that the dispersivity of loess soils can be mitigated by the addition of lime and could achieve a compacted permeability in the range 2.8 x 10^{-8} to 5.3 x 10^{-10} m/sec.

70. To counteract the potential impact of lime on plasticity, bentonite was added to the test sample but its effect on plasticity and dispersitivity were inconclusive.

71. Ms Webb concludes that loess may be suitable for use in the lining system but more testing will be required as part of the detailed design

phase to prove its suitability and other sources of lining materials may need to be identified.

72. I conclude that the use of loess in the lining system is not suitable because of its dispersive nature and relatively low plasticity. Testing conducted on the material suggests its performance can be improved by treatment with lime but the results presented by Ms Webb are not convincing and other sources of construction materials need to be identified.

Conclusions on Design Elements

73. An assessment of the site of the proposed Smooth Hill landfill against the draft WasteMINZ design requirements is provided in **Table 3.**

Table 3 Assessment of design against WasteMINZ minimum requirements

Item	Class 1 Landfill Requirements	Smooth Hill Landfill
Composite liner	HDPE 1.5mm, GCL and 600mm compacted cohesive soil @ k<1 x 10^{-8} m/sec	Proposed design conforms with this requirement, however BPEM indicates that a liner system for this type of landfill would require a clay liner one metre thick with a hydraulic conductivity less than 1 x 10^{-9} m/sec. Also, since the site is underlain by high quality groundwater and is susceptible to seismic events, an HDPE membrane of thickness 2mm would be preferable.
Suitability of construction materials	Avoid high permeability soils for liner and capping systems	Loess is dispersive and may require treatment with lime. Other sources of lining materials may need to be identified if further testing shows loess to be unsuitable.

74. I consider the WasteMINZ minimum requirement for a Type 1 landfill liner of 600mm of compacted cohesive soil with a hydraulic conductivity less than 1 x 10^{-8} m/sec to be inadequate for this facility and I suggest the BPEM requirement of 1000mm of compacted clay with a hydraulic conductivity less than 1 x 10^{-9} m/sec to be more appropriate and that the thickness of the HDPE geomembrane should be increased to 2mm to provide a more robust barrier.

75. I also consider that replacements for loess should be identified for the construction of the lining and capping and cover systems to meet dispersivity, plasticity and permeability requirements.

Will the landfill present an unacceptable risk to ecological values in adjacent wetlands?

Leachate Impact on Groundwater Quality

76. Leachate seepage through the liner system has the potential to impact groundwater quality.

77. The HELP analysis in the application (Technical Appendix C in the Groundwater Report) provides the results of modelling leachate generation in a layered profile representing the build-up of waste lifts on a liner system.

78. The HELP model carried out water balance assessments of 4 stages of landfill development to simulate the whole of landfill operation.

79. On completion, it is understood from Appendix 3 Concept Design Report, the final landfill footprint will be 18.6 Ha.

80. The HELP model produced two key results. The first is predicted volumes of leachate that would be collected, ranging from 21,000 m^3/year for Stage 1 up to 46,310 m^3/year for Stage 4 and 38,584 m^3/year at closure, which presumably will be an ongoing disposal requirement.

81. This is a significant ongoing disposal requirement for the Dunedin City Wastewater Treatment Plant and for tanker traffic on the road.

82. The second key outcome of modelling is the predicted seepage rate through the liner system. On the basis of the evidence of Mr Kirk, leakage of leachate through the liner system will be up to 1.4 m^3/year. Although this seepage rate is minor and will have a negligible impact on the salinity of groundwater beneath the site, I estimate that the impact of Persistent Organic Pollutants (POPs) on quality would be significant. This has not been considered in the application.

83. If Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) are taken as an example, a paper by Simmons, 2019, which examined leachate concentrations from 24 landfills across Victoria, is instructive. Simmons found these concentrations of the PFAS suite in leachate (**Table 4**).

Table 4 Dominant PFAS found in landfill leachate in Victoria (Simmons, 2019)

Compound	Mean concentration (µg/l)	Standard deviation (µg/l)	Range (µg/l)
Perfluorobutanesulfonic Acid (PFBS)	2.11	5.65	0.04 – 23
Perfluorohexanoic Acid (PFHxA)	1.71	1.97	0.11 – 7.74
Perfluorooctanoic Acid (PFOA)	0.79	0.76	0.09 – 3.12
Perfluorohexanesulfonic Acid (PFHxS)	0.55	0.55	0.03 – 2.41
Perfluoropentanoic Acid (PFPeA)	0.45	0.52	ND – 2.07
Perfluoroheptanoic Acid (PFHpA)	0.41	0.43	0.04 – 1.7
Perfluorooctanesulfonic Acid (PFOS)	0.32	0.29	0.02 – 1.2

84. Since PFAS is a group of chemicals that do not occur in nature, it is reasonable to assume that natural groundwater at the site will have virtually zero concentration of the compounds. On the basis of Simmons (2019) I've assumed that the PFOS concentration in the leachate will be 1 ug/L. The resultant impact of groundwater quality can be calculated using a mixing equation as follows:

$$GWrc = (GWf * GWc + Lf * Lc)/(GWf + Lf)$$

$$Where\ GWrc = Resultant\ groundwater\ concentration$$

$$GWf = Groundwater\ flow$$

$$Lf = Leachate\ seepage\ rate$$

$$GWc = Groundwater\ concentration$$

$$Lc = Leachate\ concentration$$

85. The evidence of Anthony Kirk indicates that the groundwater flow rate beneath the site will reduce from 3,000 m^3/year to 2,200 m^3/year once the landfill is developed. He also estimates that the leachate leakage rate will increase to a peak of 1.4 m^3/year during Stage 4 and after closure.

86. Assuming these parameters and a PFOS concentration in leachate of 1 ug/L, the predicted PFOS concentration in groundwater would be 0.000636 ug/L, which would be an unacceptable impact as it exceeds the 99% ecosystem species protection value (0.00023 µg/L) to protect wildlife from chemicals that bioaccumulate and biomagnify in the environment.

87. The HELP analysis assumes that the liner will remain largely intact throughout the life of the landfill and post-closure. In fact, liners do degrade and fail over time and under such conditions seepage rate may increase which would result in an increase in the impact on groundwater quality. Refer to the evidence of my colleague Andrew Rumsby for references on liner failure.

88. The predicted leachate volume of 46,310 m^3/year, which will contain POPs, including PFAS compounds, will also be a significant impost on the Dunedin City Wastewater Treatment Plant where it is proposed to be disposed (Chapter 5 of Appendix 3 Landfill Concept Design).

89. I am not a wastewater treatment expert but I understand that PFAS compounds cannot be destroyed in most WWTPs and although I don’t know what treatment process is employed at Dunedin, I consider it likely that once leachate from the landfill is directed to the plant, the treated water to be discharged offshore will contain water with PFAS concentrations.

90. The study undertaken by Simmons (2019) on Victorian landfills found that the mass of PFAS in leachate accounted for about 2% of the mean mass of PFAS from all sources disposed to sewer.

91. Leachate leakage will be intersected by a groundwater underdrain to be constructed beneath the liner in the lower areas of the landfill and this will also add to the contaminant load in the emerging flow.

92. The offsite migration of POPs into the small wetlands adjacent to the site must be considered in the impact assessment since the wetlands are the headwaters of the Ōtokia Creek which feeds into Brighton Beach.

Groundwater Underdrain

93. The underdrain system will provide a permeable pathway for any seepage of leachate through the liner system. The concept design indicates that "Groundwater will either be discharged to the wetlands complex to the north of the site or used for non-potable purposes on site". If this was to occur then there would be a potential pathway for contaminated water, including PFAS, to enter the environment beyond the landfill footprint.

94. The report also indicates that if monitoring of the collected groundwater indicates unacceptable quantities of leachate, the groundwater can be extracted and treated as leachate.

95. As detailed above, any seepage of leachate through the liner system is likely to contain PFAS. If this occurs then it is likely that groundwater from the underdrain will not be permitted to be discharged offsite and so the flow would need to be added to the leachate disposal load.

96. The Brief of evidence of Mr Kirk indicates that the predicted flow of groundwater from the underdrain will initially be up to 87 m^3/day during construction but is expected to decrease to negligible levels, presumably once the landfill is capped. His evidence indicates that this groundwater will be used for non-potable purposes or discharged to the Ōtokia Creek catchment, however if the predicted leakage rate eventuates, the water will be contaminated by POPs and other leachate contaminants and this volume would also need to be discharged to the Dunedin Wastewater Treatment Plant.

Conclusions on Potential Impacts

97. I consider that the predicted liner seepage rate of 1.4 m^3/year would have an unacceptable impact on concentration of POPs in the underlying groundwater system as well as the groundwater emanating from the underdrain and in the event of liner failure the predicted impact would be worse.

Is the Draft Management Plan adequate and appropriate for the proposed facility?

98. The Draft Landfill Management Plan (4th June 2021) was prepared to "support the construction, operation, closure and aftercare of the Smooth Hill Landfill".

99. The Draft has many omissions which are flagged to be finalised "following issuing of consent". In my experience, the landfill application should be accompanied by a detailed landfill management plan that would identify the responsibilities of the landfill operator, provide details on waste acceptance criteria, indicate how leachate and landfill gas are to be managed, specify monitoring requirements of the environmental segments as well as closure, rehabilitation and post-closure responsibilities.

100. Section 2.1.2 Water Quality – No data on water quality monitoring is provided, although this information is available in the Appendices to the application.

101. Section 2.1.2 indicates that "Baseline sampling of groundwater and surface water quality has been undertaken in accordance with the ORC resource consent conditions, for the purposes of setting trigger levels for monitoring to detect leachate leakage effects on groundwater, and leachate, suspended solids and turbidity on surface water quality." In spite of this, no trigger levels are provided in the draft management plan.

102. Section 2.2 Roles and Responsibilities – provides role names but does not provide responsibilities.

103. Figure 2 – Organisational Structure is missing. A draft should be provided to indicate who will be responsible for the facility.

104. Section 2.5.1 Communication indicates that communications procedures will be implemented by Landfill Operator but this definition is not recognised in Section 2.2 Roles and Responsibilities.

105. Section 3.2 Landfill Formation – The stability of the landfill in an area that may be subject to seismic activity is an important consideration however there is no detail provided in this section.

106. Section 3.3 Leachate Containment and Management - There is no indication of the volumes of leachate to be removed, its quality and its suitability for disposal. The HELP modelling section of the Groundwater Report indicates that the predicted leachate volume may be up to 46,310 m^3/year. This represents a significant management issue for the operation of the landfill and post-closure. The Management Plan provides insufficient detail on how this will be managed. There is no reference to whether the leachate will be acceptable for disposal at the Dunedin City Wastewater Treatment Plant and what contingencies will be implemented if the Treatment Plant can't accept the wastewater.

107. There is no detail on landfill gas management procedures, stormwater management procedures or groundwater management procedures in the management plan.

108. Section 3.8 Construction Management contains no detail on QA/QC procedures for installation of lining systems or leachate collection systems.

109. The Landfill Operation procedures (Section 4) are inadequate and all seem to rely on content being added following issue of consents.

110. Section 5 on Landfill Closure and Aftercare does not indicate the duration of the aftercare period or how this will be determined. There is no specific reference to after-use of the site and re-vegetation strategy for the cap.

111. Section 6 Monitoring, records and Reporting provides no detail in subsections. There are no parameter lists or threshold values for any of the primary environmental sectors such as surface water, groundwater, air quality, landfill stability and cap integrity and no trigger levels are proposed.

112. A draft Environmental Monitoring Program should be included for review before consent is issued. The EMP should define and evaluate the risks to the environment associated with the operation of the landfill and the steps which can be taken to manage and mitigate such risks.

113. The EMP should indicate, for each sector of the environment, the analyte list, the frequency of monitoring and the equipment to be used.

114. The EMP should contain trigger levels for each analyte and specify contingency actions to prevent pollution when triggers are exceeded.

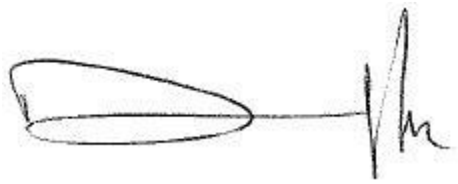
115. Monitoring records should also be made available and accessible for the community and other stakeholders and I recommend that a community consultation committee be established to facilitate this communication.

116. The Appendices on Bird Management, Vegetation Restoration, Lizard Management and Falcon Management provide more detail that should be incorporated into the main Plan.

Conclusions on Draft Management Plan

117. I conclude that the draft Landfill Management Plan has many omissions in its current state and is not fit for purpose. Given the paucity of detail it is simply not possible to assess whether management measures to be adopted at the site will be sufficient to manage the risks associated with the operation of the landfill.

118. At this point in time I could not recommend that consent be granted.



David Ife

6 May /2022

Appendix 1 References

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EPA Victoria, 2015. Best Practice Environmental Management – Siting, design, operation and rehabilitation of landfills. Environment Protection Authority Victoria, Pub 788.3, August 2015.

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Statement of Evidence of Anthony Kirk, 29th April 2022

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USEPA RCRA Seismic Design Guidance for Municipal Solid Waste Landfill Facilities (1995), EPA/600/R-95/051, April 1995.

WasteMINZ Technical Guidelines for Disposal to Land – Project Team draft, WasteMINZ, August 2018.

Table 5 Groundwater quality compared against NZ drinking water quality guidelines

			Total Alkalinity (CaCO3)	Electrical Conductivity	Calc TDS	pH	Chloride	Ammonia as N	Nitrite-N (NO2-N)	Nitrite (NO2)	Nitrate-N (NO3-N)	Nitrate (NO3)	Total Kjeldahl Nitrogen	Total Nitrogen	Sulphate	Dissolved Reactive Phosphorus	Total Phosphorus	Bicarbonate Alkalinity	Carbonate Alkalinity	Hydroxide Alkalinity	Free Carbon Dioxide	Arsenic*	Cadmium*	Chromium	Copper	Lead	Nickel	Zinc	Magnesium	Calcium	Sodium	Potassium	Iron	Manganese	Magnesium	Calcium	Iron	Manganese
			mg/L	µS/cm	mg/L	pH	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	mg/L	mg/L	mg/L	mg/L
Water Quality Criteria			-	-		-	-	**0.2**	**1.0**		**1.0**		-	-	-	**0.035**	-	-	-	-	-	**0.013**	**0.0002**	**0.001**	**0.0014**	**0.0034**	**0.011**	**0.008**	-	-	-	-	-	**1.9**	-	-	-	**1.9**
	NZ Drinking Water Standards[3]		-	-	**1200**	**7-8.5**	**250**	**1.5**	**0.2 (refer to note 5 below)**		**50 (refer to note 6 below)**		-	-	**250**	-	-	-	-	-	-	**0.01**	**0.004**	**0.05**	**2**	**0.01**	**0.08**	**1.5**	**refer to note 4 below**	**refer to note 4 below**	**200**	-	**0.2**	**0.04**	**refer to note 4 below**	**refer to note 4 below**	-	-
Sample Name	**Date**	**Laboratory Number**																																				
BH01A	6/11/19	19-40125-1	324	1610	966	7.3	145	0.03	0.05	0.16	**26.7**	**118.2**	0.81	28	182	-	-	-	-	-	-	<0.00050	0.000026	<0.00020	**0.0025**	<0.000050	0.0061	0.0078	44.6	138	79.3	5.41	0.12	0.159	-	-	-	-
	23/3/21	21-12139	437	1480	888	7.4	108	<0.005	0.058	0.19	**10.8**	**47.8**	0.18	11	202	<0.002	0.022	436	<1	<1	36.5	<0.0005	0.000086	<0.0002	0.00063	<0.00005	0.0036	0.0048	58.9	178	84.5	6.32	<0.005	0.376	-	-	-	-
BH01B	9/11/19	19-40125-2	277	876	526	7.8	76.9	0.15	0.0056	0.02	0.0591	**0.3**	0.7	0.76	59.7	-	-	-	-	-	-	0.00088	0.000023	0.00023	0.001	0.00013	0.005	0.0068	18.3	69.9	67.8	6.3	0.021	1.66	-	-	-	-
	23/3/21	21-12139	290	748	449	8.3	63.1	0.02	<0.001		0.227	**1.0**	0.22	0.45	17.6	<0.002	0.03	285	4.9	<1	3.1	<0.0005	<0.00002	<0.0002	**0.0028**	<0.00005	0.0027	0.0041	18.4	68.5	68	5.14	0.06	1.41	-	-	-	-
BH02A	9/11/19	19-40125-3	238	538	323	7.2	39.3	0.11	0.0013	0.004	0.0919	**0.4**	0.57	0.66	0.68	-	-	-	-	-	-	0.0092	<0.000010	0.00024	0.00052	0.000052	0.0032	**0.0091**	12.2	36.3	56.9	2	3.4	1.05	-	-	-	-
	25/3/21	21-14269	233	530	318	7.5	37	0.15	<0.001		0.0223	**0.1**	1.5	1.5	0.55	<0.002	0.14	233	<1	<1	15.3	0.00093	<0.00002	<0.0002	0.00041	<0.00005	0.0017	0.0025	12.7	38.6	59.7	1.8	4.69	1.06	-	-	-	-
BH02A Duplicate	25/3/21	21-14269	229	530	318	7.7	37	0.15	<0.001		0.0242	**0.1**	1.1	1.1	0.57	<0.002	0.12	228	1.2	<1	8.4	0.001	<0.00002	<0.0002	0.00043	<0.00005	0.0018	0.0038	12.7	38.4	59.5	1.8	4.6	1.07	-	-	-	-
BH02B	9/11/19	19-40125-4	275	772	463	8	89.3	0.14	<0.0010		<0.0020		1.65	1.7	4.91	-	-	-	-	-	-	0.0012	0.00013	0.00054	**0.0033**	0.00023	**0.0238**	0.0018	8.26	25.7	120	8.72	0.24	0.141	-	-	-	-
	25/3/21	21-14269	366	943	566	8.4	101	**0.27**	<0.001		0.0246	**0.1**	3.4	3.4	0.7	<0.002	0.096	357	8.7	<1	2.8	0.0011	0.00006	<0.0002	<0.0002	<0.00005	0.0063	<0.001	10.9	31.6	172	4.8	0.25	0.435	-	-	-	-
BH03A	9/11/19	19-40125-5	461	1800	1080	7.4	109	<0.005	0.0193	0.06	**4.32**	**19.1**	0.53	4.9	57.8	-	-	-	-	-	-	<0.00050	0.000039	<0.00020	0.00097	<0.000050	0.0054	0.0063	34.1	135	53.3	14.1	0.018	0.909	-	-	-	-
	25/3/21	21-14269	551	1300	780	7.4	85.4	0.04	0.0056	0.02	0.233	**1.0**	1.2	1.4	68.6	<0.002	0.006	550	1.4	<1	42	<0.0005	0.000059	<0.0002	0.0012	<0.00005	0.0055	0.0045	42.7	170	52.4	16.3	0.057	1.09	-	-	-	-
BH03B	9/11/19	19-40125-6	497	1310	786	7.5	106	0.07	0.0194	0.06	**4.35**	**19.3**	0.69	5.1	59.8	-	-	-	-	-	-	<0.00050	<0.000010	0.00021	0.0011	<0.000050	0.0056	**0.0097**	38	144	65.2	13.5	<0.0050	1.45	-	-	-	-
	25/3/21	21-14269	601	1330	798	7.6	86.9	**0.36**	<0.001		0.0948	**0.4**	<0.8	<0.1	62.3	0.004	0.01	599	2.4	<1	27.7	<0.0005	<0.00002	<0.0002	0.00072	<0.00005	**0.0247**	0.0033	49.1	171	70.6	11.2	0.015	1.42	-	-	-	-
BH04A	9/11/19	19-40125-7	248	1430	858	7.2	301	0.03	0.0163	0.05	0.0672	**0.3**	0.45	0.54	9.28	-	-	-	-	-	-	<0.00050	0.00019	0.00023	**0.0016**	<0.000050	**0.0344**	**0.027**	24.5	63	161	4.6	0.36	1.68	-	-	-	-
	25/3/21	21-14269	455	1650	990	7.5	274	0.05	0.001	0.00	0.0173	**0.1**	<0.8	<0.1	5.01	0.032	0.017	454	1.3	<1	28.9	<0.0005	<0.00002	<0.0002	0.0009	<0.00005	0.0044	0.0014	28.5	86.9	222	5.16	<0.005	0.649	-	-	-	-
BH04B	9/11/19	19-40125-8	1088	2060	1236	7.2	80.3	**0.28**	0.0061	0.02	0.029	**0.1**	0.93	0.96	44.9	-	-	-	-	-	-	0.00086	0.000032	<0.00020	0.00047	<0.000050	**0.0268**	**0.0095**	57.3	169	202	9.08	0.879	1.32	-	-	-	-
	23/3/21	21-12139	1169	2030	1218	7.8	55.7	**0.37**	<0.001		0.0024	**0.0**	0.56	0.56	15.6	<0.002	0.032	1161	7.2	<1	35	0.0024	<0.00002	0.00048	<0.0002	<0.00005	0.0029	<0.001	56.7	137	301	8.43	7.11	0.71	-	-	-	-
BH05B	25/3/21	21-14269	429	992	595	7.9	49.5	<0.005	<0.001		0.589	**2.6**	<0.8	0.59	45.9	<0.002	0.84	426	3.1	<1	11.1	<0.0005	<0.00002	<0.0002	**0.0051**	0.00016	0.0072	**0.0096**	25.1	116	68.4	10.6	0.013	0.326	-	-	-	-
BH10B	26/3/21	21-14269	403	812	487	8	28.9	0.02	0.0017	0.01	0.0898	**0.4**	<0.8	<0.1	35.3	<0.002	0.2	398	4.2	<1	7.2	0.00069	0.000066	<0.0002	**0.0025**	0.000088	0.0046	**0.058**	23.3	104	43.3	6.74	0.013	0.346	-	-	-	-
BH201	25/11/19	19-41653	267	754	452	8.1	66.4	**2.59**	0.0068	0.02	0.0379	**0.2**	3.75	3.8	17.8	-	-	264	2.8	<1.0	4.7	0.0028	0.000061	0.0003	0.0011	<0.000050	**0.013**	**0.01**	-	-	-	-	-		-	-	-	-
	24/3/21	21-12139	284	791	475	8.3	91.1	**1.61**	0.0039	0.01	**3.37**	**14.9**	2.2	5.6	15.6	<0.002	0.31	279	4.7	<1	3.1	0.0056	<0.00002	<0.0002	0.00028	<0.00005	0.0014	0.0053	23.9	57.3	86.1	12.4	0.846	0.124	-	-	-	-
BH202	24/3/21	21-12139	285	749	449	8	70	0.14	<0.001		0.0082	**0.0**	0.9	0.91	26.4	<0.002	0.41	283	2.8	<1	5.3	0.0038	0.00003	<0.0002	<0.0002	<0.00005	0.00092	<0.001	35.2	88.2	87.9	11.4	2.46	0.448	-	-	-	-
BH209	24/3/21	21-12139	229	666	400	7.7	31.2	**0.3**	0.0044	0.01	0.139	**0.6**	<0.8	0.14	67.2	<0.002	0.34	228	<1	<1	3.9	0.0036	**0.00447**	<0.0002	0.00054	0.000082	0.0052	**0.0083**	10.2	16.5	105	19.3	0.32	0.27	-	-	-	-
BH211A	26/3/21	21-14269	371	843	506	8.2	50.3	0.03	0.0066	0.02	0.464	**2.1**	1.3	1.8	16.8	<0.002	0.024	365	5.7	<1	4.4	0.00089	<0.00002	<0.0002	**0.0017**	<0.00005	0.0037	0.0044	12.5	40	137	5.03	0.065	0.176	-	-	-	-
BH211B	26/3/21	21-14269	274	640	384	8.4	46	**0.36**	<0.001		0.0026	**0.0**	1.1	1.1	1.27	0.005	0.015	268	6.1	<1	2.2	0.0006	0.000035	<0.0002	<0.0002	<0.00005	0.00031	<0.001	7.42	22.7	107	7.27	0.083	0.177	-	-	-	-
Existing Well	24/3/21	21-12139	343	881	529	7.6	76.8	0.11	<0.001		<0.002		<0.8	<0.1	29.2	<0.002	0.79	341	1.2	<1	17.9	0.00089	<0.00002	0.00034	<0.0002	0.000099	0.00091	0.0025	25.1	95.6	65.6	6.06	2.24	0.376	-	-		-
SW1	6/7/20	20-24885-1	-	325	195	6.7	-	0.05	0.0045	0.01	0.322	**1.4**	1.49	1.8	33.2	-	-	-	-	-	-	<0.00050	<0.000020	<0.00020	0.00072	<0.000050	0.0013	0.0048	-	-	-	-	-	-	8.77	15.6	4.48	0.357
SW2	6/7/20	20-24885-2	-	340	204	6.7	-	0.03	0.003	0.01	0.0245	**0.1**	1.45	1.5	32.3	-	-	-	-	-	-	<0.00050	<0.000020	<0.00020	0.00028	<0.000050	0.0007	0.0024	-	-	-	-	-	-	9.02	16.3	9.07	0.651
SW3	6/7/20	20-24885-3	-	331	199	6.7	-	0.02	0.0014	0.005	0.0506	**0.2**	1.03	1.1	29.7	-	-	-	-	-	-	<0.00050	<0.000020	<0.00020	**0.012**	0.00057	0.00083	0.0028	-	-	-	-	-	-	9.04	16.1	7.45	0.812

Figure 3 *Approximate location of Akatore Fault*