Expert witness statement – Mt Atkinson and Tarneit Plains Precinct Structure Plan, Truganina, VIC

1. I, Philip Mulvey, a Senior Principal Scientist with Environmental Earth Sciences NSW have been engaged by Rigby Cooke Lawyers acting on behalf of Mount Atkinson Holdings Pty Ltd to provide an assessment on what is appropriate in regard to buffer width and its relation to site and site activities in regard to the proposed landfill and landraising at Ravenhall, Victoria. My primary field of expertise is in contaminant soil science and hydrogeology. I have a Bachelor of Agricultural Science (majoring in soil science) and a Masters in Applied Science (majoring in environmental geology and hydrogeology) with over 35 years experience in soil and groundwater related problems. I am a Stage 3 Certified Professional Soil Scientist (CPSS). A summary of my Curriculum Vitae is attached.
2. I am a statutory environmental auditor of contaminated land in Victoria and have been for 20 years and in NSW and South Australia for the entire time the scheme has been in place in these states. I attend and have presented on leachate monitoring to the frequent Landfill Auditors meetings.
3. During my career I have worked in the design, supervision of emplacement, operational issues, including fires, monitoring of emissions, leachate evaluation, closure, design of reuse and audit of landfills and other waste disposal and recycling facilities. In the last 18 months I have acted for objectors for a proposed landfill at Arthurs Seat (Victoria), an applicant for the extension of the Mangrove Mountain Landfill (NSW) and a lessee assessing the impact of odour on a proposed lease close to a landfill (Western Melbourne). I have provided an audit opinion on the use of biosolids for a landfill cap (Geelong, Victoria), undertaken a 53V audit for closed landfill monitoring (Dandenong, Victoria), assisted another auditor in an 53V operational audit (Altona, Victoria), prepared a RAP and reuse plan, including leachate and gas assessment and mitigation for two closed landfill for different clients (Silverwater and Milperra, NSW) and overviewed the companies' monitoring advice at over 10 landfills (Victoria, NSW and Qld). I have published a number of papers on landfill management and leachate control and a number of papers on leachate monitoring and buffer (or attenuation) distance in the mining industry as well as for landfills.
4. In preparing this document I have reviewed Melton Council Planning Submission Response in regard to the planning Permit Application to extend the existing landfill. In particular I note the figure at the back of this document, showing the extent of the proposed landfill with waste. I note that in this figure the landfill/landraise operations will occur right up to several boundaries. Furthermore landraising will also occur to an elevation of waste extending to 30m above the plain (current levels).
5. I have prepared this statement for the Precinct Structure Plan Proceedings.
6. I have read the *Guide to Expert Evidence – Planning Panels Victoria* and agree to be bound by this.
7. Though I have had insufficient opportunity to review all documents in full detail, I have made the enquiries which I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld.

Documents and Items Reviewed

8. The following reports letters and items were reviewed as part of this statement:

- Melton Council Submission, 2016, *Planning Permit Application PA2016/5118 and Works Approval Application 1002191 – Extension to the Landfill at 408-546 Hopkins*

Road, Truganina and 1154-1198 Christies Road, Ravenhall, 11 July 2016, Planning Application Submission Response.

- Figures 6-2 and 6-3, AECOM, 2016, *Melbourne Regional Landfill, Hydrogeological Assessment, 2016*.
- VicEPA Submission to MPA, 30 May, 2016, *Submission to Director Structure Planning, Metropolitan Authority*, *Reference, 500650 – Opportunity to comment – Amendment C162*.

I have also referenced information from the following guidelines, reports and papers:

- *Best Practice Environmental Management Guideline for the Siting, Design Operation and Rehabilitation of Landfills (Landfill BPEM),* (EPA Publication 788.3, 2015).
- *State Environmental Protection Policy (Air Quality Management) (SEPP (AQM)) Schedule A 'Class 1,2,3 & Unclassified Indicators & Design Criteria',* State of Victoria 1991.
- Victorian Government (December 1997) *State Environment Protection Policy - Groundwaters of Victoria, (SEPP GoV),* Victorian Government Printer.
- *State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade) No. N-1 (SEPP Noise).* Victorian Government Gazette No. S31.
- Victoria Government Gazette (1997). *Variation of the State environment protection policy (Waters of Victoria) – insertion of Schedule F6. Waters of Port Phillip Bay*.

Theory of Buffers

9. Buffer Zones are placed around activities for two reasons; planning reasons and compliance. Planning issues relate to protecting the amenity of neighbours from obnoxious industry. Planning buffers are also set up to consider catastrophic events. A good example of the use of a Buffer Zone is the explosive zone buffer of 1,000 m, excluding residential development around the Coode Island Hazardous Liquid Storage Facility. These buffer zones acknowledge that if a catastrophic event were to happen, although the likelihood is small, the magnitude of impact would be greater if certain activities occurs in the buffer zone. Thus planning controls are placed to avoid those impacts. These types of buffers can be placed beyond the title of the source property and can include many adjoining and neighbourhood titles. They are usually placed well before loss of value associated with the placement of such a buffer is likely to occur.
10. The second type of buffer zone is the emission monitoring buffer in which emissions affecting the amenity of users is protected and pollution is avoided. These buffers relate to pollution events. Pollution events are defined by law for odour, gases, groundwater seepage, surface water flow, noise, litter and dust. For all these emissions it is essential that monitoring occurs substantially within the title of the activity so that correction activities can be put in place before the emission leaves the boundary and becomes a pollution event.
11. Thus for emissions that move in a medium of water or air it is usual to have a double ring monitoring system around the facility. The first ring is to monitor fugitive or planned emissions to confirm the existing mitigation or avoidance management practices are working and to leave enough room for time based monitoring to put a correction strategy in place if the current systems fail. This sufficient room is the buffer which has the second ring of monitoring points at its outer boundary. Thus the inner boundary of the

buffer is at the outer boundary of the activity, and the outer boundary of the buffer is where the outer ring of monitoring occurs (designed to confirm that mitigation measures for failure of environmental controls has been successful).

12. Gas, dust and odour migration can be rapid and monitoring and management responses reflect this; if conditions are adverse site management practices can change within minutes. Nevertheless to ensure pollution does not occur the buffer needs to represent the dilution within the mass of air (or other relevant medium) before the boundary for the time interval that a planned correction response can occur.
13. Groundwater velocity compared to wind speed is slow but if a leachate plume is moving substantially faster than predicted or in a different direction or location, locating the cause and designing and emplacing correction measures are also difficult to put in place and take time, often several years. Having an activity to the edge of a site with groundwater monitoring on the boundary means that by the time a leachate plume is confirmed, pollution (as defined as exceeding criteria defined in the SEPP for Groundwater or that precludes a beneficial use) is already occurring and that there is no time to put into place measures that could prevent pollution. Typically, leachate monitoring occurs via a system of two rings of monitoring bores: the inner ring close to the landfill at sufficient distance to confirm the conceptual model and the outer ring locates at the end of the buffer at sufficient distance to allow time to install correction measures in case of failure of primary leachate mitigation (i.e. the liner and leachate collection system of the landfill)
14. By approving an activity going to the edge of a legal title with the first monitoring of emissions occurring on the boundary implies that the planning authorities are condoning pollution. This is not consistent with the Planning and Environment Act in that the planning authority has to consider potential for pollution and mitigation in granting consent. Thus a buffer to exclude inconvenience or amenity or impact by emissions must be wholly within the site to comply with the intent of the Planning and Environment Act and associated regulations related to landfills (Landfill BPEM). All require that pollution be prevented and that management of the site be set up to have contingencies in place to reflect deviations from the site conceptual model. Note the BEPM applies to landfills and that a landfill with significant landraise component is likely to have more stringent controls beyond the BEPM.
15. Papers on such an approach particularly for landfills and mines have been available for over 20 years and are considered by auditors undertaken landfill audits. (see the minutes of landfill committee 2016 – Phil Mulvey's presentation on groundwater monitoring)
16. See also the paper by Phil Mulvey on Groundwater Monitoring of landfills and mines.

Buffers At Mount Atkinson

Groundwater

17. Two major gas pipeline easements abut the western boundary of the land proposed to be quarried and to be considered as part of the landfill. The pipes are steel pipes. Steel pipe is particularly susceptible to anoxic sulfide attack. A landfill of this size will quickly reach the third stage of landfill leachate generation, methanogenesis, which produces extremely reducing water. Under these conditions sulfate is reduced to sulfides. The general experience of historic landfills is that hydrogen sulfide is comparatively minor as a result of the presence of rusted iron and steel waste in the land fill, which precipitates the sulfides as metal sulfides. As recycling becomes more effective in part due to the

increase in landfill levy promoting financial incentive to remove as much as possible from the waste stream, there will be little iron in the waste in the decades ahead and therefore an increased opportunity for hydrogen sulfide to occur. Furthermore the impact of builders waste such as gypsum will increase (as other wastes are removed), promoting the likelihood of increased hydrogen sulfide. Even if this landfill leachate has minimal hydrogen sulfide, the high reducing conditions of the leachate will result in conversion of any sulfate in the rock, groundwater, soil or backfill of services to hydrogen sulfides. Methanogenic leachate either in the groundwater or as a result of perched water in the soil due to the development of groundwater mound should not be allowed to come in contact with the gas pipes. Although likelihood is small that this will occur, the magnitude is substantive if a pipe fails.

18. Thus in relation to landfill leachate, any buffer developed for the landfill needs to be accommodate 5 to 10 years of travel distance in terms of groundwater velocity between the first monitoring point and the sensitive receptor (pipeline). Thus, assuming the liner fails, if the groundwater velocity with the imposed head of the landfill is 20 m/year, the buffer should be at least 200 m between the inner monitoring piezometer and the gas pipes. Assuming in basalt a sufficient distance to validate the conceptual model is 20 metres, the first ring of monitoring wells will be 20 metres from the edge of the landfill. Thus for this example the minimum buffer distance between the closest gas pipe line and the edge of the landfill is 220 metres to ensure from a planning perspective a catastrophic event does not occur. If a site boundary occurs within this planning buffer, a pollution event is plausible and thus the buffer should be moved back so that pollution will not occur in the event of failure of the liner and seepage collection system.

19. The likelihood of some sort of failure has been addressed widely in literature including a comparatively recent study in Italy. My paper on landfill leachate in the 1990s cited work on the impact of holes in the HDPE liner. Recent work done by Dr Bill Albright, of the Desert Research Institute at Reno on liner liners and caps found that clay liners compacted at a permeability of greater than 10^{-7} cm/sec with time (greater than 10 years) approached 10^{-4} cm/sec. This permeability range fails the design criteria of liners. Thus it is not a matter that liners are tight but simply when will the liner fail and what happens when it fails. With smaller landfills this has never been a great issue as the environment attenuates the leachate and natural wetlands occur at the point of the discharge. Large landfills, however, provide a large near constant widespread source and when the liner fails, correction is difficult. Furthermore the leachate discharge extent, rate and constant discharge overcome the capacity of the natural systems to attenuate the leachate.

20. As an example of failure of a very large landfill, TPI's facility at Tullamarine, designed and supervised by Golder Associates with a substantive clay liner (reportedly 3 m thick on the walls) has failed and leaks well above the design rate. Reportedly considerable work has been done to address the magnitude of the leak

21. A buffer needs to reflect the repair zone needed for failure before a pollution event occurs and to protect catastrophic events even if the likelihood is remote. For these reasons the buffer for leachate needs to be on site and of sufficient distance from the site boundary to be reflective of failure under the most conservative conditions (ie. worst) to prevent pollution and catastrophic event ever occurring.

Landfill Gas Migration

22. Putrescible waste is a dominant waste in a modern landfill. It decays anaerobically to produce landfill gas which is a mix of carbon dioxide, carbon monoxide and methane with minor amounts of other gases. The relevant percentages of gases varies depending on the stage of degradation which the waste is undergoing. Regardless of

the percentage, landfill gas can asphyxiate due to absence of oxygen or explode, when it migrates from a landfill. Landfill gas is lighter than air and will flow upwards along permeable pathways. Methane is soluble in water and will migrate with groundwater, only degassing when the overlying strata is more permeable.

23. The buffer zone of 500 m (Landfill BPEM, 2015) from any building or structure for landfills in both the UK and Victoria and up to 1,000 m recently considered for the current site (VicEPA submission, 2016), to address gas migration has no scientific basis but is set based on magnitude of a perceived hazard. It does not consider depth of the landfill or permeability of the formation. Landfill gas in very permeable terrain such as a clean, aeolian sand, barely migrates beyond the edge of the landfill, as it vents vertically almost immediately unless obstructed by buildings, pavement or the landfill cap. The gas seeks the most permeable vertical or horizontal pathway. In fractured basalt or clayey sand, vertical migration is limited and the gas may flow laterally in the formation in fractures or more permeable zones vertically until the surface is intercepted (which is usually backfilled with a bedding sand which is very permeable) or is confined under a structure such as a building and consequently collects at these structures. Historically, the rule of thumb in the 1980's, was a 250 m buffer for the first 10 m thickness of landfill and 100 m increase in the buffer for every additional 10 m of vertical thickness of landfill. The buffer was also varied according to the permeability of the formation and the presence of services. Degasing had to occur before important services (infrequently accessed, leading to residences, or a regionally significant trunk line), if encountered and permeable material reduced the width of the buffer. Engineering structures such as degassing wells or cut off trenches could also be used to reduce the buffer distance.

24. In landfills located in fractured basalt, gas will migrate laterally along fractures some distance from the landfill. The upper and lower parts of a lava flow can often be gaseous leaving behind vacuoles that may be connected or be subject to fractures. The central path of a lava flow is typically massive with no porosity and consequently exceptionally low permeability. The quarry at Ravenhall is mining at least two basalt lava flows and it appears in the cross-sections (AECOM, 2016) that a paleosol has formed between the two flows. Landfill gas flowing along the deeper lava flow would migrate some distance until the paleosol is absent, or a fractured zone leads to the overlying flow and vents to the surface.

25. On the western boundary of the landfill there is a substantial service, a trunk gas line, that will intercept landfill gas and provide an uncontrolled vent point both laterally along the pipeline and vertically through the backfill of the pipeline which is not contained by an impermeable barrier. Thus, gas will need to be vented before the pipe corridor or have sufficient buffer for the gas to vent naturally. For 50 m depth of fill, the buffer distance may be as much as 650 m, unless degassed by wells or a gravel cut off trench installed before the pipeline.

Dust, Litter, Noise and Odour

26. The western plains are comparatively flat, bisected by incised creeks. This is largely a result of the geology; comprising basalt flows. A landfill extending at least 30 metres above the plain, sitting on a rise, will result in a major problem with dust, noise and particularly odour and litter. The buffer required for a land raising in a flat terrain is far greater than a landfill (The BEPM does not envisage substantial land raising with waste). Though a portion of the operation will be land filling, a large portion is land raising. It is very unusual to have a land raising on a flat windy plain, not just for the visual amenity during operation but also because of the operational difficulties of containing litter during unloading and odour. Though the wind has a predominant seasonal dominance for a

particular direction, almost all wind directions are likely. Odour modelling is done to reflect topography and wind direction.

27. The Victorian odour design criterion for mixed odorants as described by the *State Environmental Protection Policy – Air Quality Management (SEPP (AQM)) Schedule A 'Unclassified Indicators'* is a maximum of 1 odour unit (ou) with 3-minute averaging applied at and beyond the boundary (State of Victoria, 2001). For dispersion modelling based on averaging times of one hour or less, the 99.9 percentile predicted concentration from the dispersion model is defined as the predicted maximum concentration (State of Victoria, 2001). Under windy conditions this is a very difficult measure to meet particularly when the tipping face is 30 m high with the toe effectively on the site boundary. Odour in these conditions will travel in excess of several hundred metres and the buffer is required to reflect the containment of odour above 1 odour unit to the boundary

28. Litter leaving the site is pollution. In a strong breeze, loose blown litter from a 30 m tipping face, close to the toe in a strong breeze will require a substantitive buffer (maybe 200 m) to hit and be contained by secondary fencing, which are used to hold litter that escapes the litter fences at the tipping face.

Conclusion

29. For such a landfill and landraising and for one that extends at least 30 m above the plain, it is apparent that a substantial buffer will be required onsite to prevent pollution and that these buffers are required to be on site to prevent a pollution event. The buffer has not been calculated as at the time of the review site parameters were not available. Nevertheless based on experience at similar sites a buffer on site of approximately 500 m is likely to ensure sufficient protection for pollution mitigation from operational activities or failure of management systems

30. Landfill gas migrating across a site boundary is considered pollution and therefore the buffer should be located wholly within the property. As proposed here, with the landfill edge on the boundary, the landfill operators are relying on a buffer zone of 500 m which will include approximately 470 m of adjoining land holders land. The exclusion of buildings or structures on this 470 m of land with be a serious imposition on those landholders and is dependent upon planning approval acknowledging pollution is acceptable which is at odds with the Planning and Environment Act, 1987.

Signed:

Date: 02/09/2016

On behalf of
Environmental Earth Sciences NSW

Philip James Mulvey

ANNEXURES

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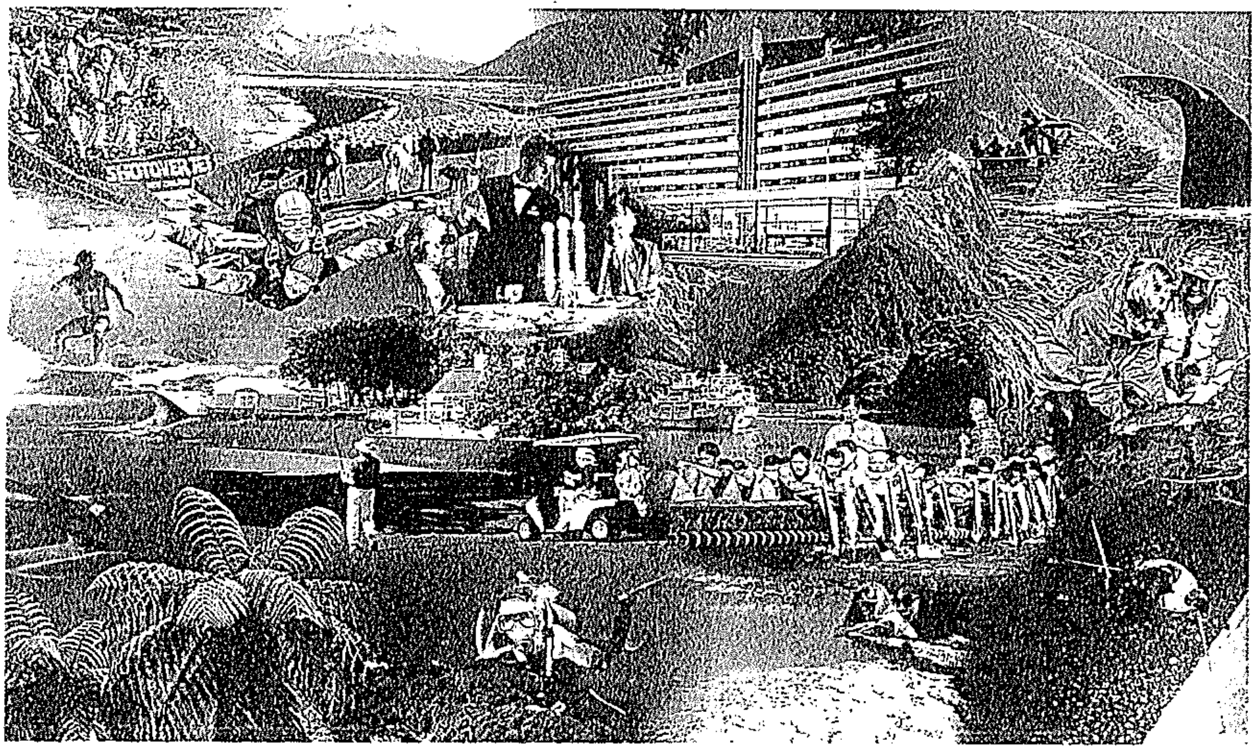

Plaza International Hotel, Wellington, New Zealand
29th September – 3rd October 1997

SESSION PROCEEDINGS
VOLUME 1

ISWA '97 WORLD CONFERENCE

CONCEPTUAL MODEL FOR MONITORING LANDFILL LEACHATE

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Abstract

Landfills are essentially bioreactors and no matter how good. the liner/capture system will eventually leak. Groundwater monitoring is usually undertaken to detect leaks. The nature of the leachate can make detection difficult. The recent trend towards statistical methods tends to confuse rather than facilitate the detection of a leak. Too often in monitoring the chemistry of interaction is ignored. Though landfill leachate can vary considerably between regions, all peutrecible landfill leachate undergoes similar stages. The leachate generated reacts with the ground and displaces native cations, producing by-products and bacterial waste products. These move ahead of the traditional front contaminants. This paper presents a conceptual model based on Proactive Monitoring. The model covers positioning and spacing of bores, frequency of sampling and analytes to be tested based on an understanding of the chemical and physical ground conditions. The use of ratios in interpretation overcomes some of the problems that statistics are supposed to address. Ratios highlight differences in relative concentrations well before background is exceeded. Usually a highly variable ion is compared to an ion that is consistent with time, or inversely, highly variable ions can be compared.

1 Introduction

The most significant potential for widespread environmental degradation from landfills comes from the potential to contaminate groundwater. Petts(1993) in a review of landfill risks had four of the eight risks relating to leachate and three of those relating to groundwater. The US-EPA has estimated that 75% of the 55 000 landfills in the USA have contaminated aquifers (cited in Jones-Lee & Lee, 1993). This paper focuses on groundwater monitoring of landfills that contain peutrescible matter, which includes domestic refuse, greenwaste, paper, cardboard, timber and tree stumps.

2 Why monitor

In most countries in the world the potential impact of landfill leachate on groundwater and surface water has resulted in monitoring being made a statutory requirement. Some countries such as New Zealand require no measurable affect on ground and surface water resulting from landfilling activities. Other states such as Victoria, Australia require no adverse impact on potential beneficial users. This is a more practical approach as it must be understood that - ALL LINERS WILL FAIL, possibly many decades after closure (Street 1993 cited Mulvey 1996).

Pollute is defined as the affect on the amenity of a user (UK Royal Commission on Environmental Pollution, 1984). Therefore a regulatory authorities environmental goal should be to recognise that landfills will leak and emphasise the protection of aquifers from pollution without ignoring potential adverse impacts from groundwater in aquitards. This more appropriate goal is the basis behind the proposed monitoring strategy. Thus the objective of monitoring is two fold; to ensure that the nature of leachate migration is at the predicted rate; and that early warning is provided for adverse plumes so that previously planned correction measures can be put into place. Thus effective monitoring includes threshold levels requiring a planned response this could be increased frequency of monitoring, through to remediation measures. To achieve effective monitoring, an understanding of background groundwater chemistry, leachate chemistry and local geology is required.

3 Location and construction of monitoring bores

It is important when planning an environmental groundwater investigation to assess permeability, gradient, geology medium and direction of groundwater flow to help determine piezometer installation details and location. Areas of natural preferred pathways can be established by defining lineaments from aerial photographs, geological structural mapping and geophysical techniques. More monitoring bores are required down gradient than upgradient.

In landfills, interface drainage (perched water table) is often ignored. Bores should be placed into the interface between soil layers or the natural rock at the topographical low. Water only collects in these bores during periods of prolonged rainfall, a seasonal wet period, or after the landfill leachate levels exceed the level of the B/C horizon boundary in soil. Not only is placement of bores important to ensure proper monitoring but so too is construction. The aim of the monitoring bore is to ensure representative sampling.

Ideally, to ensure remediation or correction measures have sufficient time to be installed, a double ring monitoring system should be used. The first ring of monitoring bores is placed close enough to rapidly detect leachate and the second ring of monitoring bores is placed to confirm the conceptual model and to allow sufficient time for correction measures to be put in place. Based on experience, the distance from the inner ring of monitoring bores should be no less than that travelled by groundwater in two years.

Hirschberg (1993) points out the limitation of slots placed across geological strata. A good example is shown in monitoring results from a landfill in Western Sydney, presented in Table 1, where landfills are located in former clay quarries underlain by a sand aquifer. In the region there are only three classes of water: the good quality water in the sand, represented by BH 10; the very poor quality water in the clay, as found in BH 9, and leachate whose quality lies between the two. As many of the monitoring bores intercept both the clay and the upper silty portion of the sand aquifer, the water monitored represents a mix of both waters, as identified by bores BH18, BH19, BH 3 and BH101. As leachate quality falls between the two natural waters but is significantly different only for potassium, the monitoring system is to some extent compromised by incorrect construction of the monitoring bore.

BH9	Clay	4.4	7 350	260	7.13	>4 280	2.50	Class II
BH3	C+siS	4.9	1 230	9.43	16.48	241.67	4.42	Class IIB
BH101	C+siS	6.1	4 030	20.00	9.75	58.50	11.11	Class IIB
Leachate		7.2	2 350	0.68	13.18	0.35	0.87	Class III
Sea water		-	-	3.13	7.14	-	1.07	-

C=Clay, S=Sand, siS=silty sand

Thus as well as bore placement, constructions of the piezometers and particularly slot placement is crucial to a successful monitoring program. An idealised piezometer construction is shown in Figure 1.

4.0 Frequency of monitoring

Frequency of monitoring normally depends on government or licence requirements. However the most important criteria is permeability of the rock or soil. Table 2 shows the time taken for leachate to reach a piezometer at given distance from the landfill after breaching the liner collection system. The landfill has been constructed with a 0.8 m compacted clay liner and collection system (0.5 m head) compared with one without a collection system (10 m head) in a variety of geologic media and assumes there is no unsaturated follow. When sand, weathered sandstone and permeable aquifers are immediately beneath the landfill, the plume once it penetrates the liner is rapidly transported. Thus composite liner systems are required and monitoring bores inner ring should be located within 5 m of the landfill and outer ring at greater than 100 m from the landfill.

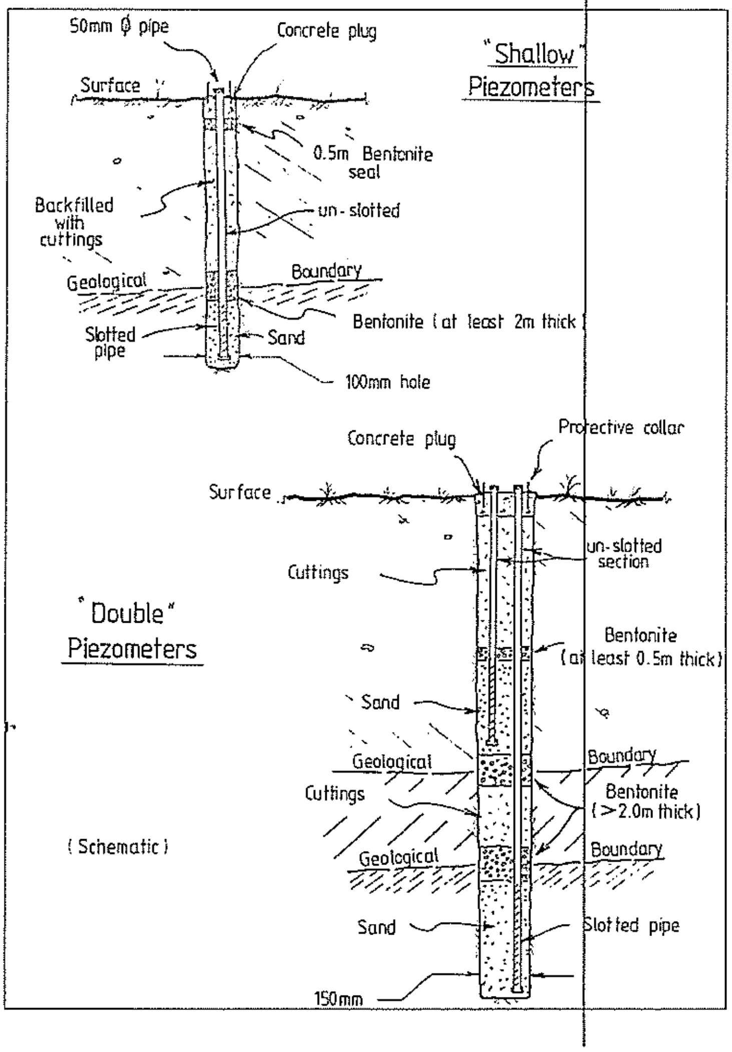

Figure 1
Idealised piezometer construction

Landfills without a leachate collection system, located in weathered shale, siltstone, and fractured clays should have monitoring bores ideally located at approximately 10 and 50 m from the edge of the landfill. A landfill in the same environment with leachate collection should have piezometers located at 5 m and between 15 and 20 m from the landfill edge.

Table 1 Chemistry of Groundwater beneath a landfill in Western Sydney

Bore	Lithology	pH	TDS mg/L	Mg/Ca	Cl/SO_4	Cl/HCO_3	Ca/K	
BH10	Sand	5 7	100	0.42	>24	2.58	5.50	Class I
BH18	S–C	6.0	230	0.20	>60	4.00	16.67	Class IB
BH19	S–C	5.4	145	0.18	>38	4.05	13.40	Class IB
BH9	Clay	4.4	7 350	260	7.13	>4 280	2.50	Class II
BH3	C+siS	4.9	1 230	9.43	16.48	241.67	4.42	Class IIB
BH101	C+siS	6.1	4 030	20.00	9.75	58.50	11.11	Class IIB
Leachate		7.2	2 350	0.68	13.18	0.35	0.87	Class III
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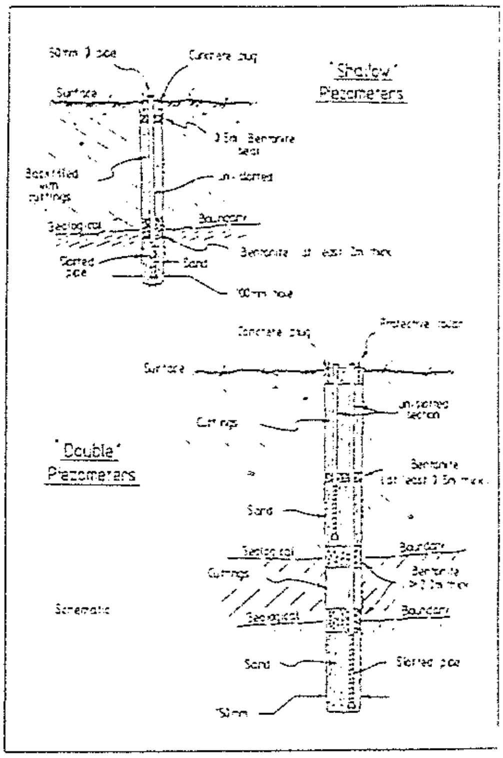
When sand, weathered sandstone and permeable aquifers are immediately beneath the landfill, the plume once it penetrates the liner is rapidly transported. Thus composite liner systems are required and monitoring bores inner ring should be located within 5 m of the landfill and outer ring at greater than 100 m from the landfill.



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Idealised piezometer construction

Landfills without a leachate collection system located in weathered shale and siltstone, and fractured clays should have monitoring bores ideally located at approximately 10 and 50 m from the edge of the landfill. A landfill in the same environment with leachate collection should have piezometers located at 5 m and between 15 and 20 m from the landfill edge.

Table 2. Time required for leachate to flow various distances.

	Distance from Landfill (m)	Liner only h = 1.0m	Liner and collection h = 0.5m
Liner alone	-	309 days	7 years
Sand/some volcanic's $k = 10^{-4}$ m/sec	5 10 50	1.6 hrs 6.4 hrs 6.7 days	13 hrs 53 hrs 56 days
Clay $k = 10^{-9}$ m/sec	5 10 50	29 years 117years 2940 years	244 years 976 years 2440 years
Fractured Clay $k = 10^{-6}$ m/sec	5 10 50	13.4 days 54 days 3.6 years	111 days 1.2 years 30 years
Shale/siltstone $k = 3.1 \times 10^{-9}$ m/sec	5 10 50	3.5 years 14 years 355 years	30 years 118 years 3000 years
Weathered Shale/siltstone $k = 1.0 \times 10^{-6}$ m/sec	5 10 50	8 days 32 days 2.2 years	67 days 267 days 18 years
Sandstone $k = 2 \times 10^{-7}$ m/sec	5 10 50	13 days 54 days 3.7 years	111 days 1.2 years 30 years
Weathered Sandstone $k = 5 \times 10^{-5}$ m/sec	5 10 50	2.6 hours 10 hours 11 days	1 day 3.5 days 90 days

Notes: h=head
Permeability from Fetter 1988, AGC, 1984, Porosity from Fetter.
Assume conditions are static for the interval.

Landfills located on or above a thick deposit of well compacted clay or tight mudstone/siltstone in the absence of preferred pathways, require piezometers within 1 m of the landfill edge. As drilling this close may cause fracture pathways, the closest would be 3 m for auger or core drilling rigs and 5 m for air or rotary percussion rigs. Bores beyond 5 m should be located in preferred groundwater pathways. By reference to Table 2 sampling times for different geological conditions can vary significantly. Landfills located above sand or gravel lenses, weathered sandstone and permeable aquifers essentially require semi-continuous monitoring equipment. Continuous monitoring probes are limited to electrolytic conductivity (EC) which is only useful when the total dissolved solids in the groundwater are below 2 500 mg/L, but can nevertheless be a useful indicator of leachate. Probes require regular maintenance and calibration to remain reliable. Though pH probes would also be useful we have found that probes are yet to live up to manufacturers claims.

If semi-continuous monitoring is not possible then pH, redox potential (pe), EC, odour and colour should be measured in the field weekly or fortnightly and appropriate constituents ideally monthly, at worst quarterly. In all other instances, except stiff clay and unweathered shale, the location of the inner bores should be placed to allow quarterly monitoring. Outer bores should only be added for background sampling or if there is a response in the inner bores. By using quarterly monitoring an early breakthrough can be detected and an appropriate strategy put into place depending on the quality prior to the groundwater reaching the outer ring, which should lie inside the site boundary. In a *controlled seepage landfill* remediation should be unnecessary and monitoring is used to collaborate the landfill conceptual model and confirm successful attenuation.

For stiff clay and unweathered shale the inner bores, and bores on preferred pathways, should be monitored quarterly for pH, pe, EC, odour and colour and six monthly or even annually for appropriate constituents.

5 Leachate chemistry

To understand the concept of controlled seepage the generation of leachate and variation of leachate with time needs to be understood. The nature of the reactions in a landfill, and the type of peutrescible material partially decides the constituents of the leachate. Typical domestic refuse will contain between 50 to 70% carbohydrate which is readily degraded. Interaction of the leachate with the night cover and underlining soil/rock also has a significant impact on the nature of the leachate. Landfill leachate undergoes three decomposition stages simplified as followed:

1. Immediately after wet deposition, decay begins (heavy compaction with night cover delays the onset of decay). Aerobic microbes use oxygen to convert cellulose and sugars to energy, water and carbon dioxide in a process known as respiration. By another pathway organic acids such as oxalic acid are also readily produced. This creates an initial leachate that is high in organic acids and carbonic acid. These compounds lower the pH of leachate to between 4 and 5 and raise organic carbon concentration in the water. The leachate is also high in chloride, sodium, sulfate and potassium. Apart from excess nutrients and salinity the deleterious compounds released in this stage is limited to occasional zinc and iron. As the leachate moves into the ground pH is attenuated by neutralisation reaction, while potassium and calcium and to a lessor extent sodium can be attenuated by cation exchange. This alters the balance of cations in the water. The initial stage is usually very short lived.

2. During the fermentation process of stage 2, all chemically bound oxygen is consumed, firstly from soluble ions such as nitrate and sulfate and then from minerals or solids containing nitrate, sulfate, manganese and iron. These minerals could be sourced from the rubbish (eg. rust) or the soil (goethite nodules) used as night cover. As the chemically bound oxygen is consumed, increasing amounts of methane (CH_4) are produced; and ammonium, iron, and manganese appear as ions in the leachate at the expense of organic acids (they contain organically bound oxygen). The pH increases by the consumption of hydrogen in the formation of ammonium, methane, bicarbonate and hydrogen sulphide. Hydrogen sulphide will not form in the presence of iron and heavy metals, which are precipitated as sulphide resulting in 99.9% metals being confined within the landfill (Belevia Baccini, 1989). This stage is the most frequently detected in monitoring bores. The first stage is usually attenuated and is missed in all but sandy systems.

3. Anaerobic processes continue to take over, which converts organic compounds to ultimately produce methane and water. Bicarbonate levels drop as does sulfate and BOD. Ammonium usually remains elevated. The consumption of remaining organic matter within the landfill can result in the release of organically bound constituents, such as pesticides. Though hydrocarbons, pesticides and herbicides are usually co-

co-metabolised. Hazardous gases may appear in the gas phase but rarely in the groundwater.

A landfill that becomes rapidly fermenting will maximise gas production and reduce the organic acid and low pH phase in the leachate. However ammonium and bicarbonate will increase. It is important therefore to recognise these stages during the landfill monitoring program.

6 Analysis of data

Monitoring programs should be designed to recognise the phase of a leachate plume and evaluate the impact on the ground and surface water.

Leachate plumes

The nature of the plume both in concentration and how it is attenuated depends on the initial concentration and local ground conditions.

A heavy clayey soil or rock with clay minerals and low permeability will attenuate and fragment the plume, resulting in widely separated distinct phases of arrival. A non-reactive porous medium will result in a poorly attenuated plume. A positive detection in a bore may not be due to the groundwater thought to be monitored. If a plume in an attenuating environment arrives as a pulse, rather than in distinct phases, or the phases are only slightly separated, leakage down the hole from interface drainage or surface runoff may be the cause. Normally in such a bore, standing water levels show greater variation than other bores.

Identifying leachate breakthrough

In high or variable background groundwater salinity, breakthrough of a plume is often difficult to establish. The breakthrough may be occurring within the existing background variation. The first indicator will be a change in the relative ratios of native cations and anions(Ca/Mg, Na/Ca, Ca/K, Cl/SO_4 and Cl/HCO_3). The alterations in these ratios are often detectable before concentrations exceed background levels, pH falls, or ammonium and BOD rises.

Background water quality (B/G), leachate and bores with breakthrough plumes (BH9) are shown for a number of landfills in NSW, Australia and Auckland, New Zealand in Table 3. Analysis of leachate coming from the base of a heap of woodchip after rain is also shown. In most groundwater systems potassium is subdominant to calcium and magnesium, while ammonium and nitrate are very low. The exceptions for potassium are micaceous volcanic and igneous rocks such as the basalt flows around Auckland. Quite high levels of nitrate and ammonium are common in groundwater in Australia from nitrogen fixing vegetation. Nevertheless, in no natural water does potassium and ammonium occur in significant concentrations together.

Table 3 Dominant Cations and L/N ratio for landfills in Australia and New Zealand

		Geology	TDS	Na	Ca	Mg	K	$NH_4 + NO_3$	L/N
Woodchip leachate			2380	290	63	75	370	205	134.3
Sydney 1 (G) (peutrescible)	B/G	Sand	530	175	9.5	13	4.3	0.05	2.2
	BH13s	Sand	2820	500	170	96	130	150	36.6
	BH9d	Sand	3080	740	75	150	200	51	26.0
	Leachate		3450	550	190	93	260	170	51.6
Sydney 2 (K) (Peutrescible)	Leachate		3000	205	390	85	230	260	72.1
Sydney 3 (L) (nondomestic)	B/G	Clay	8060	2300	2.1	510	1.7	0.63	0.1
	Leachate		3800	860	115	110	195	66	24.1
Sydney 4 (S) (nondomestic)	B/G	Clay	8456	2810	190	340	27	1.7	0.9
	BH7	Clay	6550	1860	140	260	50	12	2.7
	Leachate		5780	930	51	125	590	1090	152.0
Riverina (Peutrescible)	B/G	Clay	3390	980	126	105	2	0.1	0.2
	BH9	Sand lens	1500	250	148	59	78	70	32.4
Sth Coast NSW (peutrescible)	B/G1	Sand	440	60	69	24	1.3	6.8	5.3
	B/G2	Sandstone	1340	200	210	68	23	8.1	6.5
	BH1	Sand	2740	410	180	230	135	100	28.7
	BH9	Sandstone	1990	270	230	125	90	72	25.9
Auckland 1 (G)	B/G	Siltstone	220	28.1	17.8	21.9	2.73	0.03	4.1
	BH27	Siltstone	960	112	170	95	31	0.54	8.4
	Leachate			1390	102	150	600	1383	120.8
Auckland 2 (R)	B/G	Siltstone	102	22.5	7.5	4.6	1.75	0.01	5.1
	BH02	Siltstone		26.6	45.6	31.6	15.4	1.024	15.8
	Leachate		5360	770	390	195	530	445	72.0
Auckland 3 (C)	B/G	Basalt	301	71	21	12	19	0.1	18.4
	BHPD1B	Basalt	1050	200	70	41	138	1.1	44.7

Sodium, magnesium and calcium are the normal dominant cations of natural groundwater. Though these cations do occur in landfill leachate they are not significantly elevated over background concentrations to the same extent as potassium and ammonium. Mulvey (1996) developed the leachate/native cation ratio or L/N ratio as a monitoring aid using these differences. The ratio is defined as:

$$L/N = (K + NH_4 + NO_3) / (Mg + Ca + Na) \times 100$$

As can be seen in Table 3 the L/N ratio differs greatly between background and leachate, so that breakthrough is readily apparent even when background salinity is high. When background water quality is good, use of ratios and the L/N ratio in particular usually does not give any earlier warning, as the difference between leachate and background is so great and attenuation is usually small.

A leachate breakthrough signature varies depending on the geology and background water quality but is usually recognised by;

- The first phase has a relative increase in bicarbonate and sulfate to chloride, an increase of calcium, magnesium and sodium (native cations, N) relative to potassium and ammonium (leachate cations, L). This indicates the displacement of native cations has occurred in advance of the main front, causing the L/N ratio to initially fall. Nitrate (if present) also falls;

BH9	Clay	4.4	7 350	260	7.13	>4 280	2.50	Class II
BH3	C+siS	4.9	1 230	9.43	16.48	241.67	4.42	Class IIB
BH101	C+siS	6.1	4 030	20.00	9.75	58.50	11.11	Class IIB
Leachate		7.2	2 350	0.68	13.18	0.35	0.87	Class III
Sea water		-	-	3.13	7.14	-	1.07	-

C=Clay, S=Sand, siS=silty sand

Thus as well as bore placement, constructions of the piezometers and particularly slot placement is crucial to a successful monitoring program. An idealised piezometer construction is shown in Figure 1.

4.0 Frequency of monitoring

Frequency of monitoring normally depends on government or licence requirements. However the most important criteria is permeability of the rock or soil. Table 2 shows the time taken for leachate to reach a piezometer at given distance from the landfill after breaching the liner collection system. The landfill has been constructed with a 0.8 m compacted clay liner and collection system (0.5 m head) compared with one without a collection system (10 m head) in a variety of geologic media and assumes there is no unsaturated follow.
When sand, weathered sandstone and permeable aquifers are immediately beneath the landfill, the plume once it penetrates the liner is rapidly transported. Thus composite liner systems are required and monitoring bores inner ring should be located within 5 m of the landfill and outer ring at greater than 100 m from the landfill.

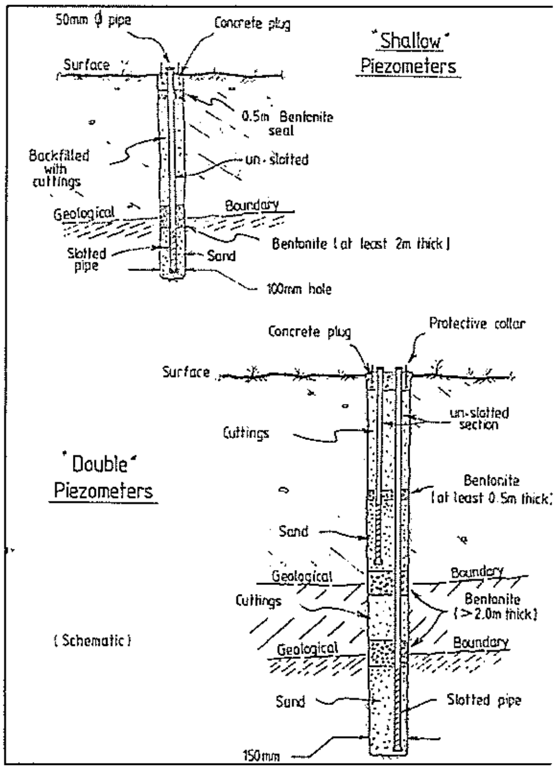


Figure 1: Idealised piezometer construction

Landfills without a leachate collection system, located in weathered shale, siltstone, and fractured clays should have monitoring bores ideally located at approximately 10 and 50 m from the edge of the landfill. A landfill in the same environment with leachate collection should have piezometers located at 5 m and between 15 and 20 m from the landfill edge.

- The second phase typically has BOD, ammonium and potassium rising sharply, iron, zinc and the L/N ratio starting to rise. This phase may commence with a drop in pH; and
- This is then followed by a rise in pH, a sharp rise in bicarbonate and a decline in sulfate, iron and zinc. As ammonium and potassium continue to rise so to does the L/N ratio.

If leachate has a considerably higher TDS than background, TDS will rise over all phases as the plume passes.

Figure 2 Leachate Breakthrough

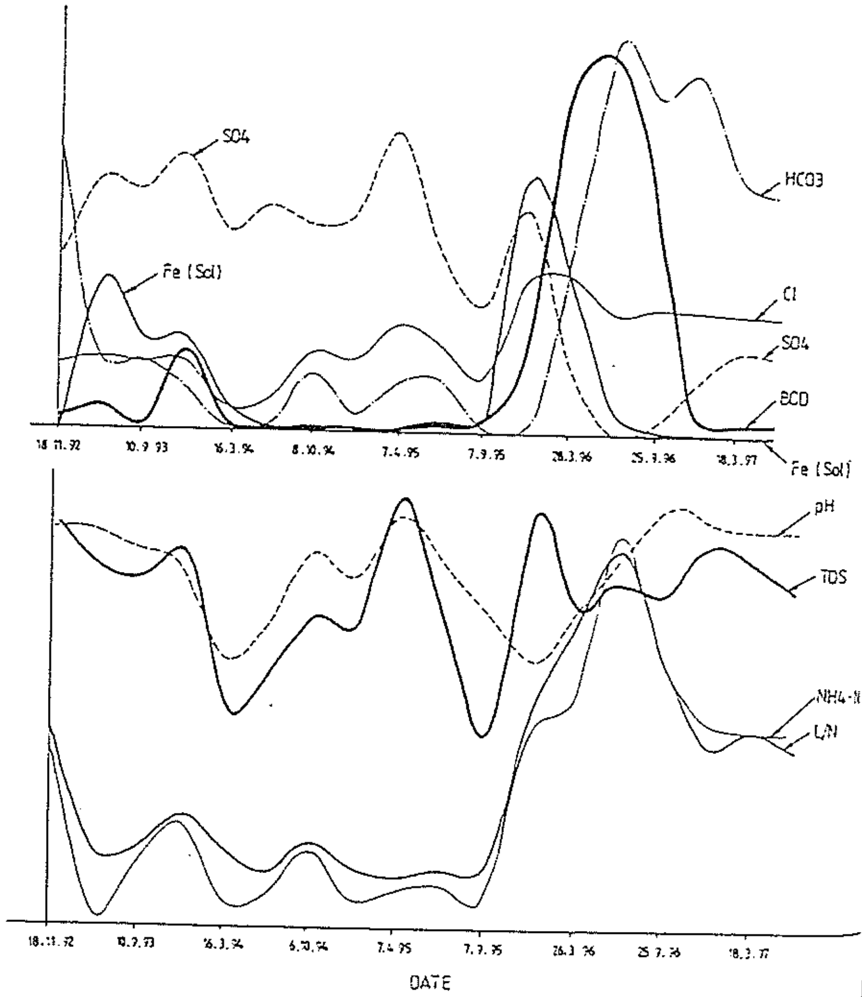


Table 4 and Figure 2 shows breakthrough data from a bore located over a sand aquifer. Because of the highly permeable aquifer and the seasonal rainfall, plumes come in pulses rather than a sequential breakthrough plume. Even given the limited attenuation the first two stages of a breakthrough plume are evident.

The data commences with the pulse of one plume decaying away in 1992 and 1993. In July 1995 a second plume commences with a rise in Cl/SO_4 ratio. This is followed by the commencement of a fall in pH in July 1995 followed in January 1996 by a fall in the Ca/K ratio accompanied by a rise in BOD, potassium, ammonium, chloride, iron, ratios of Mg/Ca and L/N. This represents the aerobic acidic stage of the front. The anaerobic phase commences in March 1996 with a fall in sulfate, iron and zinc. This is accompanied by a rise in bicarbonate, pH and a continued rise in ammonium and potassium.

As this bore was located in a sand aquifer within 5 m of the landfill, leachate was not significantly attenuated and consequently not only is the plume not preceded by displaced native cations but the phases of the plume overlap. These are plume features associated with non reactive sediments/rock.

Table 4 Groundwater Monitoring Data for a Bore showing 2 breakthrough plumes from a Landfill located on a Sand Aquifer (See Figure 2)

Date	pH	TDS	BOD	Na	Ca	K	Mg	NH4-N	Cl	NO3	SO4	HCO^3	Zn (Sol)	Fe (Sol)	Mg/Ca	Ca/K	Cl/ CO^3	Cl/ SO^4	L/N
11/92	6.4	2300	10	205	410	57	105	32	260	10	660	1200	0.08	0.2	0.26	7.2	0.2	0.39	13.8
6/93	6.4	2050	20	200	275	27	86	2.4	290	0	1000	290	0.04	120	0.31	10.2	1.0	0.29	5.2
9/93	6.1	2000	5	260	235	12	42	12	270	4.1	960	230	0.06	72	0.18	19.6	1.0	0.28	5.2
12/93	5.3	2130	65	210	280	26	94	19	275	0	1100	130	0.19	73	0.34	10.3	1.5	0.25	7.7
3/94	4.3	1240	5	100	200	9	56	4.3	95	5.5	800	0.9	0.37	19	0.28	22.2	106	0.12	5.4
6/94	4.3	1460	<2	97	240	5.3	68	5.6	120	3.4	900	18	0.37	2.3	0.28	41.4	6.7	0.13	3.7
10/94	6	1790	3	280	230	18	51	14	310	0	820	230	0.01	4.2	0.22	12.8	1.3	0.38	5.7
1/95	5.6	1730	<5	235	225	12	75	4.7	280	4	860	69	0.25	1.4	0.33	13.8	4.1	0.33	3.9
4/95	6.6	2460	2	330	330	17	100	7	420	2.3	1190	190	0	0.3	0.30	19.4	2.2	0.35	3.5
7/95	5.8	1720	9	265	200	13	60	7.5	350	0	710	210	0.05	5	0.30	15.4	1.7	0.49	3.9
9/95	5	1120	7	150	135	5.1	43	5.6	210	2.7	510	5	0.17	10	0.32	26.5	42.0	0.41	4.1
1/96	4.3	2380	55	200	150	30	85	36	600	0	890	<1.0	0.29	200	0.57	5.0	600	0.67	15.2
3/96	5.2	1350	280	240	170	58	66	42	620	0	270	650	0.16	130	0.39	2.9	1.0	2.30	21.0
6/96	6.1	1990	300	270	230	90	125	72	480	0.26	0	1560	0	22	0.54	2.6	0.3	480	26.0
9/96	6.3	1920	190	350	200	67	95	50	500	0	38	1340	0.02	2.7	0.48	3.0	0.4	13.1	13.1
12/96	6.5	2200	15	400	220	52	93	38	500	0	200	1430	0.08	0.1	0.42	4.2	0.3	2.50	12.6
3/97	6.4	2130	9	360	230	57	92	36	490	0	330	1030	0.14	0.56	0.40	4.0	0.5	1.48	13.6
6/97	6.4	1950	9	355	220	45	79	36	480	0	310	950	0.03	0.17	0.36	4.9	0.5	1.55	12.4

This data also shows that other effects such as earthworks for closure, seasonal effects or two distinct pulses rather than a single continuous source are other variations that may influence the monitoring data and explain variable behaviour of leachate plumes.

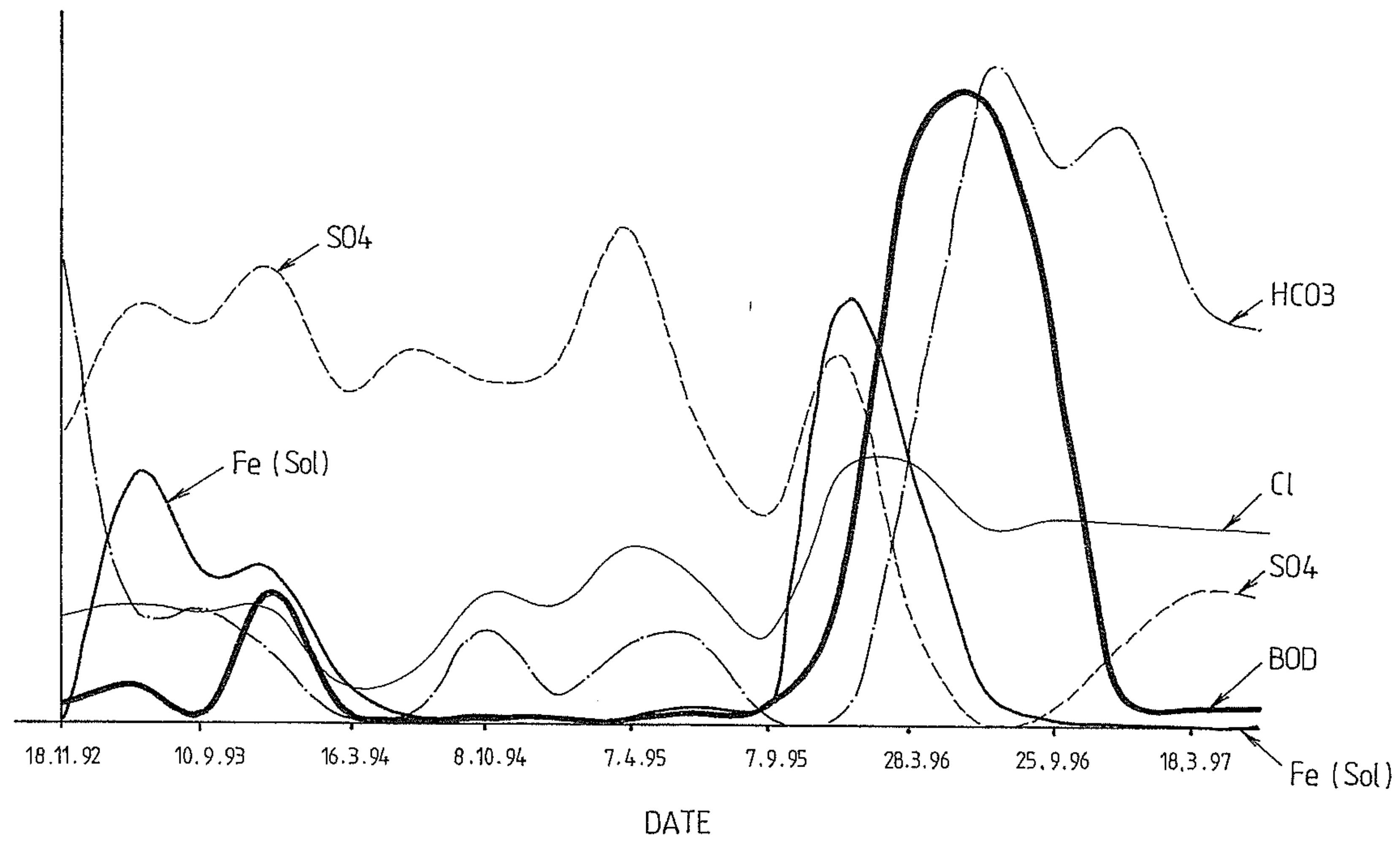
8 CONCLUSION

Landfill monitoring should be undertaken to confirm controlled seepage of leachate is behaving as predicted and that it is having little or no measurable effect on the natural ground and surface water. It should also have an action plan based on the conceptual model of the leachate plume. Groundwater monitoring, bore location and the frequency of monitoring depends on the nature of the surrounding soil or rock within which a landfill is located. Location and frequency of monitoring should not be haphazard or uniformly applied, instead they should be tailored for local site conditions. A simplistic local conceptual model should be derived to highlight the monitoring requirements. Generally regional authorities in New Zealand appear to be taking this approach, whilst some Australian authorities ignore site locations.

When interpreting the monitoring data, focus should be centred on recognising the phase and nature of leachate breakthrough fronts and designing action responses accordingly. Constituents monitored for early warning should be pH, electrical conductivity and redox potential in the field as well as chloride, bicarbonate, sulfate, BOD, ammonium, nitrate, calcium, manganese, sodium, potassium, iron and TDS analysed in the laboratory. Only after the second front has passed should heavy metals or organics be monitored. Ratios, particularly the L/N cation ratio, should be used to highlight differences in the anions and cations, particularly when background water salinity is high.

9 REFERENCES

Australian Groundwater Consultants (1984) Effects of Coal Mining on the Groundwater Resources in the Upper Hunter Valley, NSW Coal Association.


SO4
Fe (Sol)
HCO3
Cl
SO4
BOD
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18.11.92
10.9.93
16.3.94
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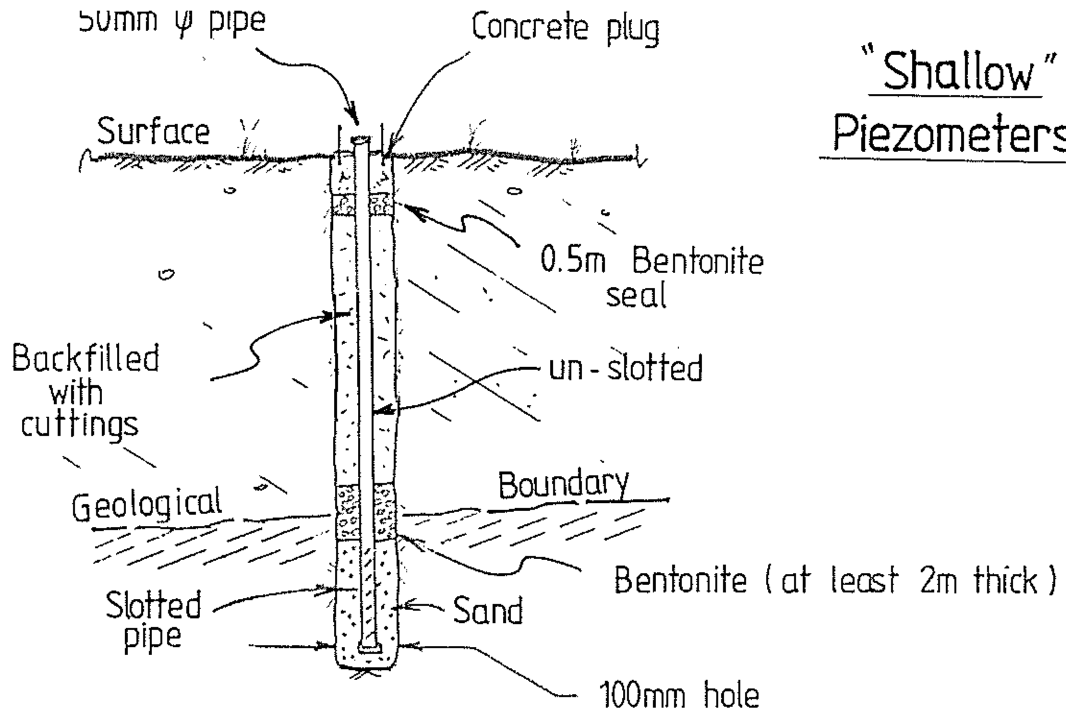
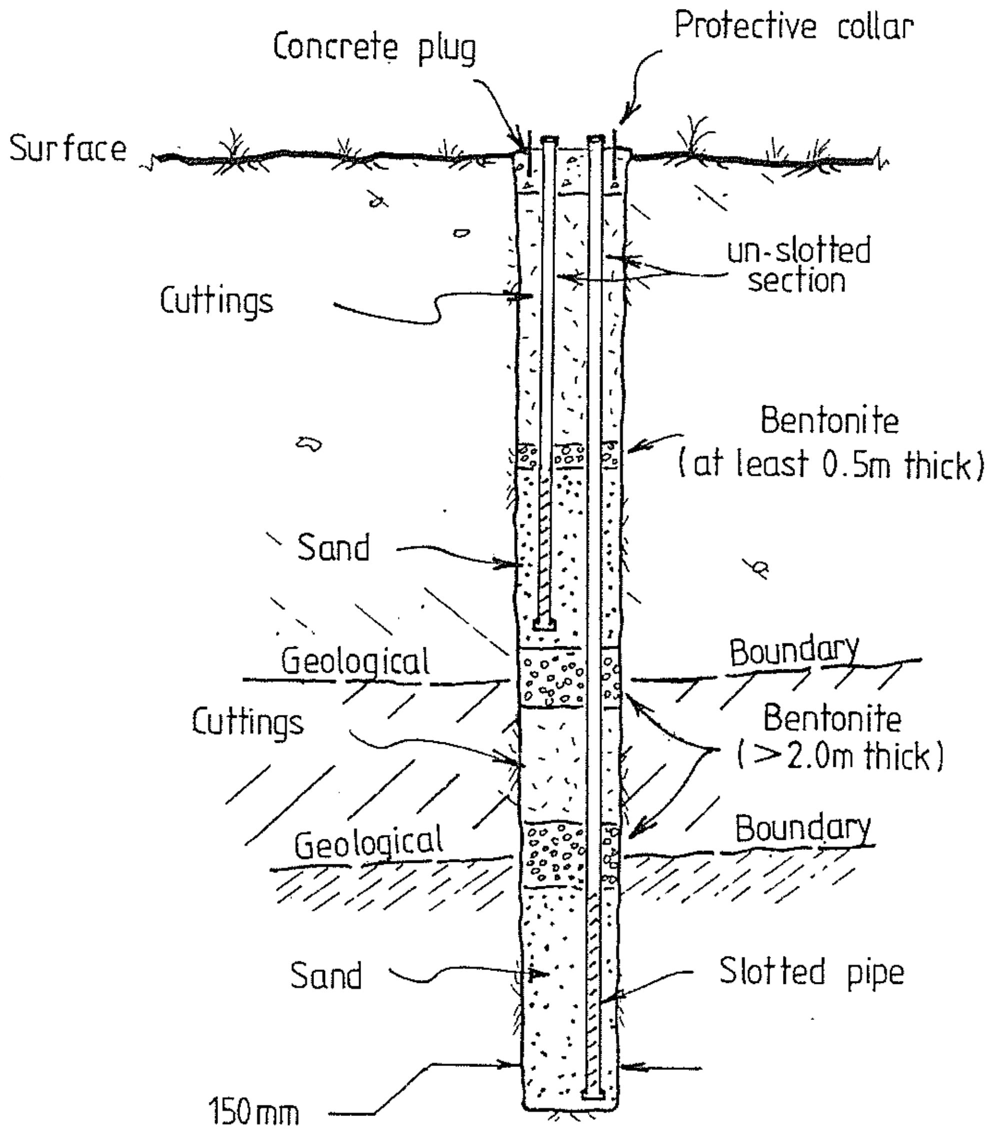
7.9.95
28.3.96
25.9.96
18.3.97
DATE

"Shallow" Piezometers



"Double" Piezometers

(Schematic)



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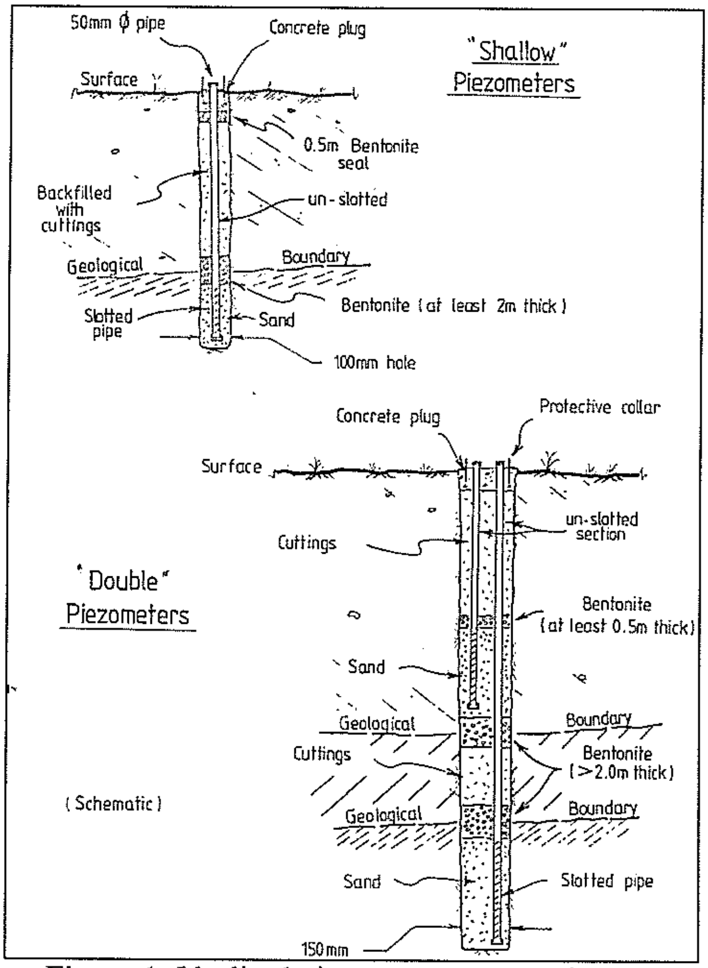

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Table 2. Time required for leachate to flow various distances.

	Distance from Landfill (m)	*Liner only h = 10m*	*Liner and collection h = 0.5m*
Liner alone	-	309 days	7 years
Sand/some volcanic's $k = 10^{-4}$ m/sec	5 10 50	1.6 hrs 6.4 hrs 6.7 days	13 hrs 53 hrs 56 days

- The second phase typically has BOD, ammonium and potassium rising sharply, iron, zinc and the L/N ratio starting to rise. This phase may commence with a drop in pH; and
- This is then followed by a rise in pH, a sharp rise in bicarbonate and a decline in sulfate, iron and zinc. As ammonium and potassium continue to rise so to does the L/N ratio.

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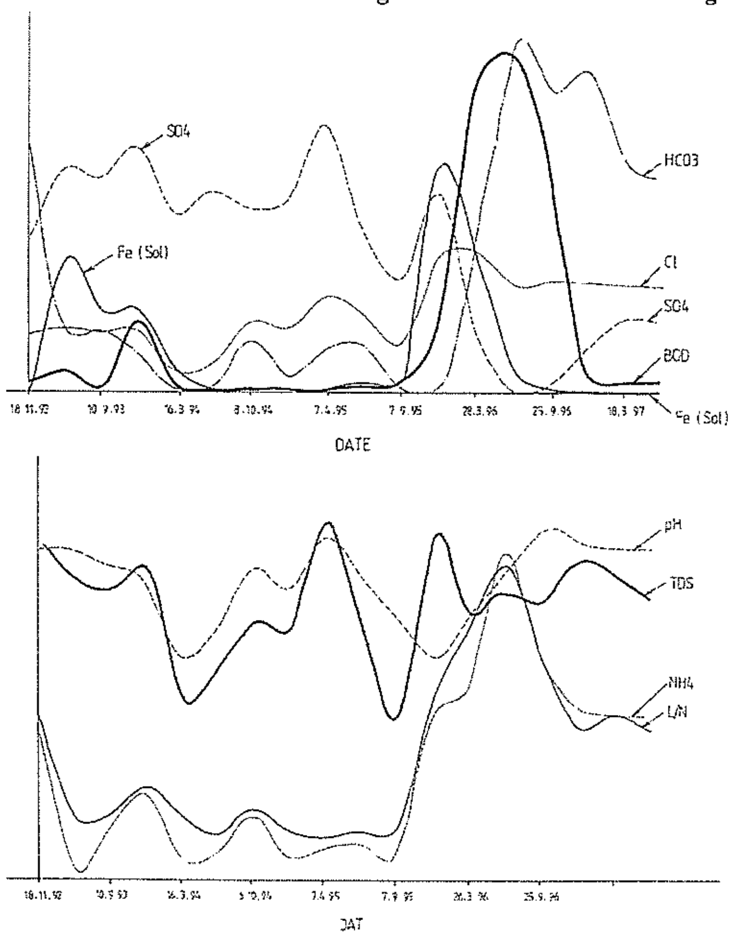

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MONITORING LANDFILL LEACHATE

P Mulvey, S Brisbane

ABSTRACT

Groundwater monitoring is usually undertaken to detect migration of contaminants or leachate from a landfill. This paper discusses the positioning and frequency of monitoring as well as the constituents monitored, with particular reference to the recent draft guidelines released by the NSWEPA. The latest draft landfill guidelines presented groundwater indicator parameters to be monitored. If a statistical difference in the concentration of the indicators over time is found then an assessment plan needs to be addressed. In some cases this may be too late as the initial front of the contamination plume is already present hidden by background variations in the indicators or may have actually passed, . The authors propose a scientific method based upon the initial chemical interaction of the soil/rock and leachate. The method depends on the construction of a simple conceptual model and comparison of relative concentrations and clusters of alterations. Ratios are used to highlight differences, particularly in areas of saline groundwater. This method will help aid in the earlier identification of a contamination plume which will ultimately offer more productive and cost effective solutions as responses to contamination can be preplanned rather than be reactive.

KEYWORDS

Groundwater, piezometers, liners, contaminants

1 INTRODUCTION

The most significant potential for widespread environmental degradation from landfills comes from their potential to contaminate groundwater. Petts, 1993, in a review of landfill risks talked about four of the eight risks relating to leachate and three of those relate to groundwater. The USAEPA has estimated that 75 % of the 55 000 landfills in the USA have contaminated aquifers (cited in Jones-Lee & Lee, 1993). However vast areas of the USA, Netherlands, Denmark, New Zealand, Iceland and Japan have ground conditions that do not readily support landfills, which is not true in Australia. Nevertheless, aquifer protection is important.

The type and nature of landfill as well as the location affect the nature of groundwater monitoring undertaken.

2 LANDFILL TYPES

There are two philosophies of waste disposal in regard to landfill: disposal and storage. Within these philosophies there are several different landfill types defined by Westlake 1995 as :

Disposal. *Dilute and attenuate:* essentially old practise of the non-engineered landfill;

Simple Containment: defined by ISWA, 1992 as a landfill site where the rate of release of leachate into the environment is extremely low, such that polluting species are at acceptable concentrations;

Controlled Seepage: accepts that leakage will occur and designs a landfill to safely leak (Mulvey, 1992 Loxham 1993);

Accelerated Bioreactor: minimises compaction and night cover and optimises moisture content to increase gas, Harvest it and then undertake a second lift;

Storage. *Dry Tomb:* Endeavours to prevent water entering and leaving the waste.

The dry tomb landfill type is practised in the USA (Westlake, 1995) and advocated in a draft document by the NSW EPA. In effect it hopes to achieve exclusion from the environment. However at some point the cap or the liner will fail, possible many decades after closure, and the biological process within the landfill will be reactivated. The dry tomb also prolongs acidic leachate with a high biological oxygen demand and metal content. The disadvantages of such an approach are now being openly canvassed in the USA (Lee and Jones-Lee, 1993).

In NSW there are essentially three types of landfills: (1) inert waste (includes demolition rubble), (2) solid wastes -food wastes are not necessarily included at all solid waste landfills; (3) hazardous waste. Groundwater monitoring is necessary at all three types. Essentially this paper will address landfills that contain peutrecible materials which include the first two types. The principles also apply to the hazardous waste landfills.

3 WHY MONITOR?

The environmental goal in the Draft NSW Environmental guidelines for solid waste, in regard to groundwater is to "ensure that leachate is controlled within the landfill site and that neither groundwater nor surface water is contaminated". This goal is not a sustainable landfill practise and impossible to achieve - ALL LINER SYSTEMS WILL FAIL. Table 1 shows leakage rates through membrane liners, compacted soil and composite liners under best, average and worst cases. Clearly monitoring is necessary either to detect failure and correct it in the case of the current philosophy or to confirm that the controlled seepage is behaving as predicted.

Groundwater is defined in the Draft NSW Guidelines as "any water contained in or occurring in an aquifer". Aquifer is defined as "a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients". Thus the goal should be not to contaminate aquifers. Interestingly, most landfills in NSW do not occur above aquifers but do occur above groundwater.

The term contaminate is defined as "to render impure" whilst pollute is "to affect the amenity of a user" (UK Royal Commission on Environmental Pollution, 1984). Therefore the environmental goal should be to recognise the feasible and emphasise the protection of aquifers without ignoring potential adverse impacts from groundwater in aquitards. Such a goal may require a risk based rather than an empirical approach. This more appropriate goal is the basis behind the proposed monitoring strategy.

4 LOCATION OF MONITORING BORES

There are two types of subsurface water monitoring devices; suction lysimeters for the unsaturated zone and bores for the saturated zone. Lysimeters are usually used as part of a leak monitoring system in hazardous waste landfills and are placed beneath the liner. Their use is normally limited to clay liners as installing them under artificial liners is difficult. Although the ceramic caps are readily available the riser has to be tailored.

When planning an environmental groundwater investigation it is important to assess permeability, gradient, geological medium and direction of groundwater flow to help determine piezometer installation and location. Areas with natural preferred pathways can be established by defining lineaments from aerial photographs, by geological structural mapping and by geophysical techniques Most of this information can be obtained from quarries prior to landfilling. More bores are required down gradient than upgradient.

In old landfills in quarries and in landfills that are not in quarries, interface drainage (perched water table) is often ignored. As there is usually no surface expression of interface drainage, bores should be placed into the interface between the soil (usually clayey) and the natural rock at the topographical low or below the lowest lip of the quarry. Water only collects in these bores during periods of prolonged rainfall or a seasonal wet period and usually discharge into local water courses some distant down gradient. These interface drainage monitoring bores should be sampled immediately after rainfall.

Table 2 shows the time taken for leachate to reach a piezometer at given distance from the landfill. The landfill in the example has been constructed with a 0.80 m compacted clay liner and collection system (0.5 m

Table 1 Calculated flow rates through liners. (Flow rates in litre/ha/.day

Type of liner	Best case	Average case	Worst case
Geomembrane alone	2,500 (2 holes/ha)	25,000 (20 holes/ha)	75,000 (60 holes/ha)
Compacted soil alone	115 (k = 10^{-10}m/s)	1,150 (k = 10^{-9}m/s)	11,500 (k = 10^{-8}m/s)
Composite	0.8 (2 holes/ha, k = 10^{-10}m/s poor contact)	47 (20 holes/ha, k = 10^{-9}m/s. poor contact)	770 (60 holes/ha, k = 10^{-8}m/s, poor contact)

After Street (1993) Cited in Westlake 1995 head) compared with one without a collection system (10 m head) in a variety of geologic media and assumes there is no unsaturated flow. When sand aquifers or weathered sandstone aquifers are immediately beneath the landfill, composite liner systems are required and monitoring bores should to be located within 5 m of the landfill as well as at about 50 m from the landfill. Landfills without a leachate collection system, located in weathered shale and fractured clays, clearly should not be located close to an aquifer and monitoring bores would be ideally located at approximately 10 and 50 m from the edge of the landfill. A landfill in the same environment but with leachate collection should have piezometers located at 5 m and between 15 and 20 m from the landfill edge. Landfills located on or above a thick deposit of well compacted clay shale without preferred pathways requires piezometers within 1 m of the landfill edge. As drilling this close may cause fracture pathways, the closest would be 3 m for auger or core drilling rigs and 5 m for air, rotary percussion rigs. In this case bores beyond 5 m away are a waste of money unless in preferred pathways. In low permeability ground a positive response is often due to surface water or interface drainage water flowing down the annulus of the hole. Bentonite seals must be used above the test zone and at the surface. In such an occurrence, all constituents of plume arrive at once, rather than attenuated.

5 SAMPLING INTERVAL

The draft guidelines specify sampling at three monthly intervals. Reference to Table 2 shows that this sampling time is often inappropriate. Landfills located above sand or weathered sandstone aquifers essentially require semi-continuous monitoring. Continuous monitoring probes are essentially limited to electrolytic conductivity (EC), which is only really useful when the total dissolved solids in the groundwater are below 2500 mg/L. If semi-continuous monitoring is not possible, then pH, pe (Eh), EC, odour and colour should be measured in the field weekly and appropriate constituents, ideally monthly, at worst quarterly. In all other instances except the stiff clay and unweathered shale, the location of the inner bores should be placed to allow quarterly monitoring. Inner monitoring bores should be designed so that a detection at theses bores will take three years to reach the next level of bores and consequently these are monitored infrequently. By using quarterly monitoring an early breakthrough can be detected and an appropriate strategy put into place prior to the groundwater reaching the site boundary. In a controlled seepage landfill, remediation should be unnecessary and monitoring is used to collaborate the landfill conceptual model and confirm successful attenuation.

For unweathered shale and a thick deposit of stiff clay, the inner bores and bores on preferred pathways should be monitored quarterly for pH, pe, EC, odour and colour at six monthly or even annually for appropriate constituents. Outer bores should only be added for background sampling or if there is a response in the inner bores.

6 LEACHATE CHEMISTRY

6.1 Development of leachate

The nature of the reactions in a landfill, particularly of the putrescible material, partially decides the constituents of the leachate. Typical domestic refuse will contain between 50% to 70% carbohydrate, which is readily degraded. Interaction of the byproducts of the landfill bioreactor with the night cover and underlying soil/rock also has a significant impact on the nature of the leachate.

Decay begins immediately after wet deposition, (heavy compaction of the landfill with night cover only delays the onset of decay). Aerobic microbes use oxygen to convert cellulose and sugars to energy, water and carbon dioxide in a process known as respiration. By another pathway organic acids such as oxalic acid are also readily produced. This creates an initial leachate that is high in organic acids, intermediate fulvic and humic compounds and dissolved carbon dioxide, which is also known as carbonic acid. The presence of these organic acids and the undissassociated carbonic acid lowers the pH to between 4 and 5. The leachate is also high in chloride, sodium sulfate and potassium. This rapidly consumes the available oxygen.

This initial stage is usually very short lived and the landfill rapidly becomes a fermentation vat, providing the acidity is neutralised by the waste. Anaerobic fermentation converts organic compounds to produce, ultimately, methane and water. Though this is overly simplified, every stage of the processes is catalysed by micro-organisms, usually bacterium. During the fermentation process, all chemically bound oxygen is consumed, firstly from soluble ions such as nitrate and sulfate and then from minerals or solids containing nitrate, sulfate, iron and manganese minerals, particularly goethite (rust). These minerals could be sourced from the rubbish or the soil used as night cover. As the chemically bound oxygen is consumed, increasing amounts of methane (CH_4) are produced; and ammonium, iron, and manganese appear as ions in the leachate at the expense of organic acids (they contain organically bound oxygen). The pH increase caused by the consumption of hydrogen in the formation of ammonium, methane, bicarbonate and hydrogen sulfide. Hydrogen sulfide will not form in the presence of iron and heavy metals, which are precipitated as sulfide, resulting in 99.9% metals being confined in the landfill (Belevia Baccini 1989). A tip that becomes rapidly fermenting will maximise gas production and reduce the organic acid and biological demand in the leachate, however, ammonium and bicarbonate will increase.

6.2 Leachate Constituents

In summary, early stage leachate is dominated by sodium, potassium, chloride sulfate, nitrate and organic acids. It has a low pH (4.5 to 6.0) and has a high biological oxygen demand. Later stage leachate is dominated by sodium potassium chloride and bicarbonate with sulfate and ammonium being codominant or subdominant and pH is neutral. Iron and manganese are minor constituents. In both cases heavy metals, petroleum organics and halogenated organics comprise less than 1% of the leachate constituents.

6.3 Theoretical Movement of Contaminants in the Groundwater

If there were no physical and chemical mechanisms of attenuation, the leachate would arrive at any point at maximum concentration, that is, as plug flow. Various mechanisms, however, result in the decrease in concentration of the leachate.

A landfill leachate normally contains high concentrations of ions and discharges into groundwater or surface water with a lower concentration. Initially and when the leachate discharge is low compared to that of the receiving waters, dilution occurs. This results in a reduction in concentration of the ions, which usually has little effect on the comparative dominance of ions in the groundwater, that is their ratios to one another. Dispersion, like dilution, results in a reduction in concentration, normally without alteration of the ionic ratios. Alteration of ionic ratios is the result of the preferential removal of one ion compared to the others or the

Table 2 Time required to flow various distances

	Distance from Landfill (m)	Liner only h = 10m	Liner and collection h = 0.5m
Liner alone	-	309 days	7 years
Sand	5	1.6 hrs	13hr
$k = 10^{-4}$ m/sec	10	6.4 hrs	53 hrs
ρ= 0.4	50	6.7 days	56 days
Clay	5	29 years	244 years
$k = 10^{-9}$ m/sec	10	117 years	976 years
ρ= 0.4	50	2940 years	2440 years
Fractured Clay	5	13.4 days	111 days
$k = 10^{-6}$ m/sec	10	54 days	1.2 years
ρ= 0.5	50	3.6 years	30 years
Shale	5	3.5 years	30 years
$k = 3.1 \times 10^{-9}$ m/sec	10	14 years	118 years
ρ= 0.15	50	355 years	3000 years
Weathered Shale	5	8 days	67 days
$k = 1.0 \times 10^{-6}$ m/sec	10	32 days	267 days
ρ= 0.3	50	2.2 years	18 years
Sandstone	5	13 days	111 days
$k = 2 \times 10^{-7}$ m/sec	10	54 days	1.2 years
ρ= 0.1	50	3.7 years	30 years
Weathered Sandstone	5	2.6 hours	1 day
$k = 5 \times 10^{-5}$ m/sec	10	10 hours	3.5 days
ρ= 0.2	50	11 days	90 days

* Permeability from Fetter 1988, AGC, 1984, Porosity from Fetter.
* Assume conditions are static for the interval.

appearance of new ions. Ions are reduced in concentration by precipitation, co-precipitation, ionic substitution and ionic exchange. The latter two also cause the appearance of new ions, as does bacterial action and change in the oxidation/reduction status.

Ionic exchange is more common for cations than anions. It works on the principal that some minerals, known as colloids, have an unbalanced charge across their surface and, as a result, they have an excess negative charge. To balance this charge, cations from the pore water are drawn in and held on the surface. In nature, these cations come from the weathered rock and the relative proportion on the surface of the colloid should be typical of the surrounding rock minerals, except that certain cations are preferred over others. As these ions do not go into the mineral but are parked on the surface, they are known as exchangeable or adsorbed cations. Those exchangeable cations sourced from the weathering rock are known as 'native' cations, and include calcium, magnesium, potassium and sodium. Native cations are usually readily displaced by leachate cations and often appear in groundwater before the leachate, or at the very latest at the start of the plume. They are detected by an alteration of the ratio of the natural cations in groundwater.

Bacterial decay, initiated within the landfill, continues as the leachate moves through the clay liner, unsaturated soil and into the surrounding saturated zone (rock or unconsolidated sediments). Essentially they continue the degradation process of organic acids started in the landfill. Due to their activity, bicarbonate concentrations increase (at neutral pH) and sulfate and nitrate reduction continue. The redox activity of the water becomes, if not already so, reducing that is, pe is negative.

6.4.Behaviour of Landfill Leachate

Landfill leachate goes through varies stages that correspond both to the influence of the stages of the landfill and attenuation within the ground. If the liner of the landfill is too permeable, the tip is highly compacted and quite young, then the initial leachate is high in organic acids. This results in an elevated biological oxygen demand (BOD), iron, manganese, nitrate chloride and bicarbonate and a low pH. This elevated BOD stimulates endemic microbes in the soil which reduce the organic acids, consume the nitrate producing ammonium, converting sulfate to sulfides and elevating bicarbonate concentration. Ammonium is adsorbed, displacing native cations while the reducing conditions mobilise iron which either precipitates the sulfides, or gets adsorbed, further displacing native cations, and the bicarbonate is washed downgradient. In sandy soils or colloid free rock, ammonium, and to a lesser extent iron, will also proceed down gradient. Chloride is common to all landfill leachates, is rarely chemically attenuated and is found at the front of the plume, together with bicarbonate (a bacterial byproduct), BOD and either with or just behind displaced native cations. Early leachate detection can be achieved by monitoring these ions.

The stages that a landfill goes through in time, so does leachate with distance, as the redox state is controlled by the minerals and the cation exchange capacity of the stratum. The development and passage of the plume through any one point with time is directly correlated with the variation of the plume with distance at any given time.

When increased or changed ratios of native cations initially appear before or at the same time as a rises in chloride sulfate and bicarbonate the aerated leachate front is passing that point. Usually when this detection occurs gross levels have not risen above background. As the front continues to pass, the second phase begins, with ammonium and biological oxygen demand (BOD) rising above background levels as do potassium, sodium, sulfate and chloride and bicarbonate, if they not already done so. In the absence of appropriate bacteria in the soil/rock, BOD may begin to rise in the first phase. Iron and manganese follow but could be significantly delayed if the exchange capacity of the soil is high. Iron and manganese can also be sourced from the soil as the water becomes increasingly reducing. When all the iron and manganese minerals have been dissolved, redox is controlled by sulfate oxidation where the sulfate concentration will be drastically reduced. Iron is then precipitated as a sulfide, which causes rapid reduction in iron concentration and the water to smell of rotten egg gas. Any polar absorbed organic acids will be displaced and may be briefly mobilised prior to consumption by the bacteria and bicarbonate levels reach a maximum. Finally the last stage of the plume, known as the methanogenic stage which is rarely seen except in the closest monitoring bores, passes. Organic acids reduce to low levels, methane is detectable in the gas phase and in the water, ammonium levels rise, displacing the remaining native cations, causing them to increase in the leachate and chloride remains high. Other metals and chlorinated hydrocarbons, with the exception of vinyl chloride, very rarely extend beyond the landfill but may be associated with this last stage.

In other areas, after the oxygenated plume passes and before the iron/manganese zone, there is a zone where redox is controlled by the reduction of nitrate. In theory, and from experience in monitoring landfills, testing of ground waters at any one bore can be limited to pH, redox and electrolytic conductivity in the field, as well as biological oxygen demand, ammonium, nitrate, sulfate, chloride, carbonate species, calcium, magnesium, potassium and sodium by the laboratory. If any change is noted, iron, manganese and sulfide should be monitored. Monitoring other ions and compounds are unnecessary on a regular basis and would be only considered necessary for public reassurance or if the first two phases of leachate have been detected at a bore.

Proposed landfill leachate is initially less salty than much of the underlying groundwater. A positive identification of a landfill plume is usually made by at least two above background readings, or appearance of ammonium and biological oxygen demand, but, using ratios, the plume can be identified before concentrations exceed background and can highlight variations in native cations (Mulvey 1990, 1993).

7 NATURE OF THE PLUME

The nature of the plume, both in concentration and how it is attenuated, depends on the initial concentration and local ground conditions. Thus, different geological media produce different plumes. A heavy clayey soil or rock with clay minerals and low permeability will attenuate and fragment the plume, resulting in widely separated, distinct phases of arrival. A non-reactive, porous medium will result in a poorly attenuated plume - the plume arrives without distinct phases and is essentially a dilute leachate. A positive detection in a bore may not be due to the groundwater thought to be monitored. If a plume in an attenuating environment arrives as a pulse, rather than distinct phases or the phases are only slightly separated, leakage down the hole from interface drainage or surface runoff may be the cause. Normally in such a bore standing water levels show greater variation than other bores.

8 EXAMPLE OF BREAKTHROUGH PLUME

Table 3 presents the groundwater monitoring results for a general landfill (no household or domestic

Table 3 Water Monitoring Data for a non-domestic and industrial Refuse Landfill

	BH 1	BH7	BH7	BH7	BH7	BH7	BH7	BH7	BH7	BH13	BH13
Months after closure	0	-5	5	5	8	14	18	20	24	11	17
pH	7.2	6.8	6.8	6.8	7	6.7	6.6	6.6	6.8	7.2	6.9
TDS	5780	5490	6200	5900	6200	6550	7450	6870	6920	8456	8420
BOD	290	5	40	10	22	20	35	30	20	<2	9
Iron	0.62		0.06	1.4	0.15	0.1	0.7	0.09	0.1	0.07	0.1
Sodium	930	1760	2090	1860	1860	2000	2330	2090	2190	2810	2630
Calcium	51	92	20	135	140	130	150	125	130	190	170
Potassium	590	15	38	41	50	46	44	49	49	27	28
Magnesium	125	180	210	220	260	280	270	280	280	340	285
Ammonia	1050	0.6	4.9	7.9	12	34	8.5	14	19	1.7	1.1
Chloride	1290	2350	2480	2250	2570	2660	3250	2940	2880	4240	4120
Nitrate	39	<0.1	<0.1	0.13	<0.1	<0.1	3.5	<0.1	0.63	3.1	1.6
Sulfate	100	420	120	130	130	140	150	150	120	380	390
Bicarbonate	5260	1430	2470	2520	2370	2380	2480	2400	2430	1720	1530
Cl/S04	13	5.6	21	17	20	19	22	19	24	11	11
Cl/HCO3	0.25	1.64	1.00	0.89	1.08	1.12	1.31	1.23	1.19	2.47	2.69
Ca/K	0.09	6.1	0.53	3.3	2.8	2.8	3.4	2.6	2.6	7.0	6.1
Cl/TDS	0.22	0.43	0.4	0.38	0.41	0.41	0.44	0.43	0.42	0.50	0.49
Na/K	1.6	117	55	46	37	43	53	43	45	104	93
L/N*	104	0.76	1.84	2.20	2.74	3.31	1.90	2.52	2.6	0.85	0.9

*L/N = (K + NH4)/(Mg + Ca + Na) x 100

refuse) situated in sandy, clay sub-base with saline groundwater. Goundwater has been monitored during and after the operational phase of the landfill. BH1 is located within the landfill and samples landfill leachate. Bore BH 7, located 10 m down gradient from the landfill, was initially sampled just after the first phase of a pollution plume, and before the actual closure of the landfill. BH 13 is a background bore located 25 m upgradient from outer landfill edge and the results are representative of background water quality. Monitoring began 5 months before closure. The leachate is less saline than the natural water, but is dominated by ammonium sodium and potassium. The natural water is dominated by sodium calcium and magnesium.

To highlight the breakthrough of displaced native cations and leachate breakthrough, a special ratio known as the L/N ratio has been derived. The L/N ratio is defined as the addition of the dominated cations in the leachate divided by the addition of the dominant cations in the groundwater multiplied by a factor (usually a hundred). When a cation is dominant or co-dominant in both waters it is included in the divisors only. Usually the differences in the L/N ratio of leachate and groundwater is at least two orders of magnitude.

Contaminant concentrations are at or just below background, thus the characteristic of the plume can only defined by the use of ratios.. Unfortunately monitoring commenced as the initial phase of a leachate plume was occurring. Compared to the upgradient background bore BH13, BH7 has a classic breakthrough signature. At initial sampling (-5 months), relative increases in bicarbonate and sulfate (to chloride) and a reduction in nitrate have occurred and calcium + magnesium + sodium (native cations, N) have increased relative to potassium + ammonium (leachate cations, L) indicating the displacement of native cations has occurred in advance of the main front. The second phase is apparent in the next sampling, BOD rises sharply, ammonium and iron starts to rise, relative to chloride, sulfate is reduced, and potassium + ammonium rise relative to calcium + magnesium + sodium.

Earthworks for closure, seasonal effects, or two distinct pulses rather than a single continuous source could explain the variable behaviour of the plume after the second phase of the breakthrough. As could the adsorption and desorption of polar organic compounds onto colloids as the front passes. After 24 months of monitoring heavy metals were either at background levels or undetected and chlorinated and petroleum hydrocarbons remain undetected.

9 CONCLUSIONS

Groundwater monitoring bore location and frequency of monitoring depend on the nature of the surrounding soil or rock within which the landfill is located. Location and frequency of monitoring should not be haphazard or uniformly applied but tailored for local site conditions. A simplistic local conceptual model should be derived to highlight the monitoring requirements.

In general the initial breakthrough front will see an alteration to the L/N cation ratio, and a rise in chloride, bicarbonate and sulfate. This is usually followed by a second front that is high in biological oxygen demand, chloride, bicarbonate, ammonium and potassium and lower in nitrate and sulfate. An increase in iron and manganese normally follows. Thus constituents monitored should be pH, pe and electrolytic conductivity in the field as well as chloride, bicarbonate, sulfate, biological oxygen demand, ammonium, nitrate, calcium, magnesium, sodium and potassium analysed in the laboratory. Only after the second front has passed should organics and heavy metals be monitored. Ratios, particularly the L/N cation ratio, should be used to highlight differences particularly when background salinity is high.

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ATTACHMENT 1 CURRICULUM VITAE

Philip Mulvey – Landfill

Chief Executive Officer/Senior Principal Scientist

Qualifications

- B.Sc.Agr. (Soil Science) — Sydney University (1981)
- M.App.Sc. (Hydrogeology) — University of NSW (1985)

External Training

- Environmental Auditor (Contaminated Land) — Vic EPA (1995)
- Site Auditor (CLM Act) — NSW EPA (1998)
- Site Contamination Auditor – SA EPA (2009)
- CPSS (Level III) — Australian Society of Soil Science Inc
- Study tour of North America, 1983. Included Waterloo University (Prof. Cherry, Dr R Gillam) and Colorado School of Mines (Prof. Langmuir)
- USA-EPA, Risk Assessment and Risk Communication Course 1993

Skills

Philip is the Chief Executive Officer/Senior Principal and Hydrogeologist with Environmental Earth Sciences. He is CPPS Leading Professional Stage 3, an Environmental Auditor (Contaminated Land) Vic EPA and Site Auditor (CLM Act) NSW EPA. Phil is a specialist in soil and water chemistry as well as interactions between the two media. He has over 30 years experience in soil sciences, hydrogeology, environmental geological, environmental risk assessment and waste management. He has conducted numerous projects involving contamination assessments, remediation planning, remediation supervision and validation of contaminated sites; geochemical and hydrogeological studies at mine sites throughout Australia; landfill design, management and decommissioning; mine closure planning and supervision. Often, in so doing, providing innovative new solutions that have impacted on industry practices.

Employment History

- Environmental Earth Sciences International, Chief Executive Officer (2008 – Current)
- Environmental Earth Sciences International, Manager (1999 - 2008)
- Centre for Contaminant Geoscience, Principal Research Scientist (2002 – current)
- Environmental Earth Sciences, Senior Principal (2000 – current)
- Environmental Earth Sciences, Principal Scientist (1990 – 1999)
- Environmental Earth Sciences, Senior Scientist (1983 -1990). Seconded to Golder Associates 1985
- Australian Groundwater Consultants, Hydrogeologist/Soil Chemist (1981 -1983)
- University of Sydney, Demonstrator/Tutor in Soil Science (1980)

Professional Affiliations

- Australian Society of Soil Science — Certified Practicing Member Level III (CPSS)
- International Society of Soil Scientists — Member
- International Association of Hydrogeologists — Member
- International Solid Waste Association — Former Member

Appointments

- Member certification subcommittee for Davis Langdon (mining rep) June 2001- 2006
- Co-convenor 11th National Soil Conference April 1998
- Foundation Committee member of ACLCA 1998-1999
- One of three on the development committee to found Australian Contaminated Land Consultants Association (ACLCA) 1997
- Hon. Secretary National Executive Australian Soil Science Society August 1996 - Jan 1999
- Convenor First National Soil Phosphate Conference November 1995
- President, NSW Branch of the Australian Soil Science Society July 1994 - Sep 1996
- Hon. Secretary, NSW Branch of the Australian Soil Science Society June 1995 - Sep 1996

Project Summaries

Landfill Projects

Managed the Following Landfill Projects:

- MAB – Investigation of development opportunities for the Broadmeadow Landfill
- Melbourne Water – Statutory audit for land partly covered with a landfill
- Bairnsdale Council- Landfill cell Construction - Statutory auditor sign off
- Wagga Wagga City Council – Design of strategic 50 year plan for Gregadoo regional landfill – First specifically designed bioreactor landfill in Australia and ongoing monitoring for last 20 years
- Wagga Wagga City Council – Preparation of a risk management plan for putting out a buried landfill fire at Gregadoo
- Wagga Wagga City Council – Closure plan and supervision of Forest Hill Landfill
- Landcom – Design to mitigate impacts of building close to a landfill
- Private developer, Dural – Excavation and sorting of former landfill for residential development
- Shellharbour Council - Landfill groundwater monitoring for 23 years
- Addenbrooke – Statutory Audit of 735 unit flats built partly on and next to a landfill
- Mirvac - Investigation of fill
- Glenfield Waste - Groundwater monitoring at landfill for 3 years
- Neil International - Remediation of a landfill
- Pacific Property - Investigation and remediation of landfill for residential development
- Camide - Groundwater monitoring of 4 landfills for 5 years
- Kuringai Council – Irrigation of landfill leachate water onto a golf course
- Dunmore soil and cement - Investigation and monitoring of groundwater surrounding a landfill
- Camide - Groundwater monitoring at various landfills
- Patterson Brittan, Regents Park - Landfill leachate investigation

Significant Technical input with the following Landfill Projects:

- Department of Defence – Design hazardous waste cell
- Flower Power, Milperra – Investigate and design gas mitigation system for building on a landfill
- Flower Power, Milperra – Investigate and design wetland leachate treatment system
- Stocklands – Investigation of residential development and arterial road through an old landfill
- REROC- Investigate and prepare regional waste management plan and regional medical waste plan
- Private Developer, Brunswick – Investigate and Design gas and groundwater management system for residential development on a very old landfill
- Silverwater – Design mitigation and collection system for groundwater and gas at a recently closed landfill

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- Tomago Aluminium – design and test a hazardous waste landfill
- Small Regional Councils including Uralla, Coffs Harbour etc; groundwater monitoring and assistance in LEMP preparation
- International Manufacturer – Design and construct a hazardous waste cell for PCBs
- Penrith City Council, Penrith NSW - Evaluation of domestic landfill for development
- Land Systems, Yarra Bay NSW - Rehabilitation of uncontrolled domestic landfill - chemical aspects
- Randwick Council, Maroubra NSW - Rehabilitation of uncontrolled domestic landfill - chemical aspects
- Brambles/Cleanaway, Menai NSW - Design and installation of leachate collection system for old liquid and solid landfill
- Department of Main Roads, WA - The effect on water quality of a lake due to building a Freeway through a nearby sanitary landfill
- Shire of Upper Yarra, Victoria - Landfill appraisal - assessment of likely effects and quality of leachate
- Burswood Casino, Perth WA - The effect of the leachate quality on the Swan River due to construction of the casino on sanitary landfill
- White Industries, Yulara (Ayers Rock) Tourist Village - Location and development of water supply and geochemical evaluation of sites for sanitary landfill and evaporation ponds for desalinator extracts

Contamination Projects

During his career, Philip has undertaken or directed projects in Australia, New Zealand, Pacific Islands, East Timor, USA, and UK. An overview of the type of remediation projects is presented below.

- Remediation of over 100 petroleum service stations, depots and Terminals and total refinery;
- Remediation of over 20 MGP or gas works in Australia and UK;
- Remediation of over 20 timber treatment plants including the Kopper Mt Gambier Aldrin plant;
- Remediation of nutrient and petrol plumes using sterile cloned willow trees, Pt Phillips, Vic;
- BHP, Newcastle – Contaminated soil and groundwater remediation planning for steelworks
- Moorabbin, Vic — managed remedial program on former paint factory, including removal of 24 USTs, bioremediation of 200 m^3 solvent impacted soil and design and installation of *insitu* groundwater treatment system;
- Botany, NSW — managed investigation and remediation of former paint factory, works included UST removal and soil and groundwater bio remediation;
- Rehabilitation planning and supervision for decommissioning and shut down of 6 mines including 2 uranium mines (Mary Kathleen Uranium Mine and Nabarlek Uranium Mine)

Publications

Philip has produced over 50 publications and conference presentations. Some of the relevant papers to landfills management or disposal to landfill include:

Cartwright, Mulvey and Daly (2008) - Tarry Material: NE England case study assessing the most sustainable remediation technology, Proceedings MGP conference, Dresden, 2008

Mulvey (1998) Groundwater Monitoring, Mining Environment Magazine, July 1998 pp13-20

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