SOAKAGE IN ACCORDANCE WITH E1/VM1: THAT'S JUST A START

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ABSTRACT

There are many stories of stormwater soakage disposal systems failing soon after construction or perhaps performance is seen to slowly deteriorate over time. Many of the issues that lead to this can be traced back to the design.

When it comes to designing soakage systems the Ministry of Business, Innovation and Employment's Verification Method E1/VM1 (VM1), Section 9, Disposal to Soak Pit is often quoted by designers as a means to demonstrate compliance with the Building Code. As such, Councils are then bound to accept these calculations.

However, VM1 comes with limitations. For example, it clearly states that determining the suitability of the ground for soakage and the overall stability of the ground are outside its scope. These two factors are critical to designing soakage systems, particularly if the term "ground" is interpreted to mean the groundwater table beneath it as well as the geology. The warnings and limitations noted in VM1 are often not addressed, or perhaps not well understood, by designers when proposing soakage disposal of stormwater. Some Councils, recognising this, have prepared more comprehensive design guidelines. Others have not.

While soakage designed using VM1 is appropriate for some situations it is not for others, like subdivision scale disposal, without it being supplemented by more comprehensive investigations and expert advice. This might require a hydro-geotechnical professional, and may require carrying out groundwater modelling to understand seasonal highs or effects of soakage on a shallow water table. Like all areas of engineering, the level, complexity and detail of any particular design needs to consider site specific conditions as well as addressing, and where possible mitigating, the consequences of design failure.

Over many projects, Beca's stormwater and hydro-geotechnical professionals have identified several key factors that must be accounted for when soakage is being proposed. Some of these seek to address VM1's limitations and its perceived gaps. This paper discusses what we have learnt, including the significance of:

i. site geology

ii. the groundwater table (including its seasonal and inter-annual variability)

iii. the nature of the surrounding topography and proximity to steep slopes, structures and streams

iv. the difference between field and design percolation rates and selecting an appropriate factor of safety

v. selecting an appropriate percolation test methodology (different to that required by VM1)

vi. site testing in the location of the proposed soakage device, at varying depths, with more than one test and

vii. including pre-treatment in the design to protect the soakage device from blinding.

The implications are that the soakage disposal section in VM1 should be revised or expanded, even if just to draw attention to some of the critical wider issues and the need to address them. So, soakage in accordance with VM1? That is just a start.

KEYWORDS

Soakage, soak pits, infiltration, Building Code E1, VM1

PRESENTER PROFILE

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1 INTRODUCTION

Section E1 of the New Zealand Building Code (NZBC) deals with surface water and its disposal so not to enter buildings. As noted on the Ministry of Business, Innovation and Employment's website (MBIE, 2018):

"This clause requires buildings and site work to be constructed to protect people and other property from the adverse effects of surface water.

It sets out performance requirements to ensure drainage systems are in place for the disposal of surface water using gravity where possible, and to avoid blockages and leakage."

Included in E1 is Verification Method (VM1) (MBIE, 2017) which sets one way of designing to be compliant with E1. Within this, Section 9 deals with disposal to soak pits. Given this is the only section on stormwater soakage in the various documents associated with the NZBC, it is often applied (often incorrectly) to a wide range of soakage situations which it was not intended for (or capable of dealing with), at least without being enhanced by further assessments. The fault is not in VM1 but in the people applying it. VM1 is limited and these are clearly stated, but it does take an experienced practitioner to read between the lines.

Councils receive the building consent submissions that use VM1 stating the works "have been designed to the Building Code" or "are in accordance with VM1". The purpose of VM1, after all, is:

"For use in establishing compliance with the New Zealand Building Code. A person who complies with a Verification Method or Acceptable Solution will be treated as having complied with the provisions of the Building Code to which the Verification Method or Acceptable Solution relates. However, using a Verification Method or Acceptable Solution

is only one method of complying with the Building Code. There may be alternative ways to comply" (MBIE, 2017).

Councils are therefore obliged to accept these submissions. However, often good soakage design is not so simply demonstrated and, critically, it relies on Council officers recognising this and picking up on the issues such that they are addressed. Some Councils have good soakage guidelines that need to be followed and some do not.

Our experience at Beca, both in applying VM1 and reviewing its use by others, has identified several gaps, problems and solutions when applying or stepping beyond the limits of VM1.

This paper will outline these issues and suggest possible solutions to supplement VM1.

2 LIMITATIONS ALREADY NOTED IN VM1

VM1 lists several limitations and exclusions and these are summarised in Table 1 below and briefly discussed in the sections following the table. It is of note that VM1 is for soak pits and not large soakage basins, dispersal fields, French drains or raingardens.

The limitations noted in VM1 cover much, but not all, of what is discussed in this paper but to recognise the implications a designer would need to be an experienced practitioner well versed in the issues and risks. They are not written with the unqualified and unexperienced person in mind. Also it is significant that that four of the seven limitations relate to the underlying ground conditions.

Table 1: Limitations noted in VM1 (the bold text being the author's emphasis).

VM1 Clause	**Focus**	**Limitation (abridged)**
1.0.2	Catchment size	The following approach provides a method for verifying that a proposed building will meet the requirements of NZBC E1.3.1 and E1.3.2 in the following circumstances: a) The **catchment area does not exceed 100 ha** (but see Paragraph 1.0.6 for soak pits).
1.0.6	Ground conditions	A procedure is provided for determining soak pit requirements for surface water disposal. Such disposal is **subject to suitable ground conditions**, as confirmed by site tests.
1.0.6	Ground stability / conditions	Where soak pits are used the **overall ground stability** may need to be verified but this is outside of the scope of this Verification Method
1.0.7	Qualifications	The design procedures in this document must be performed by a person who, **on the basis of experience or qualifications, is competent to apply them.**
9.0.1	Ground conditions	Where the collected surface water is to be discharged to a soak pit, the **suitability of the natural ground** to receive and dispose of the water without causing damage or nuisance to neighbouring property, **shall be demonstrated to the**

VM1 Clause	Focus	Limitation (abridged)
		satisfaction of the territorial authority.
9.0.1	Ground conditions	Means of demonstrating the **suitability of the ground** are outside of the scope of this Verification Method
9.0.2	Complex attenuation basins	Does not cover the design of **soak pits with overflows** discharging to outfalls. Such soak pits are often provided to retain water until peak flows in the outfall have passed and it is normally considered sufficient to design them for an event having a 10 minute duration and a 10% probability of occurring annually.

2.1 A 100 HECTARE CATCHMENT

VM1 does not explain why it selects a 100 ha limit. This is a very large area for disposal by soak pits e.g. a 1,000 x 1,000 m housing development is the size of a suburb or 13 km of road carriageway. For a development of this scale, it suggests large and complex civil engineering with extensive site works and issues where a simple method for soakage disposal would be risky. But soakage problems can happen in very small catchments as well as large, it is just the magnitude of the consequences that change.

The qualification referring to clause 1.0.6 does not result in any additional clarification on the catchment area but instead refers to comments on ground conditions.

2.2 SUITABLE GROUND CONDITIONS

This is one of the fundamental risk areas with soakage and where so many designs can fall over. VM1 rightfully places significant emphasis on this requiring the ground conditions be suitable and assessed as such but other than permeability testing, the requirements for these wider geotechnical issues are not addressed.

One of the limitations refers to "*the satisfaction of the territorial authority*" and so provides leeway for additional requirements to be added by Councils and some, such as Auckland Council, do have detailed soakage design guides (Auckland Council, 2013) which provides a more comprehensive design method. Other Council's such as Hamilton City Council have a brief section in their Infrastructure Technical Specifications and an associated practice note but largely refer back to VM1.

2.3 AN EXPERIENCED AND QUALIFIED PRACTITIONER

Although not the first limitation, it is perhaps the most important one. For soakage, this must be taken to be as someone who has a good understanding (or has been informed by someone who has), of the nature of the underlying soils, their permeabilities and also their interaction with the groundwater table.

It would not be unreasonable for Councils to require a designer to have experience beyond just applying VM1 and be qualified and/or experienced in geotechnical engineering and/or hydrogeology as well as stormwater design. This can be beyond general civil/stormwater engineers other than the experienced.

2.4 SOAK PITS WITH OVERFLOWS DISCHARGING TO OUTFALLS

This limitation is curious and is somewhat unclear as to what is meant by a "soak pit with an overflow to an outfall" and the terms involved seem to suggest detention / attenuation basins that incorporate soakage. VM1 is notes that "*such soak pits are often provided to retain water until peak flows in the outfall have passed and it is normally considered sufficient to design them for an event having a 10 minute duration and a 10% probability of occurring annually*". The part about designing them to a 10% AEP, 10 minute storm is unclear and confusing as to what it is referring to. A 10% AEP 10 minute storm in the receiving system is not an event commonly examined when reviewing coincidence of peaks.

Further to this, VM1 defines an outfall as "*that part of the disposal system receiving surface water or foul water from the drainage system. For foul water, the outfall may include a foul water sewer or a septic tank. For surface water, the outfall may include a natural water course, kerb and channel, or a soakage system*". This suggests many urban residential soak pits are excluded from VM1 as at some stage they will almost certainly overflow to the kerb and channel or a stream, for instance in storms more severe than what the soak pit is designed to. For the same reason, so too would soak pits serving roads be excluded if kerbs are present (which is not uncommon).

3 PROBLEMS AND SOLUTIONS

Soakage design fundamentally needs a good understanding of the ground conditions and groundwater table in the location of the proposed soakage device, whether this be a small soak pit or a larger device. VM1 states this in its first clause: "*the suitability of natural ground to receive natural ground to receive and dispose of the water without causing damage or nuisance to neighbouring property*". Much of the issues encountered in applying VM1 come back to this. Table 2 below lists the issues and potential solutions that the authors have developed from a range of projects both large and small. These are then discussed in more detail following Table 2.

Table 2: Summary of the problems and possible solutions.

No.	Problem	Solution
1	Unqualified and unexperienced designers. Risk: failure to understand the implications of underlying ground/groundwater conditions, limitations in VM1 or different storm events. Consequence: underperformance leading to a range of effects from nuisance ponding to land instability.	Involve an experienced practitioner with experience in soakage design, geotechnical engineering and/or hydrogeology. Require qualifications in these areas stated with the design calculations submitted for building consent.
2	Just considering a 10% Annual Exceedence Probability (AEP) with a 1 hour duration storm miss the critical volume for storage. Risk: a 1 hr event may not give critical runoff or volume yields. Consequence: undersized devices, overflows more frequently and not meeting the expectations of the owner.	Assess a wider range of storm return periods and durations and the implications on performance.
3	Geological conditions can vary significantly over a short distance. VM1 does not provide guidance as to an appropriate density of testing which is a problem for large developments. Risk: Insufficient testing to understand site variability and resultant soak pit performance Consequence: underperformance leading to a range of effects from nuisance ponding to land instability.	Soakage testing needs to be carried out in the location of the proposed soak pit(s). For larger developments where multiple devices, or a single large footprint device, are to be used then adopt a testing spread as recommended in R156 (CIRIA, 1996) , that is, 1 test per device or every 25 m x 25 m.
4	No guidance is given on what are suitable soils or how to assess the existing soils. The testing method is also limited and is not preferred. Not enough guidance is given to the depth, location, number and timing of testing. Risk: without the means to determine suitable from unsuitable, then it falls to judgement which can be ill informed. Consequence: using soakage in areas where soakage should not be	Appropriately scoped and site specific testing is essential for understanding the suitability of a site. For testing, use a double ring infiltrometer (for surface soakage systems) and test pits (for deeper system designs). Multiple tests in the location of the soakage device above, at and below the design application level. It is preferable to test during seasonal high groundwater conditions.

No.	Problem	Solution
	used, assessment method overestimates permeability resulting in undersizing. Consequences are as noted above.	
5	There is no emphasis on needing to understand the interaction of soakage with the groundwater table and how its seasonal variation could affect performance. Risk: groundwater rises above bottom of the device. Consequence: reduction in performance or failure leading to overflowing or mounding of the groundwater table, impacting on surrounding property.	Testing must locate the depth to groundwater table in the position of the soakage device at the time of testing. However, ongoing monitoring is also recommended for assessing the seasonal range. Review records from nearby piezometers and look at wider scale /regional trends. Assess the potential and consequences of the groundwater table being higher. Set the soak pit a minimum of 1m (preferably 1.5m) above this.
6	There is no factor of safety required so no allowance is made for reduction of performance over time, the inherent variability of soil permeability or limitations of site testing. Risk: using just the test permeability with no factor of safety will overestimate long term performance. Consequence: underperformance and failure leading to range of effects from nuisance ponding up to land instability.	Use a factor of safety such as recommended by CIRIA Report R156 (1996).
7	When used in large developments it does not address cumulative effects. That is, the joint effects of many soak pits all discharging water to the groundwater table. Risk: not understanding cumulative effects until it is too late to do anything about it. Consequences: range of effects from system failure, to nuisance ponding and land instability.	If the scale of the development allows or warrants it, use a groundwater model to understand effects.
8	There is no guidance given on proximity of a soakage device to structures, assets or wider topographical features. Risk: soakage can affect the stability of adjacent slopes, structures	Do not locate soakage devices near retaining walls, on steep terrain, up gradient of houses, at the top or bottom of gullies or near surface water bodies.

No.	Problem	Solution
	or assets. Consequence: at worst it could cause these assets to fail, at best is may reduce their performance (nuisance effect).	Show proximity to such features on plans.
9	There is no commentary provided on measures to minimise clogging of the soak pit with sediment. Risk: without pretreatment then sediment can clog up the soak pit and reduce its capacity or cause it to fail. Consequence: underperformance and failure leading to range of effects from nuisance ponding up to land instability.	Review clogging potential and risks and apply pre-treatment in accordance with Auckland Council's TR2013/040, Section 7.4 and 7.5.2 (Auckland Council, 2013). Use a factor of safety in the design. Provide for inspection and maintenance and carry out that maintenance.
10	The detail in Figure 13 of VM1 does not show pre-treatment. Risk & consequence see item 9.	Review the source of the runoff and include a pre-treatment device to trap sediment. Then monitor and maintain it.
11	Maintenance is not mentioned. Risk: the soak pit performance will reduce over time if it is not maintained. Consequence: underperformance and failure leading to range of effects from nuisance ponding up to land instability	Allow for soak pits to be inspected and maintained. Include measures to facilitate this and focus on preventative maintenance.

3.1 A 10% AEP 1 HOUR STORM

The 10% AEP 1 hour storm requirement sets a single specific event and flow rate. While it does not preclude designing for other events, often a device is designed just to this single storm without considering other possibilities. For example, take a typical small, three house residential subdivision say, 1,500m^2 in area, and each with a single soak pit. Using some simplified assumptions for the purposes of this example, then the following peak flows and volumes result:

Q10 10 min = 29 L/s V10 10 min = 3 m^3
Q10 30 min = 16 L/s V10 30 min = 15 m^3
Q10 1 hr = 11 L/s V10 1 hr = 39 m^3
Q10 24 hr = 1 L/s V10 24 hr = 115 m^3

As this simple example shows ignoring the effect of different storm durations on peak flow and volume can leave for ponding on the ground, particularly if the soakage rate is relatively low. Say testing derives a (high) soakage rate of 300 mm/hr and the soakage pit is a 1050 mm diameter well some 3 m deep. Assuming soakage only through the base, gives a 0.07 L/s soakage per pit and 0.21 L/s with all three combined, rates which are very much smaller than the incoming peak flow rates. Therefore storage is needed (as predicted in the notes in VM1) but with only 8 m^3 available in the devices this is not enough for all but the smallest of storms. Each house would need an unrealistic 5 soak pits to contain the 1 hour storm without surface ponding (or additional storage).

However, the method in VM1 for determining storage assumes a 1 hour storm which could be misinterpreted as the critical time of concentration of the site but a development of this scale would be more likely to have a time of concentration pit closer to 10 minutes (if not less) and so when other storm durations are considered with this time of concentration then the following volumes result (back to assuming one soakage pit per house):

Vstor 10 min = 21 m^3
Vstor 30 min = 31 m^3
Vstor 1 hr = 38 m^3
Vstor 24 hr = 101 m^3

Not dissimilar at longer durations but a different story for short duration storms. It is interesting to note that even a short sharp 10 minute storm will still result in surface ponding for a single device per house. When the average house owner's expectations are considered, they would probably think something is wrong when their soak pit overflows in these frequent storms. It is interesting to reflect on this as VM1 talks of disposing of stormwater without causing nuisance (clause 9.0.1) to neighbouring property, although not the property it serves.

It is interesting to note that some Councils require more, such as Waipa District Council who require soakage to be designed to dispose of all runoff during a 50% AEP storm for all durations up to 72 hours (as well as the 10% AEP 1 hour storm). In this case a 50% AEP storm gives a maximum depth of 87 mm at 72 hours and a maximum intensity of 61 mm/hr at 10 minutes compared to the 10% AEP 1 hour storm of 34 mm depth and 34 mm/hr intensity. It is therefore the 50% AEP storm that sets both volume and peak flow conditions.

So while the 10% AEP 1 hour storm gives one specific result, other durations should also be considered if nothing more than to just understand the performance of the design and make suitable adjustments or communicate this to the owner.

3.2 DESIGNING FOR A LARGE DEVELOPMENT AREA

Geological conditions can vary significantly over a short distance, for example, in fluvial (river) deposits, old meander channels can result in localised areas of very high permeability at the outer edge of old bends (where the largest grain sizes are deposited) or very low permeability in old channels, ox-bows etc that have been infilled with finer sediments. Similarly where alluvial deposits have infilled buried topography, the geology and permeability can vary significantly over short distances. In terms of a large residential development, this can result in variable permeability from one house lot to the next. Hence, for situations where a number of smaller devices are proposed testing may need to be undertaken at each and every location.

Likewise, where very large devices are proposed, more than 1 test should be undertaken across its footprint to see if there is any variability. Report R156 (CIRIA, 1996) recommends a minimum of one test for every 25 m x 25 m of device. If significant variability is encountered, further testing may be necessary.

Typically, only a single round of investigation is undertaken however, for large development areas a staged approach to testing may need to be undertaken with an initial assessment of viability undertaken at the concept stage and more intensive site-specific testing and assessment following on to support the detailed design.

It is emphasized that the degree of investigation, testing and analysis required on any project, should be considered along a spectrum that is commensurate with the scale of the project and consequences of soakage failure.

3.3 SUITABILITY OF UNDERLYING SOIL

For a site to be suitable for accepting soakage it should be of moderate to high permeability and be unsaturated. It is also helpful to have a hydraulic gradient across the site to further promote the rapid dispersal of water with minimal mounding.

Whilst many authors, guidelines etc. provide tables of indicative permeabilities and infiltration coefficients, the ranges for each soil type can vary over 3 orders of magnitude and so whilst review of geological maps and published tables may provide a useful first indicator, site specific testing is still essential.

The exact nature of the tests undertaken may depend on stage of design, site access, expected ground and groundwater conditions and should be agreed in consultation with a Geotechnical Practitioner. A variety of test methods are available and appropriate selection should depend on the type and scale of stormwater discharge, the ground conditions and project risk profile.

3.3.1 TIMING OF THE TESTING

If possible it is best to carry out testing at earlier stages of design i.e. concept rather than detailed design. This means any potential issues such as shallow groundwater, low soakage rates, impermeable layers etc can be identified early, and alternative disposal methods, locations or sites can be considered before site layouts are decided upon.

3.3.2 LOCATION AND DEPTH OF TESTING

If the location of the proposed soakage system is known then testing in that location and at the anticipated depth is critical. If it the location is unknown then make provision for it in future project stages.

If time and budgets allow it is always recommended to extend the testing below the target depth. In some cases, there will be more permeable strata at greater depths which could reduce the soakage area. Conversely if there are constraining (lower permeability) layers at depth then it can be helpful to identify and test these also.

In the 3 house subdivision example, not understanding the soil conditions at depth across the site could result in using a lower rate, say, only 50 mm/hr soakage, when just another metre or two deeper there is the potential to discharge into more favourable soils with a soakage rate of 300 mm/hr.

3.3.3 SCALE OF TESTING

The test method in VM1 is based on a 100-150 mm diameter borehole. For a shallow bore (say < 3 m deep) the volume of water that can be discharged through a single falling-head style test could be less than 50 L. These test results are then extrapolated up to cover a soakage device that could be tens of meters in area and/or discharging upwards of 10 L/s or 100 m^3 as per the example figures in Section 3.1.

Testing in narrow diameter boreholes does not stress the aquifer sufficiently to provide an indication of wider aquifer behaviour. Rather the test provides an indication of the immediate area around the borehole, and, if not done right, may only test the storage effects of the borehole annulus and so giving a false indication of permeability.

A larger scale test, such as a test pit or double ring infiltrometer is preferable.

3.3.4 PRE-WETTING

In summer conditions, when the soil is very dry and capillary suction is very high, testing could overestimate soil permeability. To avoid this, and find the expected long term soakage rates, testing should be performed under onerous site conditions even if this means manufacturing them. This means either testing in winter, after recent heavy rainfall (when the groundwater level and soil moisture contents are at their highest) or by pre-wetting.

As testing cannot always be timed with such conditions, it is essential that the ground is pre-wetted prior to testing. Previous authors (Trigger, 2017) have shown the variability in test results when the tests are pre-wetted which confirms the importance of mimicking wet antecedent conditions.

VM1 recommends a minimum 4 hours pre-wetting except where "*soakage is so great that the* hole *completely drains in a short time*". It does not provide further guidance what to do in this scenario. We recommend that in this instance, pre-wetting should still be undertaken by emptying at least 4 test volumes in the hole, in quick succession, prior to testing.

3.3.5 HIGHER RISK SITES

Where site investigation indicates the following conditions, the site may not be suitable for soakage and longer term monitoring and/or a more detailed assessment (i.e. groundwater modelling) may be warranted:

- Low permeability soils (i.e. predominantly silts or clays, iron pans, ashes) near the surface or which form a laterally extensive layer
- High groundwater level (i.e. a seasonal water level within 1 m of the likely device invert level)

- Wetlands at the surface or water tolerant vegetation or existing surface flooding after large rainfall events (all of which may indicate the presence of the above).

3.4 UNDERSTANDING GROUNDWATER CONDITIONS

Soakage disposal relies on discharging water to the shallow groundwater table. Shallow groundwater levels vary inter and intra-annually. The magnitude of this variation and its relationship to rainfall varies widely and can have a significant effect on soakage design.

Mention of the groundwater table is conspicuous in its absence from VM1. It is mentioned only once (clause 9.0.2a) in instructing a permeability test to be undertaken at the groundwater table should it be encountered during the test.

3.4.1 DEPTH TO GROUNDWATER

As a general rule of thumb, the highest (winter/spring) groundwater should be at least 1 m below the invert level of the soakage system. This was developed with individual house lots in mind.

However, it is important to remember that a 1 m separation does not equate to 1 m^3 of storage in the ground. Most soils have a void ratio / porosity in the order of 10 % to 30 % and hence a 1 m separation might only provide 0.1 m^3 to 0.3 m^3 of storage per m^2 below a soak pit. Therefore, where the stormwater catchment is very large and infiltration focused over a relatively small area(s) a greater separation to groundwater may be required, as the volume of voids between the invert of the soakage device and the groundwater table may be smaller than the volume of the device (i.e. the drained water has nowhere to go).

If the groundwater level is above the bottom of the device (i.e. mounding occurs) then the soakage rate will likely reduce significantly further exacerbating the mounding and causing it to extend laterally which cause damage and/or nuisance to neighbouring properties (refer VM1 limitation 9.0.1 on this).

It is therefore critical that site specific testing is undertaken to prove the groundwater level (at the time of testing) but this be reviewed for its potential to change.

3.4.2 SEASONAL VARIATION OF GROUNDWATER

To provide greater certainty on design groundwater levels, it is recommended to undertake at least one year of groundwater level monitoring at a site to allow an assessment of its seasonal range. It is acknowledged that this takes some advance planning and may not always suit cost and programme expectations. However, in one South Island example (Purton et al., 2012), the groundwater level rose more than 2 m over a 7 month period resulting in the maximum natural groundwater level being above the proposed invert level of a soakage basin. Whilst soakage at this site was still considered possible due to the high permeability of the soils, the design had to account for a much reduced soakage rate and a longer drain-down time during peak conditions.

Monitoring is also useful for evaluating when such conditions occur, in the above example the peak water level was in October (late winter – early spring) however monitoring on several projects in the Waikato indicates that the peak water level there tends to occur anytime between October and December (i.e. into early summer).

A full year of monitoring is not always practical, and groundwater levels will vary between dry and wetter years also, so it is very important to review the site in the context of longer term groundwater level records held by regional councils as this may provide guidance on different design groundwater levels and how the design assumptions fit with wider trends.

3.4.3 TYPES OF GROUNDWATER REGIMES

It is also important to understand the groundwater regime at a site as this also has implications for soakage design. Generally, a shallow unconfined groundwater table is assumed with a strong connection to atmospheric conditions (i.e. seasonal range in response to rainfall recharge) and a hydrostatic pressure profile.

However, in alluvial deposits and residually weathered soils, perched water tables are common. In this case the shallowest water table may not be continuous (in lateral or vertical profile) but rather exists as a "lense" of water that is hung up on a lower permeability horizon. These conditions are not uncommon and on a recent Waikato project example, where surface flooding was known to occur, site investigation indicated an iron pan had developed near the surface. The investigation, and longer term groundwater level monitoring, indicated a very shallow water table and poor infiltration capacity in the soils above the iron pan, but unsaturated conditions (a water table > 8 m below ground level) and high infiltration capacity in the soils below the iron pan. If testing had only been done near the surface, and not confirmed that the conditions were perched, then soakage here would have been discounted. Conversely, if testing had only considered the deeper conditions, and then a shallow design selected, the soakage device would have failed.

If a confined groundwater table is present at the site then excavations which penetrate the confining layer could result in sudden release of pressure (artesian flow into excavations) which would be problematic during construction but which in the long term might also reduce the storage and soakage capacity of the proposed device.

3.4.4 GROUNDWATER SUMMARY

Again in our three lot subdivision example, consider the effect on soakage performance of assuming the seasonal high groundwater was a good 4 m below ground because the bore hole (done in winter) was pulled out at 3 m below ground without encountering the groundwater table. The proposed depth of the soak pits were 3 m deep anyway and so assumed to be clear of the groundwater table, but unbeknownst to the designer there was a 3 month lag from winter to actual peak groundwater levels and this peak was as high as 2.5 m below ground so half a metre above the invert of the newly installed soak pit. The design would have looked a lot different had this been known. This is one of the reasons that the depth of the soak pit should be kept at least 1 m (preferably 1.5 m) above the estimated seasonal high groundwater table and testing should carry on until the groundwater table is encountered (within reason).

Similarly, perhaps the site testing could have found a perched groundwater table 2 m below ground and as the investigations did not go further and gave no consideration to the wider site geology, so the designer did not know that there was a perched groundwater table and missed the opportunity to apply soakage at a depth of, say, 4 m below ground and at a more favourable depth in terms of performance.

In summary, understanding the groundwater table in the location of the proposed soak pit is a key issue in the design. This design process should:

- Use the seasonal high groundwater level when selecting the depth of the soakage device
- Fit with seasonal variation and trends derived from monitoring and/or review against larger regional scale data sets and show how the groundwater table at the site relates to these

- Identify the depth to the groundwater table even if it is not encountered during initial site testing, that is, ground investigations should keep on going until it is encountered even if this is beyond the potential design depths being considered
- Keep the application depth of the soak pit 1 m (preferably 1.5 m) above the seasonal high groundwater level and
- For large scale developments plan early to install groundwater level monitoring on site and well before detailed design starts to obtain a full year of data.

3.5 CUMULATIVE EFFECTS: THE VALUE OF A 3D GROUNDWATER MODEL

In the case of large developments with widespread and large volumes of stormwater being soaked away, taking a simplified approach with a single relatively short duration storm may not be desirable. In these situations the method does not account for the need to understand the overall effect that soakage could have on surrounding land (banks, base flow in streams, wetland water levels, contaminant spread, ground saturation etc). Neither does it provide an understanding the cumulative effect where multiple subdivisions need to be considered separately. Where this is critical then a much more sophisticated approach may be needed with development of a groundwater model.

In the example set out in 3.1 above, the design would have no way of determining the potential rise in the groundwater table (mounding) and how far this reaches. Modelling would allow an assessment of magnitude and extent of mounding. It is not to suggest that a three house subdivision must have a groundwater model but consider if the development was instead a 1500 lot subdivision some 90 hectares in size with widespread soakage and surrounding the urban areas set lower than the new development.

A well-constructed groundwater model will allow an approximation of the baseline groundwater conditions over a wider area i.e. to fill “gaps” between investigation points and evaluate the range of natural groundwater levels under different rainfall conditions. Once suitably calibrated, the model can be used to:

- test option viability such as different locations, varying depths and device sizes
- design optimisation such as refining levels, locations and sizes
- test and understand effects of individual and cumulative developments i.e. does discharge of a downgradient subdivision limit discharge from an existing upgradient site
- understand the magnitude and extent of mounding
- understand the interaction with existing streams and wetlands, for example, does the soakage result in increased flow to a stream and effect bank stability
- understand and predict the interaction with the ground and topography i.e. will the soakage effect slope stability or raise liquefaction risk.

As with all computer models, a groundwater model is only as good as the input data. Hence, 3d groundwater models are most commonly used in support of larger scale projects that have the means to provide a suitable density of investigation and in-situ testing points.

3.6 TOPOGRAPHY AND PROXIMITY OF STRUCTURES

Introducing water to the ground can have a detrimental effect on nearby features. Elevated water levels can reduce the stability of steep banks or cause tunnel gulley erosion. Similarly, pore pressure is a key factor in retaining wall and basement design and constructing a soak pit near an existing wall could have unintended consequences.

Clause 9.0.1 of E1 VM1 notes that the designer should demonstrate the ability of the "*ground to receive and dispose of the water without causing damage or nuisance to neighbouring property*" but does not clarify how this is to be done. We suggest this requires consideration of proximity of the soak pit relative to other features (existing or proposed). The following items listed in Table 3 are just some of the common features that that should be kept in mind when designing soakage devices.

Table 3: Issues of topography and proximity to structures.

No.	Feature	Issue	Solution
1	Steep banks (including stream banks, river terraces and earth embankments)	Locating soakage close to slopes can increase the risk of slope instability and cause tunnel gulley erosion.	Do not propose soakage near steep banks or on steep ground / hill sides / near streams / rivers without considering impacts on stability.
2	Gullies	Groundwater tends to be elevated in gullies and they (by default) are overland flow paths.	Avoid siting soakage devices in lower-lying areas where practical.
3	Overland flow paths	Potential for regular inundation of the soakage device with larger flows than it is designed for.	Locate them clear of the 10% AEP, preferably the 2% AEP, floodplain.
5	Retaining walls	Increased pore pressure can result in greater wall movement potentially also resulting in movement of the retained ground behind.	Keep soakage devices away from existing walls and design new walls for high groundwater conditions.
6	Buildings and structures	Increased saturation around buildings and other structures could affect stability (increased pore pressure on walls as per above) water tightness and buoyancy / drainage considerations. Particularly an issue for those buildings with basements.	Keep soakage clear of structures and review if soakage is appropriate given proximity and relative elevation of surrounding buildings and structures.
7	Neighbouring property	Increased saturation of lawns, gardens, pavement subgrade etc leading to nuisance effects or damage to structures.	Keep soakage devices away from the boundary and review design performance in context of surrounding topography, geology and groundwater table.

No.	Feature	Issue	Solution
8	Sewers and drainage	Soakage could increase unwanted infiltration into sewers or cause scour in the pipe bedding as pipe trenches are often more permeable than the surrounding natural ground.	Keep soakage devices clear of sewers and pipes in accordance with Council requirements (or in the absence of these, at least 2 m).
9	Wetlands and streams	Changes to water levels, flows causing raised water levels and/or flows impacting on sensitive ecological features or an increase stream bank instability.	Keep soakage devices clear of these areas and seek expert ecological / geotechnical advice. May need to model the impact to quantify the effect.
10	Landfills/ contaminated sites	An increase in groundwater table or flows effecting saturation, mobilization, dispersal and/or containment of contaminated materials.	Do not use soakage devices near (and particularly uphill from) these sites unless detailed specialist hydrogeotechnical and/or landfill engineering advice confirms it is acceptable.
11	Underground power cables	Underground high voltage cables can rely on the insulating properties of the backfill and assumed levels of saturation. Changing this can affect the performance of the material and the insulation of the cable as a whole.	Discuss with electrical transmission engineers and the cable owner before proposing soakage. Set backs will be needed even if soakage near to the cables is acceptable.

3.7 SELECTING AN INFILTRATION RATE AND A FACTOR OF SAFETY

3.7.1 EVALUATION OF IN-SITU TEST DATA

Most testing involves adding a known volume of water to an excavation with a known surface area, and then measuring how quickly the water level recovers to the pre-test conditions.

Often the rate of recovery will be greatest during the early stages. The method set out in VM1 recommends adopting the minimum slope of the plotted recovery curve but allows for the lower rates at the end of the test (when the hydraulic head is very small) to be discarded and a value closer to the average adopted.

However, the rate of recovery is the greatest during the early stages of a test due to the large induced hydraulic gradient, as well as a variety of other factors such as progressive wetting of the soils/influence of capillary suction, influence from the gravel pack around piezometers etc.

For this reason the later time data is more likely to reflect steady state conditions of the soils. During the final stages of the test, the water level will be close to the invert of the test pit and the infiltration rate will be close to the saturated hydraulic conductivity due to the low hydraulic gradient. Therefore, the later part of the test data should always be used to estimate the infiltration rate and not be discarded. However, this should not be taken and used in the design without applying a factor of safety.

3.7.2 FACTOR OF SAFETY

In soakage design it is not possible to have complete confidence in all of the design parameters. Parameters such as the volume of stormwater may be known with some accuracy and others, such as the hydraulic conductivity, cannot be fully understood (hydraulic conductivity will reduce over time as a result of soil saturation, clogging of the soils and/or other site constraints). To account for this a factor of safety (FoS) should be applied to the raw test results.

Some Councils have provided recommendations for a FoS when designing soakage however these vary significantly and really, should be site and design specific.

Table 4.6 in R156 (CIRIA, 1996), provides some high level guidance on the factor of safety based solely on the consequence of failure and the area of soakage. In the absence of other considerations this provides a good starting point with the recommended FoS varying from 1.5 to 10.

However, there are a number of other site specific factors that need to be considered, and that, with some engineering judgement, allows the factor of safety to be refined including consideration of the following questions:

- Are there factors that reduce the risk of soil clogging? For example, pre-treatment prior to discharge, runoff sourced stabilised surfaces etc. Conversely, is the risk of clogging higher for any reason, such as runoff coming from a road.
- What is the type and frequency of proposed maintenance going to be?
- How applicable is the site testing? Was the right method used, are there scaling factors to consider (i.e. relying on a single test in a borehole to assess a large basin is fraught), are there a sufficient number of tests for the area proposed, is the variability in geological conditions captured, was the pre-soak adequate, how repeatable are the individual tests, how do these vary and how comparable is the full set of test data. All of these factors might suggest selecting a FoS of 10.
- What is the groundwater level and how well is it understood? If it is close to the surface in summer, and there is no, good, long term records then a higher FoS might be needed to account for reduced storage capacity.
- How quickly does the groundwater level respond to peak rainfall events and could this constrain discharge?
- Is there a secondary flow path to provide relief? What are the potential consequences of soakage failure?

The US Environmental Protection Agency (USEPA, 1982), with regards to ***wastewater*** discharge, has also considered FoS selection based on the scalability of the tests undertaken, with factors ranging from 10 (for larger scale basin tests) to 25 (for small scale laboratory testing). Whilst these factors are for wastewater they do demonstrate the effect of scale in testing. The bigger the scale of the testing, the more appropriate the testing is, then the more the results can then be treated with confidence and so a smaller the FoS can be used.

In the example used in the other sections above, when applying a factor of safety, say of 10 in accordance with R156 (CIRIA, 1996), then the 300 mm/hr test soakage rate drops to 30 mm/hr and the soak pit capacity to 0.007 L/s (an order of magnitude lower than without the FoS at 0.07 L/s). Consequentially, for the 10% AEP 10 minute time of concentration, the storage requirement increases as set out below:

Vstor 10 min = 21.3 to 21.5 m^3
Vstor 30 min = 30.9 to 31.4 m^3
Vstor 1 hr = 29 to 40 m^3
Vstor 24 hr = 101 to 118 m^3

This results in only a slight change in the volumes as the volume soaked away over each duration (relative to the runoff volume) is so small. It is also noted the impact is more pronounced in longer duration events where soakage has more time to act.

3.8 PRE-TREATMENT

Sediment carried into a soakage device clogs and blinds the surfaces that are relied on to pass water (either surfaces that are part of the device such as a geotextile lining or the surrounding in-situ soil itself). However, as TR2013/40 (Auckland Council, 2013) notes, the risk of sediment blinding depends on the nature of the catchment from which the runoff is sourced. The guide concludes that:

- pretreatment is not required for roof water (other than gross litter protection) which has low sediment loading
- driveway runoff should go through pretreatment despite low sediment loads and need only pass through a standard catchpit (despite it providing only minimal treatment) and
- high sediment yield sites (such as roads, industrial sites and construction sites) need robust pre-treatment.

Auckland Council guidelines, TR2013/40 (2103) shows a sediment trap (chamber) with a half siphon on the outlet pipe. A standard road catchpit alone is not suitable as finer sediment will still be entrained by flow and carried into the soak pit. Alternatively, sand filters, rain gardens, scoria trenches or other various proprietary devices (such as Enviropods) can be used to provide pre-treatment.

3.9 SOAK PIT DETAIL

The soak pit detail included in VM1 (Figure 13) does not show a pre-treatment detail and so is exposed to the effects of sediment clogging pit over time. Some Councils show pre-treatment like Hamilton City Council (HCC, 2005) which say a sand filter upstream of the soak pit also reduces the frequency of maintenance on the pit (at the increase of maintaining the sand filter) and it protects the soak pit from clogging and blinding.

Other Councils, such as Auckland have more comprehensive details that should be used in the absence of other details (Auckland Council, 2013).

3.10 MAINTENACE

Given the difficulties involved with rehabilitating clogged soak pits, it is important that they and the pre-treatment devices are regularly inspected and maintained. Again as noted in TR2013/40 (Auckland Council, 2013), maintenance should be focused on prevention of clogging rather than rehabilitation.

It is noted that this can be problematic for private households, particularly when the ownership changes several times over the years. There is clearly a need for the home owners to be well educated as to their responsibilities and Councils will need a range of appropriate mechanisms in place to regulate and enforce action when problems occur.

TR2013/40 (Auckland Council, 2013) also has good maintenance check sheets and forms in Annexure D that can be used and adapted to schedule and document maintenance activities.

4 CONCLUSIONS

Soakage design using VM1 is sometimes not enough and the designer must carefully consider how the design addresses the various limitations within VM1. Overall, this paper suggests that VM1 should only be used for very small catchments and those with a low consequence of failure. Items that need further consideration when using VM1 include:

i. Being (or involving) an appropriately qualified and/or experienced geotechnical or hydrogeotechnical practitioner

ii. Using a design method suitable for the scale of the catchment, the size of the development, the stage of the design and the nature of the constraints around the site (this which may include groundwater modelling)

iii. Reviewing how the design performs in a range of storms and durations to select the critical event for the site, compliance with E1 and to meet the expectations of the owner/client/Council

iv. The assessment and/or design must be backed up by a suitable range of ground investigations and tests that focus equally on the site geology and the groundwater table and their variability (both spatially and temporally). For large scale projects and/or those with significant consequences of failure then groundwater monitoring is recommended (ideally for a period of 1 year)

v. The depth to the groundwater table needs to be identified and its potential seasonal variation accounted for. The design of the soak pit should keep the base of the pit at least 1 m (preferably 1.5 m) above the seasonal high groundwater level

vi. Permeability testing needs to be in the location of each and every soakage device with more than one test undertaken (above and below the target depth of the device). Larger devices will need more than one test

vii. Permeability testing should be carried out with a double ring infiltrometer (for shallow designs) and a test pit (for deeper designs) instead of using a piezometer

viii. The design must include a factor of safety applied to the permeability rate. Selecting this should account for the unknowns, the risks and the consequences of failure

ix. The design must address nearby constraints as well as those on the site (such as steep banks, structures, buried utilities, ecological features or low lying land) and identify these on the plans. This includes consideration of nuisance impacts as well as the more severe consequences

x. Consider the likely sediment loading and in the majority of cases the design will need to include pre-treatment to protect the soakage device from clogging

xi. The system must be regularly checked and maintained. The maintenance must focus on prevention rather than rehabilitation.

The above suggests that the soakage disposal section in VM1 should be revised or expanded on, even if just to draw attention to some of the critical issues, risks and the need for designers to address them.

So, soakage designed in accordance with VM1? That is just a start.

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