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technical memorandum

TO Nigel Donovan
Ministry for the Environment

FROM Natalie Webster, Graeme Proffitt

DATE 12 December 2019

RE WasteMINZ Landfill Guidelines – Options for Class 3 and 4 WAC Derivation

1.0 Introduction

This memorandum sets out options for deriving landfill waste acceptance criteria (WAC) for Class 3 and 4 landfills, but also provides background to the derivations to date and the current difficulties with the Class 4 derivations as set out in the draft WasteMINZ Technical Guidelines for Disposal to Land (the Guidelines).

This memorandum sets out, in broad terms, the philosophy adopted for the derivation, the WAC derivation methodology used to date, the information necessary to carry out the derivation, assuming a similar derivation process for Class 1, 2 and 4 landfills as has been used in the Guidelines to date.

This memorandum concentrates on Class 3 and 4 landfills but provides information on the other classes as background.

1.1 Summary

The current iteration of the Guidelines contains WAC for Class 1, 2 and 4 landfills. However, because the Class 3 landfill class is a recent addition to the Guidelines, and represents a new class of landfill, there are currently no Class 3 WAC.

PDP has been engaged by MfE to derive the Class 3 WAC. In doing so, and in order to achieve consistency with the previously-derived Class 4 WAC, PDP co-ordinated with stakeholders who have contributed to the creation of the Guidelines to date, regarding the Class 4 WAC derivation methodology. Due to the nature of the Class 4 landfill, which is intended to be suitable for an 'unlimited' land use post-closure without capping, the Class 4 WAC will be the lowest concentration required to ensure that the accepted soils do not: exceed human health guidelines; exceed ecological guidelines; or cause an excessive discharge to groundwater or surface water via leaching. To determine the required WAC to protect groundwater and surface water via the leaching pathways, a calculation must be performed which estimates the total allowable soil concentration, below which the groundwater receptor will not be excessively affected. The same calculation is also necessary for the Class 3 WAC, as the definition of the Class 3 landfill requires only the leaching pathways to be protected.

The current Class 4 derivations rely on a partition coefficient, Kd, to predict leachate contaminant concentrations from waste soil contaminant concentrations. In order to develop the Class 3 WAC, we have sought to understand the Class 4 derivations and in particular the choice of Kd utilised in the current Class 4 WAC. This is because there is a wide range of Kd values published in the literature for different

contaminants and soil types. It was our intention that once the Kd values for the Class 4 WAC derivations had been established, these could then be utilised to derive the Class 3 WAC.

However, the Guidelines provides little detail for the leaching pathway derivations and while the numerical value of the particular coefficients used were obtained, they were not able to provide the source of, nor the rationale for their use. Given this lack of information, we are unable to confirm that the values that were used are reasonable.

To gain a better understanding, we have completed some limited research into the available published Kd values, and have performed a comparison to determine how the use of different Kd values would affect the Class 3 and 4 WAC. The limited research indicates that the use of simple partitioning theory to predict leachate concentrations, along with other simplifying assumptions, is not a sufficiently robust basis for the Class 3 and 4 WAC derivations.

We have explored alterative solutions for the derivation of WAC which includes the use of Synthetic Precipitation Leaching Procedure (SPLP) testing to determine actual leaching potential of a waste soil. SPLP limits could then be used as the WAC, much as TCLP limits are used for Class 1 and 2 landfills. However, further limited work examining SPLP – total concentration relationships for a limited number of contaminants suggests that total concentration WAC could be developed from such relationships. The indication is that such WAC would be more robust than those developed from Kd values. Further work using a national SPLP dataset would be required to confirm this. We have made preliminary enquiries of laboratories which indicate a large anonymous data set could be assembled. We recommend this approach be pursued further.

A more minor issue is that some Class 4 WAC are based on ecological soil guideline values. The values used in the Guidelines were developed in 2006 and earlier. Recent government-funded research has resulted in more up-to-date values being available. We recommend the more recent values replace the older values.

2.0 Landfill Class Philosophical Basis

The various landfill classes are set out in Table 1 below, with the basis for the WAC for each landfill type. This is, in effect, a conceptual site model (CSM) as is used in contaminated land risk assessment, but it is not described as a CSM in the Guidelines. The derivation flows from what is to be protected, whether human health during the operational or post-closure phases, or the offsite environment, whether people, groundwater or surface water.

For example, a Class 1 landfill is intended to be lined and therefore groundwater is largely protected against contaminants within the fill leaching into groundwater, but contaminant acceptance is still ultimately limited by consideration of what might still escape through an imperfect liner (even plastic membranes leak). The WAC for a Class 1 landfill are not intended to be protective of workers on the landfill or people who may later visit the closed landfill, nor are the WAC intended to protect the wider environment against the effect of stormwater or sediment migration, as there will be engineered erosion and sediment controls both during the operation and post-closure. It is likely the consent conditions under which the landfill operated would require a post-closure management plan to ensure the closed landfill was properly maintained into the future. Any post-closure use of the landfill would need to be consented as a change of use under the National Environmental Standard for Assessing and Managing Contaminant in Soil to Protect Human Health (the NESCS).

Table 1: Landfill Class Summary

<table>
<tr><th></th><th>Class 1</th><th>Class 2</th><th>Class 3</th><th>Class 4</th><th>Class 5</th></tr>
<tr><td>Landfill Type</td><td>Municipal</td><td>C & D Landfill</td><td>Managed Fill</td><td>Controlled Fill</td><td>Clean Fill</td></tr>
<tr><td>Waste Type[1]</td><td>Municipal solid waste from residential, commercial and industrial sources, including putrescible material.</td><td>Non putrescible, non-hazardous construction and demolition waste, including some biodegradable material.</td><td>Contaminated soil with limited organic material</td><td>Low level contaminated soil with limited organic material</td><td>Virgin excavated natural material</td></tr>
<tr><td>WAC Basis</td><td colspan="2">Protection of groundwater with a liner in place pre and post-closure.</td><td>Protection of groundwater – pre and post closure with no liner.</td><td>Protection of groundwater pre and post- closure with no liner; and protection of human health and soil ecology post-closure.</td><td>Natural background[2]</td></tr>
<tr><td>Non-WAC controls – operational phase</td><td colspan="5">Protection of human health during operational phase by workplace health and safety controls.
Protection of groundwater via liner (Classes 1 and 2 only).
Protection from surface runoff and mobilised sediment through engineered controls.</td></tr>
<tr><td rowspan="2">Non-WAC controls post closure</td><td colspan="2">Protection of human health by landfill cap and engineered landfill gas controls.</td><td>Protection of human health post-closure by landfill cap</td><td>None – WAC low enough to protect human health for all likely uses.</td><td>None – no contamination.</td></tr>
<tr><td colspan="2">Protection of offsite environment by engineered controls – liner, cap, stormwater, sediment and landfill gas controls – and management plan.</td><td>Protection of offsite environment by engineered controls – cap, stormwater and sediment controls – and management plan.</td><td colspan="2">Protection of offsite environment by engineered control of stormwater and sediment.</td></tr>
</table>

Notes:

1. *All landfill classes can take waste acceptable in a less secure (higher numerical class) landfill, e.g. Class 1 can take waste acceptable in all other classes and Class 2 to can take waste acceptable in classes 1 – 5.*
2. *Unless soil is from a suspected contaminated source, no testing should be required.*

However, a Class 4 landfill is not intended to be lined and as per the current iteration of the Landfill Guidelines will not be capped (other than topsoiling and vegetating). The landfill is intended to be fit for most uses into the future (but is not required to be pristine) without being capped. Given this context, contaminants may leach through the base of the landfill and people may be exposed to contaminants at the surface post-closure. Setting the WAC must therefore consider multiple circumstances by which effects from contaminants could occur to people or the environment.

The essential philosophy for all the different landfill class WAC derivations is to provide generic values that are conservative and therefore protective of human health and the environment regardless of the landfill site circumstances and setting. These values can then be used within landfill consent conditions, where the consent applicant does not want to go to the trouble and expense of consenting more permissive criteria, particularly where the landfill setting indicates there is limited natural containment to protect groundwater or nearby aquatic environment.

For example, for the Class 4 Controlled Fill landfill the WAC derivation considers leaching of contaminants to groundwater and possible subsequent discharge of contaminated groundwater to a surface water body. The parameters used in the derivation suggest that the landfill is sited on a permeable, sandy gravel aquifer such as might occur in the Canterbury Plains, that a groundwater drinking-water bore is located at the downgradient (downstream) extent of the waste and that a vulnerable stream is also located at that location.

Most landfills would not have a drinking-water bore and a stream located close to the waste and many landfills will be located on less permeable geology, such as silty or clayey soils. In such cases an applicant could choose to demonstrate that the generic values were too conservative for their setting and apply for less conservative values as part of the consenting process.

3.0 Background to WAC Derivations

Currently, WAC have been derived for three classes of landfill, Classes 1, 2 and 4, with the derivation of Class 3 WAC intended as part of the current project. The broad outline of the derivation is provided in Appendix C of the Guidelines. The explanation below draws on that document with additional explanation provided to explain in simple terms some of the theory behind the derivations.

3.1 Class 1

The Class 1 WAC are toxicity characteristic leaching procedure (TCLP) concentrations, based on United States Environmental Protection Agency (US EPA) practice developed in the 1980s[1]. The TCLP test is a laboratory test in which 100 g of contaminated soil or waste is agitated for 18 hours in 2 litres of an acidic leaching fluid (i.e. a fluid – solid ratio of 20:1). The leaching fluid is intended to simulate the typically acidic conditions within a municipal solid waste landfill. At the end of the agitation period the concentrations of the various hazardous substances in the liquid are determined (units of mg/L).

Some of the Class 1 values have been adopted directly from the US EPA values. The limiting TCLP concentrations are based on the then US drinking-water criteria with a dilution and attenuation factor DAF) applied. Where a drinking-water criterion did not exist at the time for a hazardous substance,

[1] It should be noted that the US EPA has more recently advocated the use of a broader range of tests under the Leaching Environmental Assessment Framework (LEAF) (https://www.epa.gov/hw-sw846/how-guide-leaching-environmental-assessment-framework) although the use of this is voluntary, rather than mandated by regulation. The motivation was that TCLP test does not accurately represent leaching for many landfill situations and some wastes/hazardous substances.

published values of what had been determined to be a safe daily dose[2] for that substance. The safe daily dose could then be used to calculate the equivalent of a drinking-water criterion. To arrive

The US EPA carried out groundwater modelling between a notional landfill and a drinking-water bore, to determine DAFs for a range of landfill scenarios and aquifer properties. The US EPA determined that a DAF of 100 across all the toxic substances and landfill scenarios would be conservative. It therefore chose this DAF to back-calculate limiting TCLP values for each hazardous substance considered.

Additional TCLP values have been adopted from the Ministry for the Environment's 2004 document *Module 2: Hazardous Waste Guidelines – Landfill Waste Acceptance Criteria*. The US EPA had developed 39 TCLP criteria and MfE decided that a wider range of substances, particularly organic compounds, needed to be covered. The additional values were determined by carrying out groundwater modelling and developing substance-specific DAFs[3] from the worst case of either protecting drinking-water supplies (using the Drinking-water Standards for New Zealand 2000) or aquatic ecosystems (using ANZECC 2000 water quality criteria).

In addition, there are five more TCLP criteria listed in the draft Guidelines as US EPA values (sulphides, cyanides, total halogenated compounds, total synthetic non-halogenated compounds and polychlorinated biphenyls), but these do not appear to be US EPA values and no other source or derivation for these values is given.

It is not clear in the current Guidelines why the approximately 80 substances have been selected. When MfE expanded the list in 2004 there were 56 substances for the then Class A and B landfills, with fewer than half of the US EPA regulated TCLP values chosen.

3.2 Class 2

The Class 2 WAC are also TCLP concentrations. However, for the Class 2 WAC the Guidelines have adopted a DAF of 20, reflecting a different level of containment and the waste being unlikely to create as strong a leachate, given the smaller proportion of biodegradable organic and less acidic conditions. The DAF being a factor of five lower than the DAF for Class 1 means that for the TCLP values adopted from the US EPA, the Class 2 values are simply the Class 1 values divided by five. For example, the TCLP criterion for arsenic for Class 1 is 5 mg/L whereas the Class 2 TCLP value is 1 mg/L. The effect is to permit lower arsenic concentrations within the waste deposited in a Class 2 landfill than within the waste deposited in a Class 1 landfill. However, there are some exceptions, with some of the Class 2 values for organic substances being the Class 1 values divided by 10. It is not clear why this is the case.

It should be noted that the appropriateness of using TCLP criteria as a WAC is questionable for some substances (e.g. arsenic), and for Class 2 landfills, for which leaching conditions are expected to be considerably less acidic than a Class 1 landfills. However, it is not within the scope of the current work to reconsider the Class 1 and 2 criteria.

3.3 Class 4

There is a much smaller list of Class 4 WACs than for the Class 1 and 2 landfills, with only 17 contaminants listed rather than the nearly 80 contaminants for Classes 1 and 2. The values for each contaminant are determined as total available concentrations in soil (units of mg/kg) as the worst case (lowest value) of values determined to be protective of:

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[2] Variously referred to as reference doses (RfD), acceptable daily intake (ADI), tolerable daily intake (TDI) for non-carcinogens and risk-specific doses (RSDs) for carcinogens. The RfD is an estimate of the daily dose of a toxic substance that will result in no adverse effect even after a lifetime of exposure to the substance at that dose.

[3] *Waste Acceptance Criteria for Class A Landfills*, URS New Zealand Limited, September 2003.

- drinking water contaminated via infiltrating rainfall leaching to groundwater
- aquatic environments contaminated by leaching to groundwater and discharging of that groundwater to the aquatic environment
- the soil ecosystem
- people exposed via contact with the contaminated waste (soil) post-closure, with the criterion being the rural residential soil contaminant standard[4] (SCS) or where a New Zealand SCS does not exist an overseas equivalent

If the worst-case value for a contaminant is lower than the background concentration in soil, then the background concentration becomes the WAC. Background concentrations determined from testing soil around the Auckland region (as listed in the Auckland Unitary Plan) are used.

For the groundwater and aquatic environment leaching pathways, to get from a leachate concentration in the waste to a contaminant concentration within the waste/soil it is necessary to use a partitioning relationship between the waste/soil contaminant concentration and the leachate concentration. The assumption is that the leachate concentration is the starting concentration before dilution in the groundwater on its way to a drinking-water bore or a stream if transported to and discharged into the stream. A DAF of 20 is used for the drinking-water abstraction point. For groundwater discharge to an aquatic environment, the DAF of 20 is further multiplied by a factor of 5 (to give an overall DAF of 100) to allow for the additional dilution provided by a small stream.

A total soil concentration WAC is back-calculated by starting with the drinking-water standard or the ANZECC water quality (for protection of 95% of species), dividing by the appropriate DAF (20 or 100) to give the leachate concentration at the landfill, and then using the partitioning relationship to calculate the soil concentration. The derivation assumes that the soil is fully saturated (a conservative assumption) and that the leachate concentration is the same as the pore water concentration which is at equilibrium with the soil concentration. The assumption of being at equilibrium is also conservative because the residence time for infiltrating rainfall will, in many cases, be insufficient to achieve equilibrium concentrations in the pore water, with the leachate concentration consequently being lower than the equilibrium concentration.

The partitioning relationship is expressed in its simplest form as:

Soil contaminant concentration (mg/kg) = Kd (ml/g) x Equilibrium pore water concentration (mg/L)

where Kd is the distribution coefficient (or partition coefficient) for the contaminant.

Using arsenic as an example, the New Zealand drinking water-standard is 0.05 mg/L and the ANZECC 95% protection value is 0.013 mg/L (for arsenic (V), being lower than for arsenic (III)). The Guidelines derivation used a Kd of 1,550 ml/g. The calculation for the two pathways is shown in Table 2 below, with the values rounded down to two significant figures.

As it turns out, both the calculated values (310 mg/kg and 2000 mg/kg) are much higher than the human health and ecological criteria and are therefore not the limiting values. In the Guidelines, the rural residential SSC of 17 mg/kg was selected as the WAC for arsenic.

Similar calculations were carried out in the Guidelines for the organic compounds. However, the starting point for determining the contaminant pore water concentration from the soil concentration is the organic carbon-water partitioning coefficient (Koc). The Koc value is related to a Kd value for the soil by using the fraction of organic carbon (foc) within the soil. For the Class 4 derivations an foc of 1% has been assumed

[4] Soil contaminant standards are soil concentration limits derived to support the *National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health*.

in the Guidelines. The Kd value is then simply the Koc value for the contaminant multiplied by 0.01 (i.e. 1%) foc.

Table 2: Leaching Pathway Calculations for Arsenic

	Protection Criterion (mg/L)	DAF (no units)	Leachate Concentration (DAF x criterion) (mg/L)	Kd (ml/g)	Soil Concentration (Leachate x Kd) (mg/kg)
Drinking-water	0.01	20	0.2	1,550	310
Aquatic environment	0.013	100	1.3	1,550	2,000

3.4 Class 3

While Class 3 WAC are yet to be derived, it has been assumed these will be derived similarly to the Class 4 WAC except the derivation will consider only the leaching pathways to groundwater as a drinking-water source or to a stream. The same DAFs would be used.

The effect of this is that where human health or ecological pathways are the critical pathways for Class 4 for a particular substance, the Class 3 WAC for that substance would be greater (less conservative) than the Class 4 WAC. However, if one of the leaching pathways produced the critical value for Class 4, the same value would apply for Class 3. This is shown in Table 3 (next page), based on the values currently in the Guidelines. Values highlighted in blue or green are where the drinking water and aquatic pathways provide the critical values.

As currently derived, the Class 3 WAC for the naturally occurring heavy metals copper, nickel and zinc are based on one of the leaching pathways being critical and therefore the same values would apply for Class 4. In other words, for these substances Class 3 would not be more permissive than Class 4, which is not in keeping with the general intent of Class 3. It should be noted that copper and zinc are commonly elevated in waste and contaminated soil (nickel is less so) and could become the limiting contaminants for many waste consignments. This means that landfill catchment areas where elevated copper or zinc was likely (e.g. some urban land and some horticultural land) there could be little incentive for landfill operators to develop Class 3 landfills.

The organic compounds benzene, toluene and dieldrin will also have the same WAC values for both Class 3 and 4 landfills. These compounds are less likely to be the controlling compounds in a waste, but benzene or toluene may be controlling for waste from some hydrocarbon sites such as service stations.

It is also notable that total petroleum hydrocarbon (TPH) contaminated waste would have no practical limit (i.e. the value is above what is likely to occur in practice) if derived using the Koc value provided in the Guidelines.

Table 3: Class 3 and 4 WAC as per Guidelines Derivations (mg/kg)

	Class 3	Class 4
Arsenic	310[1]	17
Cadmium	10[2]	0.8
Chromium	630	290.0
Copper	>44 or soil background	>44 or soil background
Lead	1000	>60 or soil background
Inorganic Mercury	160	0.7
Nickel	310	310
Zinc	400	400
TPH C7 – C9	No Practical Limit[3]	120
TPH C10 – C14	No Practical Limit[3]	58
Benzene	0.2	0.2
Ethylbenzene	66	59
Toluene	50	50
Total Xylene	29	30
Benzo(a)pyrene (equivalent*)	54	2
Dieldrin	0.2	0.2
Total DDTs	26	0.7

Notes:

1. *Blue shading indicates drinking water pathway limiting.*
3. *Green shading indicates aquatic pathway limiting.*
3. *Not calculated in the Guidelines but if calculated using Guidelines parameters, value very large (no practical limit).*

4.0 Class 3 and 4 WAC Derivation Difficulties

4.1 Kd values

A difficulty for the Class 3 and 4 derivations and particularly for determining whether one of the leaching pathways is the limiting pathway, is that the Kd is not a fixed value. The Kd value can vary by a few to several orders of magnitude for inorganic contaminants such as heavy metals, depending on the chemical form of the contaminant, the soil pH, the soil organic carbon content, soil mineralogy and various other factors. There is less concern for organic contaminants as Koc values from which Kd values are calculated vary over smaller ranges.

It is not clear in the Guidelines why the particular Kd values used in the derivations have been chosen from the range of possible values. No references are provided and no further information has been able to be obtained.

As noted above, three of the draft WAC for Class 4 landfills – copper, nickel and zinc are based on one of the leaching pathways being critical. However, if different (lower) Kd values had been chosen for the other heavy metals considered, the leaching pathways for these may also have turned out to be limiting.

That being the case, the Class 3 and Class 4 WAC for these metals would be the same. Alternatively, if different (higher) Kd values had been chosen for copper, nickel and zinc, the leaching pathways may not have been limiting for Class 4.

We have carried out a limited search of Kd values and carried out calculations to determine what effect other published values would have on the leaching pathways for Class 3 and 4 WAC, and whether these pathways would be critical. The Kd values have been taken from two US EPA technical documents, the first being the 1996 background document to the derivations for soil screening levels[5] which provides average KD values for several chemical elements. The later three-volume review report[6] [7] on the variation of Kd values, provides values for a small number of the elements for which WAC have been calculated (arsenic, cadmium, chromium and lead). Both documents confirm the highly variable nature of the values.

The Kd values selected (in some cases interpolated to provide values at soil pH 6, as being in the middle of the range for typical of New Zealand soils, which fall in the pH range 5-8 for most mineral soils and pH 3-4 for peats[8]) are shown in Table 4, compared with the values used in the Guidelines calculations. In all cases, the Kd values taken from the US EPA documents are lower than the values used in the Guidelines, in some cases by substantial amounts. The effect of this is soil concentration limits calculated for the leaching pathways will be lower (less permissive) than those calculated in the Guidelines.

Table 4: Kd Value Comparison

	Kd used in Guidelines	Kd from USEPA (1996)	Kd from USEPA (1999) & (2004)
Arsenic	1,585	28 (As III)	6.7 (As V)
Cadmium	501	37	145
Chromium	6,310	24 (Cr VI)	135 (Cr VI)
Copper	316	-	
Lead	5,012	-	1640
Inorganic Mercury	3,981	3.5	
Nickel	794	38	
Zinc	501	36	

Notes:

US EPA values interpolated for pH 6.
Guidelines use ANZECC 2000 for As V value, being lower than for As III
Chromium Kd for +6 valence as Guidelines use ANZECC 2000 Cr VI value being lower than Cr III.

Table 5 shows the results of WAC calculations for the leaching pathways using these values and the effect on the final WAC, if the revised Kd values were used. These calculations are not intended to be used as revised WAC, rather they are to demonstrate the effect that could result from the use of different Kd

[5] *Soil Screening Guidance: Technical Background Document*, EPA/540/R95/128, United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington DC, May 1996

[6] *Understanding Variation in Partition Coefficient, Kd, Values, Volume 2*, EPA 402-R-99-004B, United States Environmental Protection Agency Office of Air and Radiation, Washington DC, August 1999

[7] *Understanding Variation in Partition Coefficient, Kd, Values, Volume 3*, EPA 402-R-04-002C, United States Environmental Protection Agency Office of Air and Radiation, Washington DC, July 2004.

[8] *Provisional Targets for Soil Quality Indicators in New Zealand*, Landcare Research Science Series No. 34, Landcare Research, Lincoln, 2008

values. A more thorough search of Kd values would need to be carried out before revised Kd values could be confidently used.

Table 5: Revised Leaching Pathway WAC Calculations (mg/kg)

Pathway	DWSNZ Human Health			ANZECC Freshwater Aquatic			Effect on Class 4 WACs (and Class 3)
Kd Source	Guidelines	USEPA (1996)	USEPA (1999 & 2004)	Guidelines	USEPA (1996)	USEPA (1999 & 2004)	
Arsenic	317	5.5	1.34	2,060	66	9	Becomes soil background (also for Class 3)
Cadmium	40	3	12	10	0.7	3	Reduce to 0.7 (also for Class 3)
Chromium	6,310	24	135	631	2	14	Becomes soil background (also for Class 3)
Copper	12,649	-	-	44	-	-	-
Lead	1,002	-	328	1,704	-	558	None (Class 3 becomes 328)
Mercury	159	0.14	-	239	0.21	-	Becomes soil background (also for Class 3)
Nickel	318	15	-	874	42	-	Becomes soil background (also for Class 3)
Zinc	15,036	1080	-	401	29	-	Becomes soil background (also for Class 3)

If the US EPA Kd values are used it is apparent that several WAC for metals become lower than the current Class 4 WAC values and, in many cases where the calculated values are close to or lower than background concentrations, would result in the WAC being reduced to background concentrations. For the metals where the leaching pathways are critical (or background concentrations need to be assigned when the calculated values are lower than background), the same values would apply to both Class 3 and Class 4 landfills.

Similar calculations have also been carried out for the organic compounds. These result in a reduction in the WACs for ethylbenzene, toluene and xylenes, the drinking-water leaching pathway being the critical pathway. In these cases, the same values would also apply to the Class 3 landfill.

To have Class 3 or 4 landfills with acceptance criteria the same as background (natural) concentrations would seriously limit the ability of such landfills to accept any contaminated waste soil, with the obvious outcome that such landfills would not be developed. However, that presupposes the calculations are providing realistic estimates for leaching. The evidence suggests they are not, as real-world experience shows that it is possible to deposit low-level contaminated soil in landfills without excessive leaching effects. In reality, the calculations demonstrate the limitations (conservatism) of the model on which the calculations are based, for example not allowing for any absorption within the aquifer, and the over-simplistic approach of attempting to model contaminant mobility using single, average Kd values for each contaminant to represent all contaminated waste soil, across New Zealand.

Several uncertainties are inherent in this approach:

- The paucity of data for New Zealand soils means overseas values must be relied on.
- It is not currently known whether the values used in the Guidelines, or the values used in the calculations above, represent a wide enough range of soils to be reasonable averages noting that the derived concentrations limits are linearly related to the Kd values; a halving of Kd value halves the soil concentration limit.
- It is not known whether the Kd values (or some other values using a wider range of data, if available) are typical of New Zealand waste soils (which may not be typical of New Zealand soils in general).

Research could be carried out to attempt to clarify these unknowns. However, such research is likely to be a large task and, because of an absence of data, unlikely to achieve all its aims. The essential problem is that, while the Kd approach is attractive because it provides soil concentration limits which are simple to test for in a waste soil, the derived soil concentration limits have a poor scientific basis. At best it might be possible to say for some contaminants (e.g. lead) that because Kd values are generally high, the leaching pathways will not be critical by some uncertain factor. However, in other cases the uncertainty will be too great to arrive at such a conclusion. That does not seem a good basis to set values intended to be protective of the environment.

4.2 Ecological Values

Four of the present Class 4 WAC have soil ecology as the limiting pathway (or potentially limiting depending on soil background concentration); the heavy metals lead and mercury, and the organic compounds benzo(a)pyrene and total DDTs[9]. The ecological values cited in the Guidelines for lead and mercury are taken from two 2006 reports prepared for the old Auckland Regional Council (ARC) by Jo-Anne Cavanagh and Kathryn O'Halloran of Landcare Research[10].

For DDT, the Canadian Council for Ministers of the Environment (CCME) agricultural use soil quality guideline was used. This is calculated as an ecological protection value. For benzo(a)pyrene, because of the ubiquity of this compound in urban environments, a nominal “background” concentration of 2 mg/kg was chosen.

The ARC values were based on international toxicity data for soil invertebrates, plants and microbial processes with values derived for 95% (minimal risk) and 50% (serious risk) protection of species. The Guidelines cite the 95% protection values which are lower than the 50% protection values. The CCME DDT value is based on secondary feeding effects on birds of prey feeding on seed-eating birds, which is quite different to the Landcare derivation. It is doubtful the Canadian derivation is relevant to New Zealand given the bird species involved. It is not clear why the Landcare values for DDT and benzo(a)pyrene were not chosen for the Guidelines, both of which are higher than the adopted values at 1.8 mg/kg (compared with 0.7 mg/kg) and 10 mg/kg (compared with 2 mg/kg), respectively.

[9] Total DDTs are the sum of DDT (dichlorodiphenyltrichloroethane) and the two related compounds DDD and DDE (dichlorodiphenyldichloroethane and dichlorodiphenyldichloroethylene).

[10] *Development of Soil Guideline Values Protective of Ecological Receptors in the Auckland Region*, Contract Report LC0506/065 prepared for Auckland Regional Council, Landcare Research Limited, Lincoln, February 2006 and *Development of Soil Guideline Values Protective of Ecological Receptors in the Auckland Region: Part 2*, Contract Report LC0506/179 prepared for Auckland Regional Council, Landcare Research Limited, Auckland, July 2006.

In addition to the four contaminants for which eco-SGVs were determined to be the critical values defining the WAC, a further five metals (arsenic, chromium, copper, nickel and zinc) are listed in the Guidelines (Appendix Table C-2) as having eco-SGVs equal to the background concentration. These values have not been used for the WAC; rather the limiting pathways have been taken to be various higher human health or aquatic protection guideline values. An explanation is provided in the Guidelines that as the Landcare eco-SGVs were derived for the Auckland region and background concentrations are region specific, only eco-SGVs that were above background concentrations have been considered. The effect of this is to have higher WAC for some of these metals than would otherwise be the case.

We are not convinced by the Guidelines logic with respect to the eco-SGVs. The Landcare eco-SGVs, being based on international data, would have arrived at the same values irrespective of whether the report had been commissioned by ARC or any other regional council. The Auckland region background concentration range for each contaminant is similar to background concentration ranges elsewhere in the country. It would have been a relatively simple matter to collate the various background concentrations available from around the country for each metal and used the higher of background or the Landcare-derived eco-SGV values as the WAC for those metals. That would have been consistent with the CSM described in Appendix C of the guidelines (summarised in Table 1 above).

We note that Landcare has since derived more up-to-date eco-SGVs as part of an Envirolink project, the original report being published in 2016 with an updated version being published in June 2019[11] (the update was prepared in response to a peer review conducted by Dr Nick Kim[12]). Part of the intent for deriving the more recent values was for developing Class 3 (now named Class 4) landfill WAC where the ecological pathway was critical. These values were not available when the Guidelines were first being developed but the authors of the eco-SGV report assumed the more recent values could be incorporated into updates as the Guidelines were developed.

Table 6 shows the difference between the 2006 and 2019 values. The more recent Landcare values have been derived for a number of land uses, including ecologically sensitive areas, residential/recreational and production land (both agricultural and non-food production land). As Class 4 landfills are intended to have unlimited use post-closure but could not be regarded as ecologically sensitive areas, the appropriate values would be the lowest of residential or agricultural production land (covering pasture, horticulture and cropping) values.

In addition, the new values have been derived using the concept of added risk. This is based on the assumption that the bioavailability of the natural background is zero or so close as to make no difference, and it is the added contamination from anthropogenic activities ('added concentration level' – ADL) that causes ecological effects. This approach allows the regional variation in background concentration to be taken into account if an assessor decides to input the appropriate regional background concentration data; however the report has published eco-SVGs which are the sum of the ACL and the lowest median background concentration from the national data set. As the landfill WAC are intended to be national values, local background is not relevant therefore the eco-SGVs presented in the 2019 report which utilise the national median background values are considered appropriate.

[11] *Updated Development of soil guideline values for the protection of ecological receptors (eco-SGVs): Technical document*, Envirolink Tools Grant: C09X1402. Prepared for the Regional Waste and Contaminated Land Forum, Land Monitoring Forum and Land Managers Group, Landcare Research; update prepared for Gisborne District Council, June 2019.

[12] *Review of work to determine background concentrations and develop ecological guideline values for soil contaminants in New Zealand*. Prepared for Marlborough District Council under Envirolink Medium Advice Grant 1847-MLDC139, June 2018.

In addition, for contaminants where there was adequate data to correlate a variation in effects with soil type (possible for copper and zinc), different eco-SGVs were derived for three different soil categories: typical soil, sensitive soil, and tolerant soil. Further, because of the common presence of these contaminants in stormwater, and the possibility that that copper and zinc spiked water may be continuously deposited onto a soil; and the difference in toxicity between this 'freshly' deposited copper and zinc and an 'aged' source of copper and zinc, different SGVs were derived for fresh and aged copper and zinc. We consider it appropriate for the WAC derivations to use the eco-SGVs for typical, aged soils.

Table 6: Eco-SGV Comparison

	ARC 2006		2019 Landcare[1]	
	Minimal Risk (95% protection)	Serious Risk (50% protection)	Residential/Recreational[2] (80% protection)[3]	Agricultural land[4] (95% protection of plants; 80% protection microbes and invertebrates)[5]
Arsenic	12	22	60	20
Cadmium	1	12	12	1.5
Chromium	-	-	390	300
Copper	45	135	240[6]	220[6]
Lead	60	100	900	530
Mercury	0.7	18	-	-
Nickel	35	110	-	-
Zinc	180	200	300[6]	190[6]

Notes:

1. *SGVs presented are the sum of the derived 'added concentration limits (ACLs) and the lowest median background concentration from the NZ-wide data set.*
2. *Includes rural residential (25% produce consumption) and residential (10% produce consumption); and recreational areas.*
3. *Protective of 80% of soil microbes, plants, invertebrates, wildlife, and livestock.*
4. *All food production land including pasture, horticulture and cropping.*
5. *Protective of 80% of soil microbes and soil invertebrates, and 95% of plants.*
6. *SGV for a 'typical soil' and aged copper and zinc discharges (e.g. the copper and zinc being assessed are not the result of not a currently occurring stormwater discharge).*

5.0 Options for Revised Class 3 and 4 WAC

As noted above, the current WAC for which the leaching pathways are critical (all values for Class 3 and six values for Class 4) have an uncertain basis for their derivation, with other WAC values able to be derived using different Kd values, and with no certainty as to which values are "best". However, the recalculated values in Table 5 appear to be unrealistically low. If the Table 5 calculations had shown that only a few of the WAC were determined by the leaching pathways, and/or that any changes to the WAC when different Kd values were used were minor, it could be a reasonable decision to accept the values as they stand with the few uncertainties being accepted as being unimportant "in the overall scheme of things". However, as Table 5 suggests that many of the WAC need revising, yet the revisions are uncertain and potentially unrealistic, an alternative approach should be considered.

One such approach is to use the SPLP[13] test to estimate leachate concentrations. This test is intended to model leaching from rainfall and, in New Zealand, uses ordinary water as the leaching fluid[14]. Back-calculating using DWSNZ and ANZECC limits as the starting point and the same DAF values as before, will result in limiting SPLP values, which can be adopted as SPLP WAC. A possibly more accurate SPLP WAC could be derived by contaminant transport modelling within the groundwater, but to be consistent with the US EPA derived TCLP criteria for Class 1 and 2 landfills, the additional sophistication is probably not required.

In practice, testing would be carried out for both total contaminant concentrations within the soil and SPLP concentrations. This is more expensive than just testing for total concentrations but not excessively so relative to other costs of waste disposal, given testing is only required for every 500 – 1,000 m^3 of waste. For a Class 4 landfill, the SPLP analysis results would be compared against the SPLP WAC for each contaminant, and the total soil concentrations would be compared against the adopted soil WAC (being whichever was the critical pathway other than the leaching pathway).

For example, for arsenic, the critical non-leaching pathway total concentration is 17 mg/kg (being the human health SCS). If the actual soil concentration was lower than this value but an SPLP test failed the SPLP WAC for arsenic, the soil would be rejected. (In reality, arsenic at such low concentrations will not leach significantly and the 17 mg/kg would likely prevail).

Where the volume from a particular waste source was great enough to make it worthwhile, it would be possible to develop a relationship between total concentrations and SPLP to obtain a threshold total concentration that ensure the SPLP criterion would be met for each contaminant of concern. Subject to the landfill operator agreeing to this approach, subsequent testing could be for total concentrations only. However, such a relationship could not be applied to other sources of waste.

We acknowledge that the Landfill Guideline reference group was not initially in favour of this approach when the possibility of this methodology was raised during the first reference group meeting in March 2019. Two points of opposition were primarily raised by members of the group, being the additional cost associated with the testing; and, we understand, concern that the SPLP test would not accurately reflect the concentration of contaminants in the leachate (e.g. if more acidic conditions were present in the landfill a higher concentration of contaminants could be present in the leachate, thereby increasing the potential for a discharge which could result in adverse environmental effects).

Our view, as noted above, is the incremental cost of the SPLP test relative to the overall cost of disposal is small and should not create a major barrier. With respect to the SPLP accuracy, we expect it would generally overestimate leaching (i.e. be conservative), given that it is carried out with the soil in a sufficient volume of water that the soil particles are fully saturated and the leachate concentration will not reach the solubility limit of the contaminants. Infiltrating rainfall is unlikely to fully saturate the soil and probably passes through too quickly to reach equilibrium with the soil. In addition, in general, there is no reason to suspect that waste soil placed in a landfill will be any more acidic than its source location where, provided the contamination was at the relatively low levels acceptable in a Class 4 landfill, the acidity would be similar to contaminant-free soil of its type. Additional precautions taken by landfill sites to ensure that the source of the soil is fully described (e.g. to ensure it has not been excavated from a potential or actual acid sulphate soils area) will assist operators in avoiding the acceptance of unsuitable (acidic) materials.

[13] Synthetic Precipitation Leaching Procedure

[14] As originally devised in the United States, the SPLP leaching fluid is a weak acid to simulate acid rain created by industrial pollution, but as acid rain is rare in New Zealand distilled water is used.

An alternative approach would be to obtain anonymised SPLP data from laboratories and develop a conservative total concentration – SPLP relationship for all of New Zealand. This would depend on there being sufficient data to be confident of such a relationship. Two laboratories probably perform the majority of SPLP testing in New Zealand, Hill Laboratories and Analytica. We are aware that an approach to these laboratories was made by MfE in October 2019, and that the laboratories responded that data would be made available in the interest of helping industry and the community. The provision of the data set is pending as at the date of this memo.

We have available a small amount of SPLP data for soil received into a single landfill. We would not expect it to be representative of the country, but we have used the data as an example of what could be done with a bigger dataset. Correlations have been developed between total concentration and SPLP results, as illustrated in the graph for arsenic below, with the data transformed by taking logarithms. As can be seen, there is considerable scatter around the regression line. This is not surprising, because some of the same things that affect determining Kd values also affects leachability as measured by the SPLP test. However, as we are interested in the data at only a single leachate concentration (back-calculated from the drinking-water or aquatic criteria) the variability of total concentration values is likely to be less than total concentration values calculated by using range of Kd values. In addition, rather than choosing average values, a value is chosen to include most of the scatter, a conservative value can be arrived at.

On the graph this is achieved by drawing a parallel line (the red line), offset vertically by 0.6 units to include most of the scatter. The critical leaching pathway in this case is the aquatic pathway, with the leaching criterion being 0.13 mg/kg, or expressed as a logarithm as on then graph, -0.89 (the horizontal green line). Where the green line meets the red line gives the logarithm of the total concentration equivalent to the adjusted SPLP value, about 2.38 in this case. Converting back to an ordinary number results in 241 mg/kg.

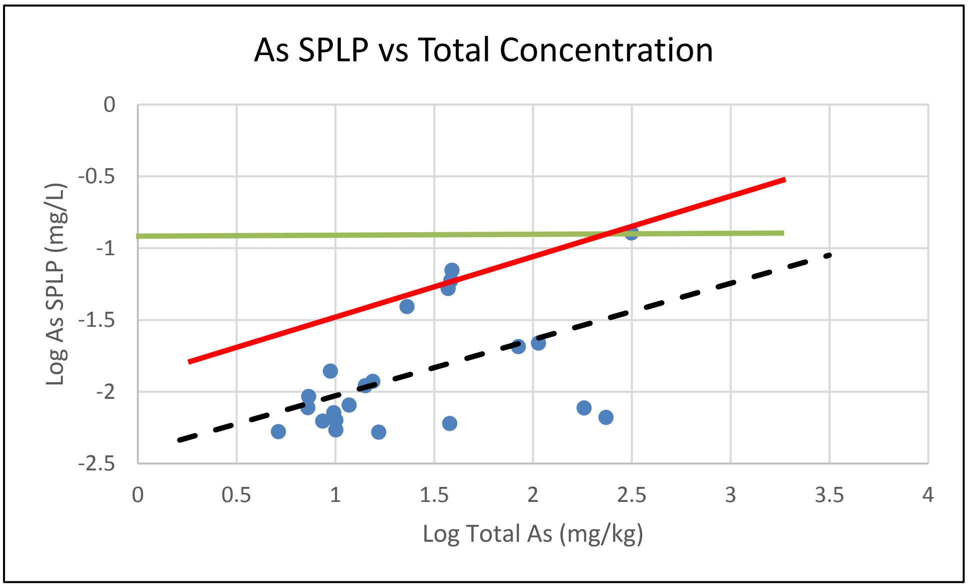

Table 7 below provides SPLP criteria for heavy metals contaminants for Class 3 and 4, back-calculated from the DWSNZ and ANZECC criteria, along with calculated total concentrations equivalent to the SPLP criteria for four of the contaminants, based on correlations between the small datasets of total concentrations and SPLP results. In the table, blue shading is used where the DWSNZ is the limiting leaching pathway, and green for where the aquatic guideline is limiting. For the particular datasets, it turns out that of the four correlations calculated, the lowest total concentrations are from the aquatic pathway in three cases and the drinking water pathway in one case.

Table 7: SPLP Criteria, Equivalent Total Concentrations and Class 4 WAC Values

	DWSNZ SPLP (mg/L)	ANZECC SPLP (mg/L)	Total Conc. (mg/kg) (Class 3)	Class 4 Non-leaching WAC (mg/kg)
Arsenic	0.2	1.3	241	17
Copper	40	0.14	842	220
Lead	0.2	0.34	547	160
Zinc	30	0.8	1,352	190

The table also provides in the righthand column the most conservative non-leaching pathway, being either a human health soil contaminant standard (taken from the Guidelines) or the 2016 Landcare eco-SGVs listed above.

The correlations are poor and therefore there is not great confidence in the calculated total concentrations, but they are useful for illustrative purposes and tentative conclusions are possible. In all four cases that have been calculated, the total concentrations from the correlations are higher than the associated SCS or eco-SGV meaning the SCS or eco-SGV would become the WAC for a Class 4 landfill. No conclusion can be drawn with respect to values for which correlation have not been performed. However, for the four values, and possibly the others but more work would need to be carried out, the calculations suggest that at least for the heavy metals the leaching pathways will not be critical for the Class 4 landfill.

If additional SPLP data is available to develop more robust correlations, the current work suggests that the WAC for heavy metals for Class 3 landfills will be a few to several hundred mg/kg, which satisfies the desire to have Class 3 landfills being able to accept waste concentrations distinctly higher than Class 4 landfills. It seems worth attempting to obtain more SPLP data to explore this further.

6.0 Conclusions

On the basis of the information reviewed during the preparation of this memo, concluding information regarding the derivation of WAC for Class 3 and 4 landfills is provided in the following sections. Where appropriate, the risks, benefits, and any recommendations for a future course of action are provided.

6.1 Class 3 and 4 WAC derivations

- The Class 3 WAC that need to be derived must be protective of the environment via the leaching-to-groundwater and surface water pathways, with the derivation requiring estimates of leachate concentrations arising from rainfall infiltrating through contaminated soil/waste placed in the landfill.
- In order to achieve consistency with the derivation methodology for the Class 4 WAC, it was intended that the partitioning coefficients (Kd values) (which represent partitioning relationships between the soil/waste contaminant concentrations and the leachate concentrations) utilised for the Class 4 WAC derivations would also be utilised to derive the Class 3 WAC.
- The Guidelines do not provide commentary on how or why the Kd values have been selected for the Class 4 WAC. We have been unable to ascertain the basis and have therefore carried out research into possible appropriate values within the very wide range of values in the literature. However, we have arrived at a point where we are not confident that the current Kd basis for estimating leachate concentrations is appropriate.

- This means we are not we are also not confident that robust Class 3 WAC can be derived using this approach.
- The same lack of confidence does not apply to all the Class 4 WACS, As Class 4 WAC are defined as the lowest of either: the most conservative of a human health SGV, an eco-SGV, or values derived to be protective of the environment via the leaching-to-groundwater or surface water pathways. The lack of confidence applies only to Class 4 WAC for which one of the leaching pathways provides the limiting value.
- A further problem is that even if appropriate Kd values could be found, e.g. some sort of average, in many cases the leaching pathways would prove to be limiting for both Class 3 and 4 WAC, with the Class 3 and 4 WAC being the same value, meaning that there was no practical basis for having both Class 3 and 4 landfills.
- The derivation of WAC for organic contaminants using the organic equivalent of a Kd (Koc) is less potentially problematic because the Koc values vary over a smaller range.

In summary, the following benefits and risks have been determined in relation to the use of the existing Class 4 WAC derivation information (and specifically the use of Kd values) to derive the Class 3 WAC:

Benefits:

- The Class 3 derivation would be undertaken using the derivation process and data which was previously utilised in the drafting of the guidelines.

Risks:

- A single Kd value must be selected for each contaminant, out of the range of Kd values published in the literature. The selection criteria for such a Kd value would need to be established.
- The single Kd value that is selected for each contaminant will be utilised to represent all soils from across the country that may be disposed of; it is unlikely that a single Kd value will be representative of the range of soils that may be disposed of to landfills. This will necessarily require the use of a Kd value that results in a highly conservative WAC.
- With no documented basis for the selection of the Kd values, document users and regulators may not have confidence in the efficacy of the derived WAC to be protective of groundwater and / or surface water via the leaching pathway (further noting that WAC derived using the Kd values from the guidelines are more permissive than WAC derived using alternate USEPA-sourced Kd values).
- Where the leaching pathways are limiting for both Class 3 and 4 WAC (noting that the number of parameters for which this is the case will vary depending on which Kd value is used), the Class 3 and 4 WAC will be the same value, meaning that there is no practical basis for having both Class 3 and 4 landfills.

Recommendation:

- That alternative WAC derivation methodologies are explored.

6.2 Consideration of alternatives for WAC derivation

- Consideration has been given to the potential for SPLP concentrations to be set as the WAC for Class 3 and 4 landfills, in concert with total soils concentration WAC for Class 4 landfills (where it is possible that different limiting pathways will be the driver for the WAC e.g. human health vs leaching to the environment).

- The limiting SPLP concentration (which would become an SPLP WAC) would be back-calculated using DWSNZ and ANZECC limits as the starting point and the same dilution and attenuation factor (DAF) values as are utilised in the derivation of the TCLP WAC for Class 1 and 2 landfills.
- An alternative approach is to develop an SPLP-total soil concentration relationship for each contaminant to arrive at total soil concentration WAC for those contaminants for which the leaching pathway is the limiting pathway. An initial comparison with a limited data set indicates that utilising this methodology would result in higher WAC for Class 3 landfills (where the leaching pathway is the only limiting factor) than would be necessary for Class 4 landfills (where the most conservative of the leaching pathways, human health, or eco-SGVs must be adopted). This is a desirable outcome from the perspective of the commercial viability of having both Class 3 and Class 4 landfills.
- Further SPLP vs total soil concentration data would need to be obtained to determine more accurate correlations and therefore to be able to set WAC via this method with confidence. Preliminary enquiries indicate such data, suitably anonymised, is available from environmental laboratories

In summary, the following benefits and risks have been determined in relation to the use of SPLP data to derive the Class 3 and 4 WAC:

<u>Benefits:</u>

- The use of the SPLP analysis provides a more direct assessment of the leaching potential of the waste soils.
- The use of limiting SPLP concentrations as WAC removes the requirement to select a Kd value to derive a WAC. As previously discussed, the selection of an 'appropriate' Kd value is open to interpretation; and further it is unlikely that a single Kd value will be representative of the range of soils that may be disposed of to landfills.
- If an SPLP – total concentration correlation can be established using a suitably large data set, the requirement to undertake additional SPLP analysis would be removed.

<u>Risks:</u>

- The WAC derivations would be undertaken using a different process than has been previously adopted during the drafting of the guidelines.
- A perception that if SPLP values alone are used as the WAC, there will be additional costs imposed on waste disposers because they will need to get SPLP analysis performed on soil samples, as well as analysis for total concentrations.
- A perception that the SPLP analytical results may not accurately describe the leaching potential of the soils, when they are emplaced in an acidic environment (such as may potentially occur in a landfill, although Class 3 landfills would not normally be expected to be particularly acidic if organic waste content is kept low), and / or if the soils are more acidic in nature (e.g. acid sulphate soils, which should be excluded from landfilling without treatment).

<u>Recommendation</u>:

- We consider that further research into the derivation of WAC via developing SPLP and total soil concentration relationships using a large data set should be pursued.

6.3 Use of ecological soil guideline values

- A further issue is that the eco-SGVs utilised in the current iteration of the guideline are from a 2006 Landcare Research document, and from older international guideline documents. More up-to-date, New Zealand derived and government-funded risk-based guidelines are available, and we consider that these should be utilised.

7.0 Limitations

This memorandum has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Ministry for the Environment and limited research into the international literature. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the memorandum. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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