THE IMPORTANCE OF AQUIFER DATA TO SIZE AND LOCATE STORMWATER INFILTRATION BASINS

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ABSTRACT (200 WORDS MAXIMUM)

Stormwater infiltration basins have become an important method of treating runoff from developed land in the Canterbury area. Infiltration basins provide a method of maintaining rainfall recharge to the underlying aquifer and hydraulic neutrality for any stormwater runoff. In most situations, infiltration basins are located above unconfined aquifers. To determine the invert level of the basin requires an assessment of the highest groundwater level along with the amount of mounding that occurs when stormwater discharges through the basin. This requires knowledge of aquifer parameters such as transmissivity and storativity.

The author's describe their experiences with the investigations required to locate and design infiltration basins so that the risk of groundwater entering the basins or compromising their operation and performance is minimised. They will describe the importance of obtaining sufficient information such as long-term groundwater records and localised measurements to ensure that the maximum groundwater levels at the location of the infiltration basin can be predicted. They will show how the data is used to size components of the infiltration basins.

The paper will also explain the impacts of not carrying out these investigations fully, particularly in relation to the operation and maintenance of the infiltration basins.

KEYWORDS

Stormwater, Infiltration, Groundwater, Aquifers, Mounding Calculations

PRESENTER PROFILE

As a senior engineer at Pattle Delamore Partners Ltd, Andrew has been working in the field of stormwater management for 15 years. He has extensive experience in consenting, designing, testing, and constructing infiltration basins over this time in Canterbury.

1 INTRODUCTION

Stormwater infiltration basins have become an important method of treating runoff from developed land in the Canterbury area. They provide a method of maintaining rainfall recharge to the underlying aquifer and hydraulic neutrality for any stormwater runoff.

Typically there has been sufficient separation between the base of an infiltration basin and the highest underlying groundwater so that interaction between the two has not been expected to occur.

Recently projects have been considered in areas with free draining strata but with higher groundwater levels. High groundwater levels combined with the mounding of the water discharging from the infiltration basin can result in water remaining in the infiltration basin for significant periods after rainfall events. This can result in the die off of the grass in the infiltration basins, as well as the basin not functioning properly when the next rainfall event occurs.

This paper describes the design philosophy of infiltration basins, methods to determine the long term groundwater levels, how to determine mounding, and methods to avoid problems.

2 DISCUSSION

2.1 INFILTRATION BASINS- BASIC DESIGN PHILOSPHY

Infiltration basins are designed to collect stormwater runoff from a developed site such as a residential or industrial subdivision. The collected water then infiltrates through the base of the infiltration basin getting treated in the process. This treatment is achieved by a wide range of processes including:-

- Filtration which removes sediments (and any contaminants such as heavy metals attached to the sediments) and some pathogenic organisms
- Adsorption of heavy metals to soil particles
- Absorption
- Uptake of nutrients by plants
- Die off of bacteria due to competition from organisms living in the soil, and generally conditions which are not suitable to their survival.

The water that infiltrates through the basin may either discharge directly into free draining strata beneath the site or, where there is less permeable strata directly below the infiltration basin, be collected by an underdrainage system which pipes the water to a soakage chamber cut into free draining strata located beneath the less permeable strata. Brough (1999), Callander et al. (1999), and Brough (2005) describe in more detail design aspects of infiltration basins.

Over the years infiltration basins have been sized to contain and treat the runoff from a variety of rainfall depths and storm durations depending on a number of factors including the potential risk to the environment and perceptions of the risks by the consenting authority processing the resource consent applications for the stormwater discharges.

When the first infiltration basins were being sized in Canterbury they were based on treating the runoff from the first 12.7 mm of rainfall (based on overseas literature, such as Schueler (1987)). Subsequently to obtain a discharge consent in a non-notified manner Environment Canterbury were requiring that all runoff from storm events of up to a 50 year return period regardless of duration required to be treated. More recently it has been common to size infiltration basins based on containing the runoff from the first 25 mm of rainfall.

Analysis of automatic weather station records for Canterbury demonstrate that sizing a treatment basin to contain the runoff from the first 25 mm of rainfall will have treated in excess of 93 % of all the runoff likely to occur from a development (PDP (a), (b), 2010).

Water in excess of the treatment capacity of the infiltration basins has either been discharged directly to ground, or in some cases directed to a surface water course.

In most situations infiltration basins have been located where there has been at least a 1 m vertical separation between the highest known groundwater level and the invert of the basin. This requirement has been included into the permitted activity for stormwater discharge to ground in the latest version of Environment Canterbury's Natural Resources Regional Plan (ECan, 23 October 2010). In the United States of America the minimum vertical separation distance varies between jurisdictions e.g. Wisconsin 5ft (1.5m) (M.A. Lowndes, 2000), Maine 3ft (0.9 m) (Maine Department of Environmental Protection, Stormwater Management Law, 27 Dec 2006).

In most situations this is sufficient to satisfy requirements to minimize interaction between groundwater mounding and the infiltration basin. However in some situations decisions have been made to utilize infiltration basins where there is less than 1 m separation between the highest seasonal groundwater level and the invert of an infiltration basin. In those situations a much more detailed investigation is required of the depth to groundwater and the calculation of mounding associated with the infiltration of stormwater through the invert of the basin to ensure that the infiltration basin can drain in an acceptable period after the end of a rainfall event.

2.2 DETERMINING LONG TERM WATER LEVEL FLUCTUATIONS

Groundwater levels in Canterbury have been recorded for variable time periods in a wide range of bores across the plains. Finding a set of data for the location of the infiltration basin with a suitable long term record is important.

Regionally the highest groundwater levels have been recorded in the mid 1970's, as shown in Figure 1. If a groundwater record close to the infiltration basin site does not go back to that period then it may be necessary to synthesize a record to estimate the maximum groundwater levels.

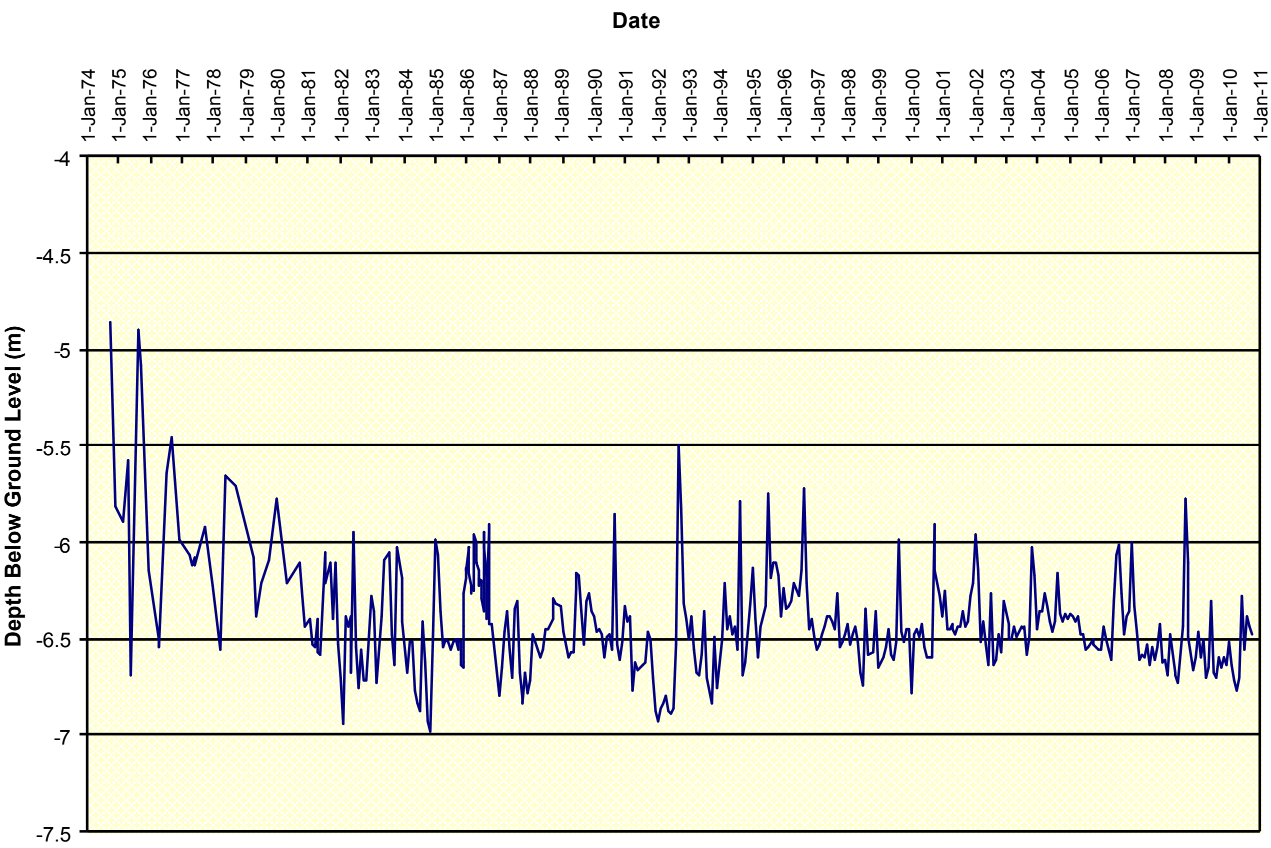

Figure 1: Example of a Long Term Groundwater Level Record (Well M35/0948) (Source Environment Canterbury)

There are several ways of determining the maximum groundwater levels. The most accurate is to install piezometers into the ground which intercept the shallow groundwater beneath the site of the proposed infiltration basin then monitor the groundwater levels for several months. At the same time the on-site groundwater levels are measured the groundwater levels should be monitored in a reference well which has a long term record of depth to groundwater. A regression analysis is then carried out on the two sets of data and using the equation obtained a long term record of the depth to groundwater at the particular site can be generated.

Alternatively one can look for groundwater level data from wells in close proximity to the site and calculate maximum groundwater levels based on that data or assess the variation at the site based on the variation at other wells close by to the site.

In each case it is necessary to consider the nature of the groundwater at each location. For instance if the infiltration basin is going to be located in free draining strata with an unconfined aquifer beneath it then one should ideally compare with a long term set of data located in a similar hydrogeologic setting. Figure 2 shows a comparison of the water level fluctuations for three wells located in differing hydrogeologic situations. The locations of the three wells are shown in Figure 3.

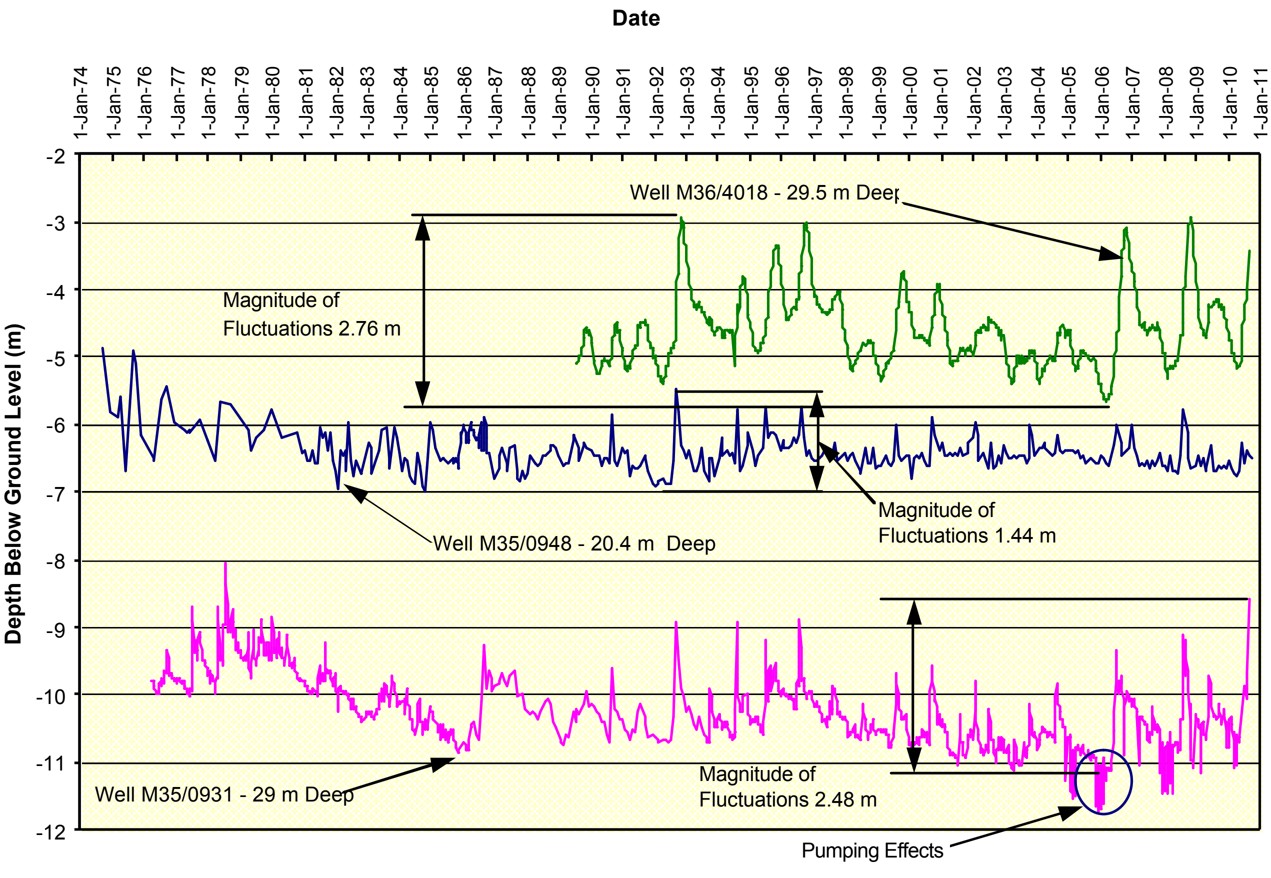

Figure 2: Comparison of Long Term Groundwater Level Records (Source Environment Canterbury)

Well M35/0948 is located in a zone where there is significant recharge from the Waimakariri River. Hence it does not show the same range of groundwater fluctuations compared with the other two sites. Well M36/4018 has a less rapid response to groundwater inputs than the other two sites probably due to differing overlying strata causing slower drainage into the groundwater of rainfall and less direct river recharge. Despite these differences, the general trend of when the maximum and minimum groundwater levels occur is similar across the three wells. Well M35/0931 also shows the drawdown effects caused by a neighbouring well being used for irrigation supply. This effect would either need to be removed from the data, or the data excluded, when generating a comparison with another location where pumping is not occurring.

Figure 3: Location of Monitoring Wells

The number and frequency of on site groundwater level measurements required to give a good comparison with longer term records needs to be considered along with the time frames available between beginning the project and commencing preliminary and detailed designs. Clearly, the longer the record that is available at a particular location the greater the certainty one has with the calculated maximum groundwater level. A shorter record will require consideration of an increase in the factor of safety between the calculated level and the design groundwater level.

If using local groundwater level data one must consider the extent of the record available. For instance, in Figure 2, the record between 1989 to 2011 shows the highest groundwater levels to be deeper than recorded in the 1970s. Where groundwater levels may be close to the invert of an infiltration basin then knowing this trend means that seeking out data from further afield from the basin may be required to establish the maximum groundwater level for design purposes.

2.2.1 EXAMPLE OF THE ASSESSMENT OF GROUNDWATER LEVEL USING REGRESSION ANALYSIS

For this example we intended to install an infiltration basin at Belfast at a location shown in Figure 4. The nearest well with a long term record is at the Tyrone St Sewage pump station (PS62) also shown on Figure 4. Groundwater level monitoring began at that site in 1984.

Figure 4: Location of Infiltration Basin and Pump Station

A piezometer was installed at the location of the proposed infiltration basin. It was monitored on 11 occasions from December 2006 to April 2007. While an attempt was made to measure the water level on the same day as measured at the sewage pump station, only 7 of the measurements occurred on the same day. The water levels recorded at each site over this period are shown in Table 1.

Date	**Site**	**Pump Station**
12/12/2006	20.374	13.425
20/12/2006	20.367	
9/01/2007	20.393	13.39
15/01/2007	20.413	
2/02/2007	20.354	
20/02/2007	20.32	13.15
6/03/2007	20.312	13.12
15/03/2007	20.33	13.105
28/03/2007	20.292	13.065
10/04/2007	20.319	
17/04/2007	20.339	13.15

Table 1: Groundwater Levels (RL metres above Christchurch Drainage Board Datum)

A linear regression analysis was applied to the set of data using the regression analysis package in Microsoft Excel 2003. This resulted in the following x variable and constant:-

X Variable: 0.22696

Constant: 17.34111

Applying these to the Pump Station data a long term data set for the site was created.

Figure 5 shows the comparison with the groundwater levels at the site, at the pump station, and those calculated for the site over the period used for the analysis.

At the site the actual groundwater measurements varied by 121 mm while at the pump station over the same period the groundwater level altered by 360 mm. The calculated groundwater levels for the site appear to have been smoothed a little compared with the actual measurements.

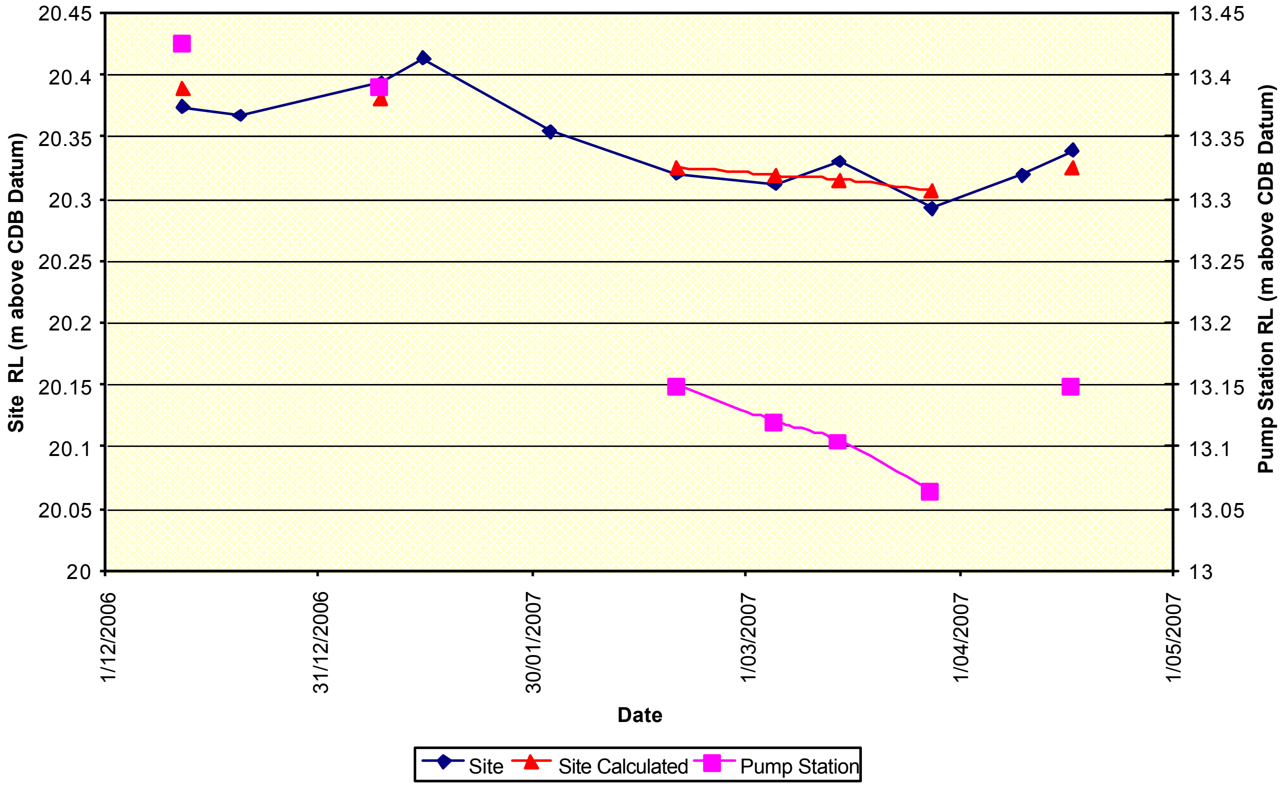

Figure 5: Comparison of Measured and Calculated Groundwater Levels

Applying the equation to the full set of groundwater data obtained a maximum groundwater level of 20.719 m at the Site which is a depth to water of 1.18 m. This is 306 mm higher than recorded on-site in the piezometer during the monitoring period. As the Pump Station record only went back to 1984, for the purposes of designing the infiltration basin at the site a groundwater level of 1.1 m was adopted.

Another method of predicting groundwater levels is to look at the local short term data and apply an increase in water level based on a visual assessment of the long term data. This can be difficult where the magnitude of variation in the groundwater level varies as shown in Figure 6. This shows the Pump Station long term record and that calculated for the Site. It shows the groundwater level at the Pump Station has a long term variation of around 3 m while the variation of the groundwater level at the Site is around 0.7 m.

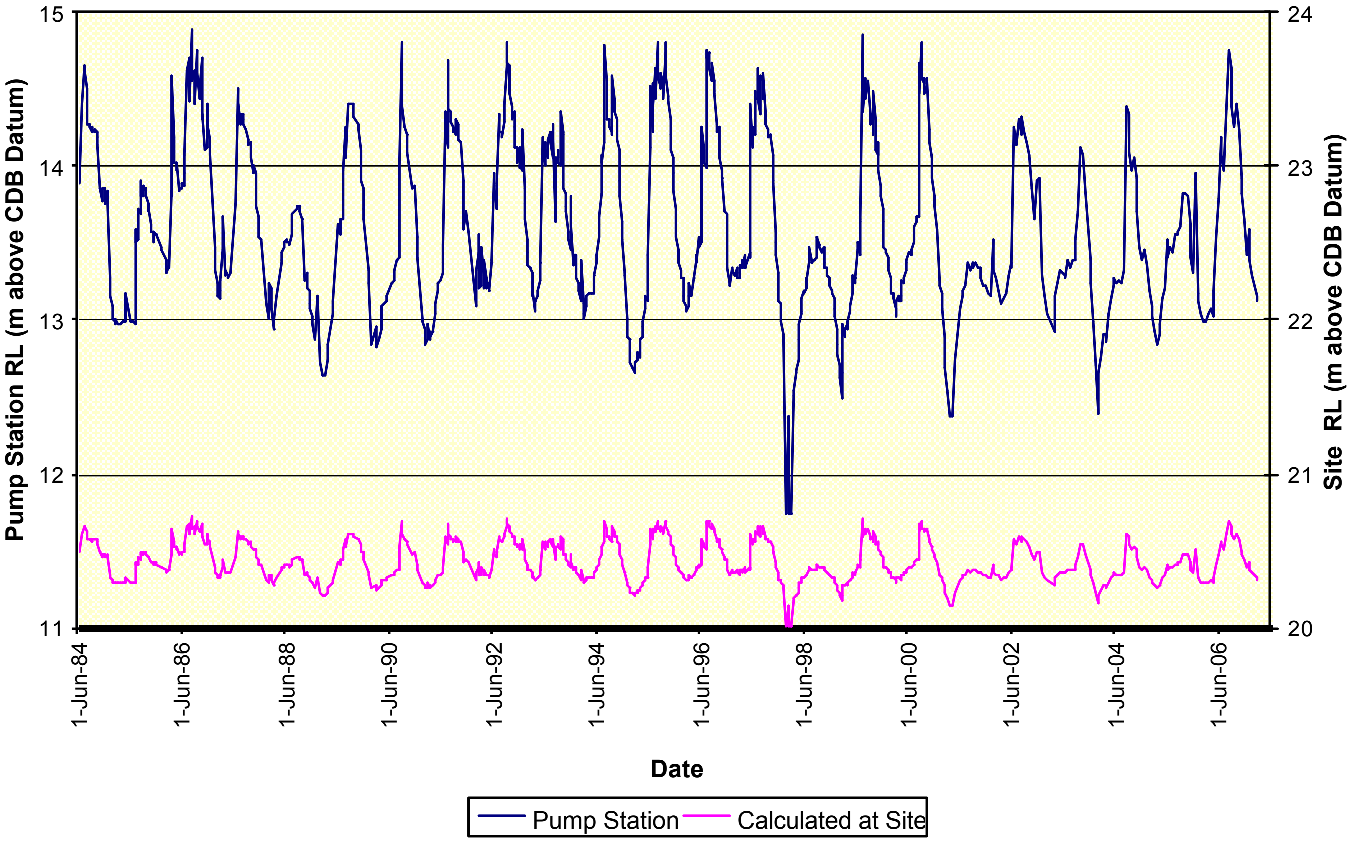

Figure 6: Comparison of Variation on Groundwater Levels

A third way of assessing the maximum groundwater at a location is to look at the maximum groundwater levels from wells in close proximity (around a 1 km radius is suitable) and compare that with the ground level at the site. As noted above the wells need to be representative of the shallowest groundwater beneath the site. For instance relying on groundwater records for deep confined aquifers will not provide a reliable assessment of the shallow groundwater. If the data available does not go back to the 1970's it will be necessary to apply a factor of safety to the groundwater level that is assessed from the shorter term data.

These last two options are less reliable as they do not take into account localized ground conditions which may result in a groundwater level that varies from the wider regional levels.

2.3 DETERMINING MOUNDING

2.3.1 HYDROGEOLOGICAL PARAMETER ESTIMATION

Review of the groundwater levels described in the previous section provides estimates of the available depth for mounding to occur within. In order to compute the likely mounding that will occur as a result of stormwater discharge, estimation of the relevant hydrogeological parameters is required.

As is the case for any groundwater model, the key parameters are the hydraulic conductivity and storativity of the underlying strata. For discharge above or directly to the water table of an unconfined or semi-confined aquifer, the key storage parameter is the effective porosity, which describes the available pore-space for the discharged stormwater and groundwater to occupy.

There are various methods that can be used to estimate the hydraulic conductivity and effective porosity. A constant rate pumping or discharge test with water level measurements made in observation wells is one of the more accurate methods, although also one of the more costly. Large scale soakage tests carried out at the depth of the proposed basin, using shallow piezometers to measure the mounding, are also useful as they provide a good replica of the stormwater discharge.

In practice, hydraulic conductivity is commonly inferred from much smaller scale tests which are cheaper to perform, such as double ring infiltrometer tests or falling head tests carried out in standpipes either above or below the water table. The problem with these tests is that they measure the hydraulic conductivity at a specific point, which may not be representative of the effective hydraulic conductivity over an area of an infiltration basin due to natural variability in the strata. It is common to interpret the infiltration rate directly as the hydraulic conductivity, which is appropriate provided that the hydraulic gradient is close to 1. The hydraulic gradient can be approximated as 1 where the infiltrating water has saturated a significant depth of strata beneath the testing device.

Most alluvial deposits are anisotropic, as the nature of alluvial depositional processes and subsequent pressure of overlying strata tend to result in material that has a much higher hydraulic conductivity in the horizontal direction than vertical (Lough & Williams, 2009). This is partly due to fine layering and because flat particles tend to be oriented with their longest dimension parallel to the plane on which they settle (Bear, 1979;). In addition, as described by Dann et al. (2008), on a large scale alluvial depositional processes tend to result in material that has a higher hydraulic conductivity in the flow direction of the rivers responsible for the deposition than in the direction perpendicular to that flow.

Anisotropy and heterogeneity in the strata need to be considered in the planning of field investigations. Where the hydraulic conductivity is expected to vary across the site set aside for stormwater disposal, the testing should aim to determine the range in values so the disposal location can be targeted to the most permeable strata.

For tests where the drainage from the base of the device is entirely vertical, such as from the base of a stand pipe or double-ring infiltrometer test located in the unsaturated zone, the interpreted hydraulic conductivity will be representative of the vertical hydraulic conductivity at that point. Beneath that point, the water may flow horizontally when it encounters lateral zones of lower hydraulic conductivity. Other testing procedures are available that can be used to assess both vertical and horizontal hydraulic conductivity.

A soakage test procedure that involves lifting the casing during the testing is an example of a test procedure that can be used to estimate both vertical and horizontal hydraulic conductivity. This method involves initially measuring vertical infiltration out the exposed base of the casing. The casing is then drawn back by around 1 m to expose the material on the sides and the test is repeated (this gives a composite of vertical and horizontal infiltration). The authors have found that, for soakage tests performed around Christchurch, the infiltration rates for the second part of the testing are often much higher than those recorded during the initial part of the testing due to vertical anisotropy.

It is important that the hydraulic conductivity is determined to a sufficient degree of accuracy for the mounding assessment as the calculated mounding is very sensitive to this parameter. If the field testing procedures do not provide for estimation of the effective porosity of the strata, this can be carefully estimated based on typical values for the type of strata encountered. The range in this parameter is small for most materials and, as such, accurately determining a value for this parameter for the mounding assessment is usually less critical than the hydraulic conductivity.

2.3.2 CALCULATING MOUNDING

There are various analytical equations and numerical models that can be used to assess the mounding that occurs beneath and around an infiltration basin. In many instances, the hydrogeological setting and discharge method will be simple enough to approximate with analytical equations. Hunt (2008) describes some analytical equations that can be used to model groundwater mounding. For complex settings where there is sufficient information to warrant a more detailed model, any one of a number of numerical modeling packages can be used to simulate mounding.

Both analytical and numerical models used for mounding assessments require the basin dimensions and an estimate of the infiltration rate through the base of the basin. For cases where the infiltration media will be less permeable than the underlying strata, the design infiltration rate through the media can be used. Most infiltration basins in Christchurch are designed to achieve an infiltration rate of between 20 and 50 mm/hr for effective treatment, while overflow basins may permit much larger infiltration rates. Where the vertical hydraulic conductivity of the strata that directly underlies the infiltration basin is lower than the design infiltration rate through the infiltration media, the infiltration rate should be set to that vertical hydraulic conductivity of the underlying strata as this will be the limiting control on the infiltration rate.

The duration of the discharge can be calculated based on the run-off rate and infiltration rate, considering secondary discharges such as overflow to a surface waterway.

The mounding that occurs around a soakage basin occurs three dimensionally as water can flow in all directions away from the basin. This means that unless the infiltration basin is very long and thin, modelling should be carried out in a manner that allows for radial flow from the basin, rather than using a two dimensional vertical model. Using a two dimensional model to simulate flow from a soakage basin can result in overestimation of the magnitude and extent of mounding, as water can only flow horizontally in one direction. Figure 7 compares the mounding predicted with an equation that allows for radial flow and an equation that allows for two dimensional flow only. The mounding is shown after 24 hours of stormwater discharge at a rate of 1.1 m/day through a 300 x 30 m infiltration basin into an isotropic unconfined aquifer with a hydraulic conductivity of 22 m/day and an effective porosity of 0.35.

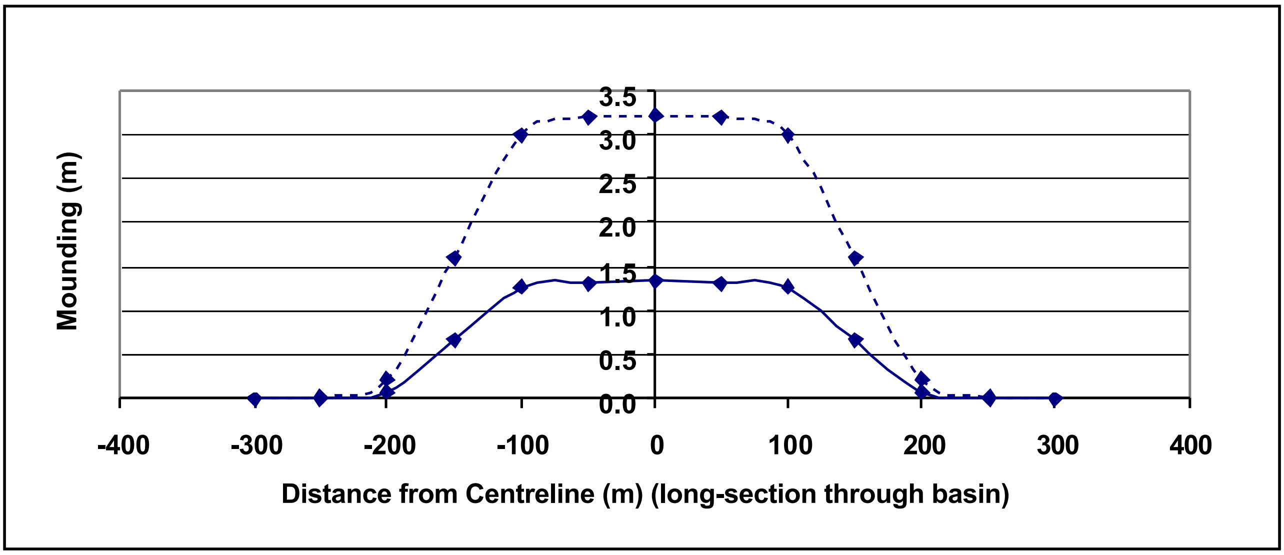

Figure 7: Predicted mounding using radial flow equation (solid line) using 2-D equation (dashed line)

Where strong anisotropy or confining layers are present, these aspects should be incorporated into the mounding assessment.

If the calculated mounding is greater than the depth to groundwater beneath the basin, ponding will occur in the basin, reducing the storage capacity of the basin and increasing the length of time for which water remains in the basin.

Figures 8, 9 and 10 provide examples of mounding occurring in the same setting described for Figure 7 for a 24 hour event. Figures 9 and 10 show the resulting piezometric contours based on background hydraulic gradient of 1 m/km. Figure 11 illustrates the peak mound height.

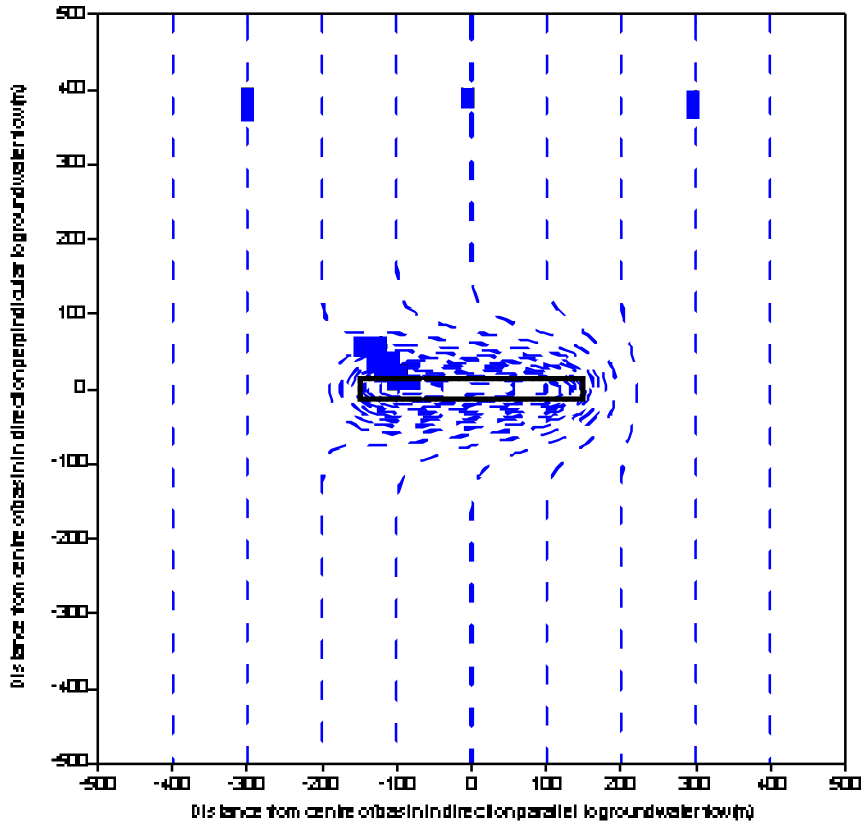

Figure 8: Predicted groundwater contours (m above datum) at 24 hours (at end of basin discharge).

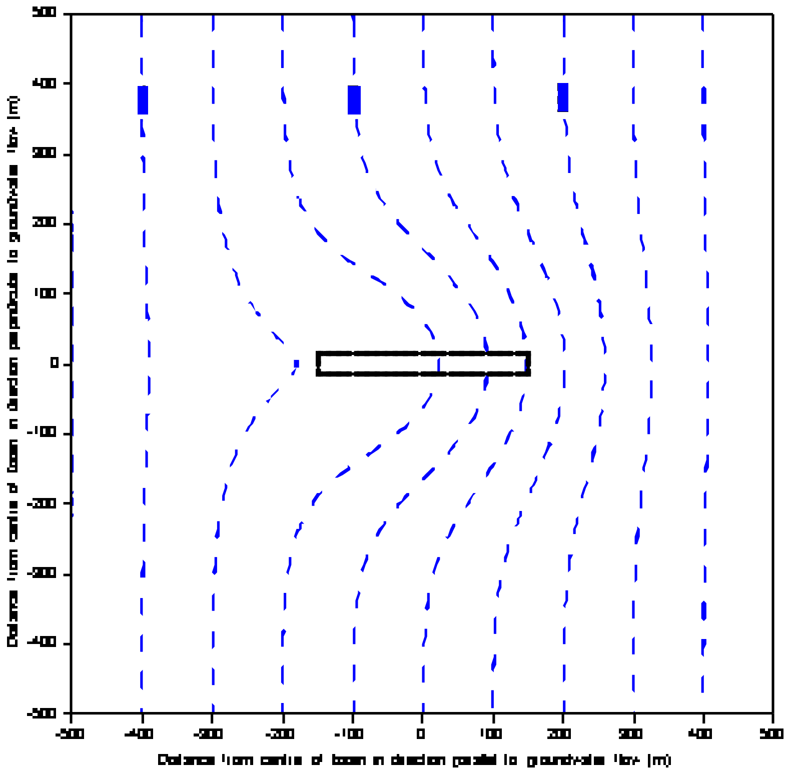

Figure 9: Predicted groundwater contours (m above datum) at 8 days (7 days after basin discharge ceased).

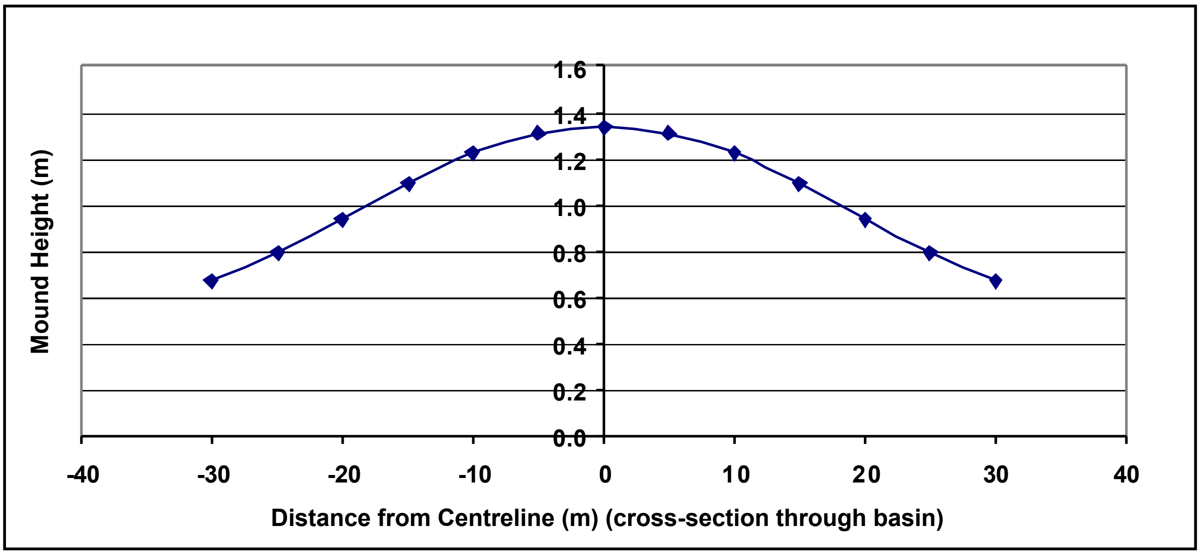

Figure 10: Peak mound height beneath the basin at 24 hours (at end of basin discharge).

2.4 METHODS TO MITIGATE GROUNDWATER MOUNDING

Methods to mitigate the effects of groundwater mounding on the operation of the infiltration basins include:-

- Relocating the infiltration basin

- Change the style of stormwater treatment from infiltration to slow release to a surface water course

- Change the design of the basin and overflow structures

- Install under-drainage facilities to drawdown the normal groundwater

These methods are discussed further below.

2.4.1 RELOCATING INFILTRATION BASINS

Generally a stormwater treatment system is located at the lowest area of a catchment to allow for gravity reticulation of the stormwater. This means that the treatment system will be located in the lowest lying land and therefore in the closest proximity to groundwater. Developers generally wish to minimize the land development costs by reducing the amount of soil that needs to be moved around the site, brought onto or removed from the site. Therefore it is often not cost effective to move the location of the stormwater treatment system.

Commonly it requires the installation of a groundwater monitoring well and measurements to determine the likely horizontal and vertical hydraulic conductivities of the strata before the groundwater mounding implications can be determined. This can take several months. Generally clients wish to proceed with this in parallel with the consents and detailed design of the site so sometimes the full implications of the groundwater mounding issues have not been determined until there has already been strong commitment to the site layout.

Combining the cost factors and the timing required to determine the implications of groundwater levels means that it is normal to investigate means of mitigating the groundwater effects at the chosen location of an infiltration basin rather than relocating the stormwater treatment system.

For sites where there is higher hydraulic conductivity strata present, such as in old river channels, on a site set aside for stormwater disposal , locating the infiltration basin in these areas can reduce mounding.

2.4.2 CHANGE TYPE OF STORMWATER TREATMENT SYSTEM

If, as a result of the groundwater investigations, the groundwater level is identified as being a problem it may be possible to change the type of stormwater treatment system. Generally the obvious change is to discharge to surface water rather than to ground, or complement the groundwater discharge with a surface water discharge for larger events/high groundwater levels. Of course this relies on the ability to identify a suitable point of discharge from the site. One that can be reached by overland flow or piped discharge and also where the discharge can be consented.

The reason to change to a surface water discharge would be because it is not possible to reduce the mounding to an acceptable level or to guarantee that the groundwater could be drawn down to a suitable level using an under drainage system. To draw down the groundwater requires the installation of a drainage system which can discharge to a surface water system as the groundwater needs to be removed from the underlying aquifer to lower its level. If the rate of discharge required from the groundwater is high relative to the rate water infiltrates through the basin then it is probably better to consider changing the type of stormwater treatment system rather than continue with an infiltration option. This is because taking lots of water from the groundwater to allow infiltration to groundwater means installing extra pipes when one could discharge stormwater (with appropriate treatment) directly to the surface water at a similar rate and minimize some of the engineering costs.

2.4.3 CHANGES TO BASIN DESIGN

In some situations it is not possible to identify a suitable location to discharge to surface water and its necessary to investigate alternative designs to minimize the impacts of the groundwater on the basin.

Generally infiltration basins are designed with an operational depth of 1.0 m. If land area is available then it is practical to have a shallower infiltration basin. In section 2.2.1 above a regression analysis was presented which showed for a site in Belfast the design depth to groundwater was 1.1 m. To achieve a suitable separation between the depth to groundwater and the base of the infiltration basin an operational depth of 0.6 m was adopted for that infiltration basin. This was located without significantly impacting on the subdivision layout.

In some situations an overflow soakage chamber is utilized to discharge stormwater in excess of the capacity of the infiltration basin. If an underdrainage system is used then this will also drain into the soakage chamber.

The groundwater mounding that occurs around a soakage chamber is a function of the design of the soakage chamber and the hydraulic conductivity of the strata. Groundwater mounding can be minimized by configuring the soakage chamber in the correct manner and using a sufficient spacing between chambers.

Anisotropy and heterogeneity in the strata must be considered in the design of the infiltration basin and any soakage chambers. In deposits that are strongly vertically anisotropic, discharging via stormwater systems with a large vertical exposed area will create less peak mounding than a system that involves discharging over a large horizontal area above the water table. An example of an appropriate system in an vertically anisotropic setting would be a large boulder filled soakage chamber excavated to several metres below ground and unlined on the sides.

2.4.4 USE OF UNDERDRAINAGE FACILITIES

Underdrainage facilities can be utilized for two reasons. Firstly, as described in Section 2.1, they are used where the natural strata immediately below the basin has low permeability. The underdrainage system is installed to capture the water draining through the infiltration basin and directing it to the soakage chamber cut into the free draining strata below the low permeability layer.

The second reason to use them is in the context of this discussion where they are used to draw down the groundwater to ensure sufficient separation between the groundwater level and the infiltration basin. As indicated earlier to reduce the groundwater level the underdrainage needs to drain to a surface water system. Therefore they can only be used in certain situations.

A good example of their use was in an infiltration basin in the Belfast area of Christchurch. The basin was located in an area where the immediate strata beneath the site was of low permeability. Beneath this layer is a partially confined aquifer. In certain situations the groundwater pressure in the aquifer is above the base of the low permeability layer.

The depth required of the infiltration basin was such that it cut into the low permeability layer to such an extent that it meant that the upward groundwater pressure penetrated the remaining layer of the lower permeability material. Consequently groundwater was entering the base of the excavation of the infiltration basin. To alleviate this problem and under drainage system was installed to capture the groundwater. The outlet of the underdrainage system is into the nearby stream.

3 CONCLUSIONS

Infiltration basins are a practical means of treating and disposing of stormwater runoff to ground. They achieve groundwater recharge which is beneficial to maintaining base flows in spring fed waterways.

In the Christchurch context basins are now being located in more marginal situations where there is less than ideal separation between the basin invert and groundwater. Suitable knowledge of the groundwater and strata beneath the basin are required to determine the size, depth, and configuration of the infiltration basin to ensure that there is a suitable separation distance between the basin invert and groundwater.

Groundwater level analysis is required to determine likely maximum groundwater levels. Hydraulic conductivity measurements are required of the strata beneath the site which are then used to determine the amount of groundwater mounding that will occur for the particular design scenarios.

If necessary, modifications can be made to the basin design to achieve a suitable separation between the basin invert and groundwater. These changes can include making the basin shallower or changing the configuration to minimize the amount of mounding.

Without the analysis of groundwater levels and a mounding assessment groundwater may at times be present in a basin. If present for sufficient periods this can compromise the operational parameters of the basin so that it does not achieve compliance with consents, as well as killing the grass and plants which can result in a costly maintenance bill. This can be minimized with the calculations, analysis and mitigation measures described in this paper.

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