

AN EXPERIENCE OF DESIGNING AND INSTALLING AN INFILTRATION BASIN IN CHRISTCHURCH

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ABSTRACT

In 1998 Christchurch City Council (CCC) was granted a resource consent from Environment Canterbury to discharge stormwater from new subdivisions to ground in an area described as the Upper Heathcote Catchment. This permitted the infiltration of the first flush of stormwater, defined as the first 12.7 mm of runoff, through the soil, with the remaining stormwater being discharged directly to the subsurface material using a soil soakage chamber.

This paper describes the work required to size the infiltration basin, and the results of preliminary monitoring for the first infiltration basin installed under the new consent. It describes the changes from the conceptual design to meet the requirements of Christchurch City Council. These requirements are intended to result in a higher level of treatment than proposed in the resource consent, which aim to reduce the environmental impact and ensure compliance with the conditions of the resource consent, whilst also making the infiltration basin more robust and easier to maintain.

KEYWORDS

Stormwater, infiltration basins, groundwater,

1 INTRODUCTION

In 1998 Christchurch City Council (CCC) was granted a resource consent (permit) from Environment Canterbury (ECan) to discharge stormwater from new subdivisions to ground in an area described as the Upper Heathcote Catchment (Figure 1). This area was identified because there was the likelihood that free draining gravels are located less than 5 m below the ground surface and there is sufficient depth to groundwater beneath the infiltration basins to allow filtration of the stormwater before it reaches the groundwater. The consent required that the first flush of stormwater, defined as the first 12.7 mm of runoff, should be treated by controlled infiltration through the soil, while the remaining stormwater can be discharged directly to the subsurface material using a gravel soakage chamber.

The background behind the rationale for selecting infiltration basins to dispose of stormwater and a description of the hydrogeological setting can be found in Brough (1999), Callander et. al. (1999).

While the consent was granted in 1998 it has not been utilized until 2004. Developers are subdividing land within the consented zone into residential subdivisions. Each development is required to treat and discharge the stormwater to ground and the developers are using this existing consent rather than obtaining separate resource consents for each individual subdivision.

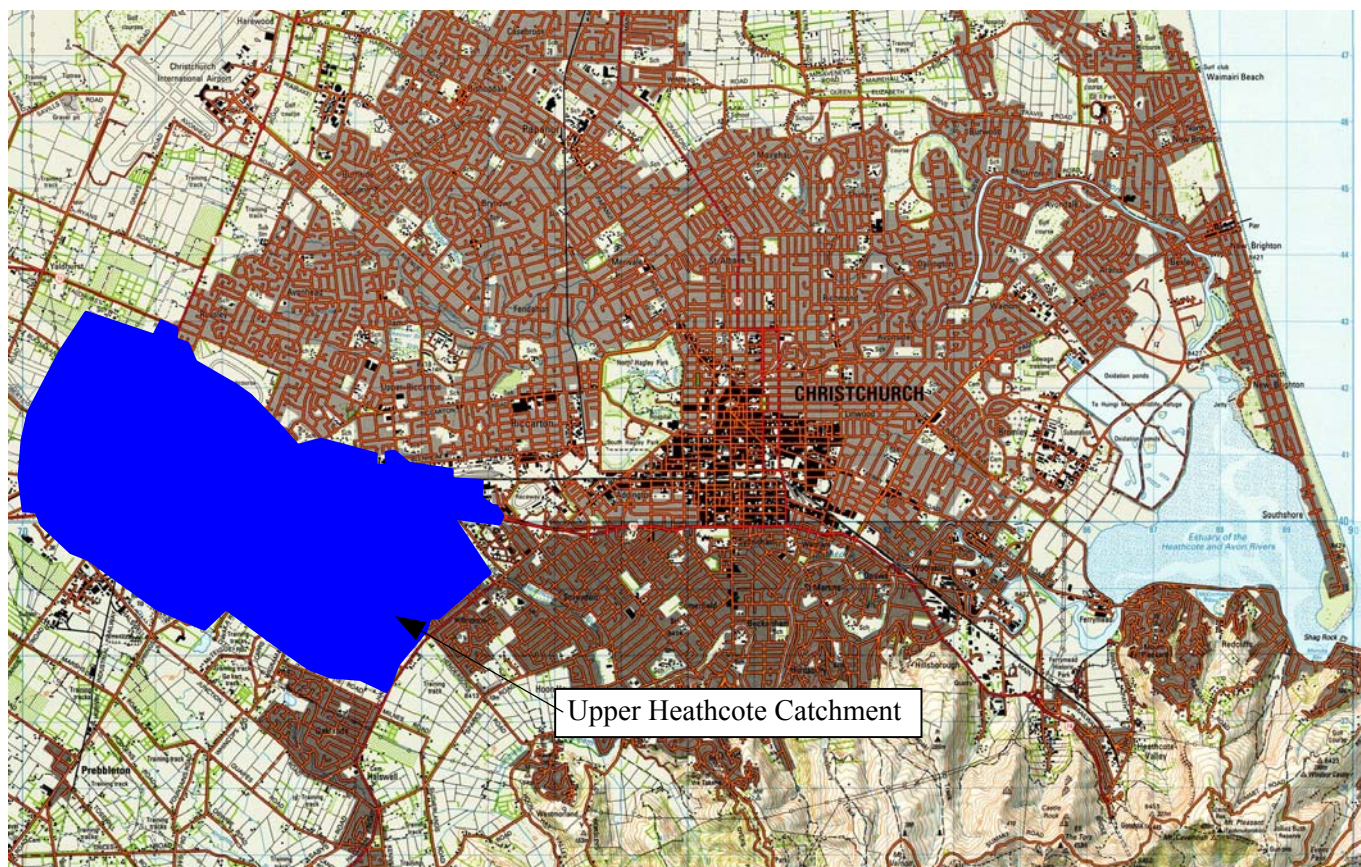
This paper will describe the experiences of preparing and installing the infiltration basin for a 4.8 hectare residential subdivision.

The developer engaged Pattle Delamore Partners Ltd to model the stormwater runoff from the subdivision, measure the characteristics of the soil and subsurface strata, and size an infiltration basin to meet the requirements of the resource consent.

Christchurch City Council staff approve the engineering design prior to construction. During this review process a number of changes were made in line with the CCC "Waterways, Wetlands, and Drainage Guide" (2003) to provide a greater level of treatment than was required to meet the conditions of the resource consent and to provide an infiltration basin that could be more easily maintained without disrupting its operation.

Since the basin became operational a single round of sampling has been carried out. Further monitoring will be carried out to meet the requirements of the resource consent.

Figure 1: Location of Upper Heathcote Catchment



2 DESCRIPTION OF THE SITE AND SUBDIVISION

The site of the subdivision is shown in Figure 2 relative to the Upper Heathcote catchment. As can be seen the site is not completely within the Upper Heathcote catchment as defined in the resource consent. As a result CCC has undertaken to obtain a variation to the resource consent to include this area along with other small areas located on the boundaries of the marked catchment which sensibly should be included within the catchment and covered by the resource consent.

The issues relating to the use of infiltration were the infiltration characteristics of the surface soils, the depth to the gravel aquifer, and the permeability of the gravel aquifer. This information would determine how the infiltration basin would be configured along with the size of the soakage chamber for the overflow to the aquifer.

2.1 INFILTRATION TESTING

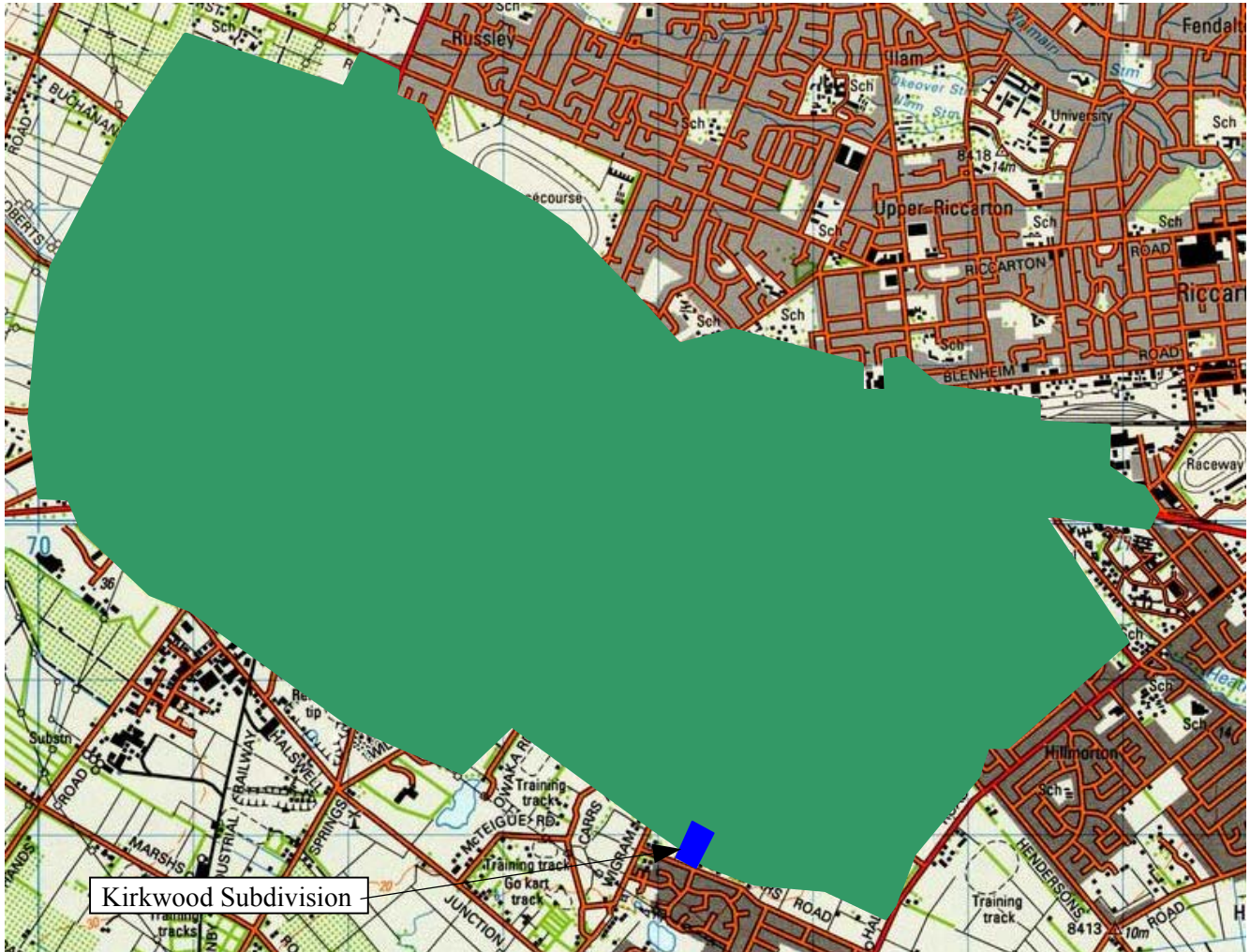
The infiltration basin was to be excavated into the existing soils to a depth of approximately 1.0 m. Therefore the infiltration rate of the soil beneath the basin needs to be determined. Two pits were excavated to a depth of 1.5 m in the location of the proposed infiltration basin. The soils exposed in the two pits were similar. The description is shown in Table 1.

The infiltration rate was tested using double ring infiltrometers. Briefly, these consist of large and small concentric rings driven into the ground to a depth of approximately 100 mm. The inner ring and outer ring are filled with water to a depth of between 100 and 200 mm (Photograph 1). The rate at which water falls within the inner ring is measured at intervals ranging from 1 minute to 1 hour, depending on the soil type, until there is an equal fall over three consecutive readings.

Table 1: Soil Description at Site of Proposed Infiltration Basin

Depth	Soil Description
0 – 0.3 m	SILT (top soil). Dark brown, dry, firm.
0.3 – 0.8 m	SILT with minor SAND. Light brown lightly speckled orange, firm, moist.
0.8 – 1.3 m	SILTY SAND. Light brown lightly speckled orange, firm, moist.
1.3 – 1.5 m	SILTY CLAY. Brownish grey mottled orange, firm, moist.

Figure 2: Location of Subdivision



Two double ring infiltrometer tests were carried out in each test pit. The ultimate infiltration rates are shown in Table 2. These show low infiltration rates that require modification of the infiltration basin to allow successful operation of the basin. The design of the infiltration basin is provided in section 3.

Table 2: Ultimate Infiltration Rates for the Subsoil

Pit #	Setup 1 (mm/hr)	Setup 2 (mm/hr)	Average (mm/hr)
1	6	6	6
2	3	6	4.5

The infiltration rate of the top soil which would be placed back within the infiltration basin was not measured. The soils are described as Kaiapoi deep and moderately deep silt loams on the ECan GIS database. This is consistent with the field observations. CCC (2003) provides expected infiltration rates for Kaiapoi silt loam as ranging from 5 to 10 mm/hr. The implications on the design of the system are described in Section 3.

Photograph 1: Infiltration Testing of Sub-soils



2.2 PERMEABILITY TESTING OF AQUIFER

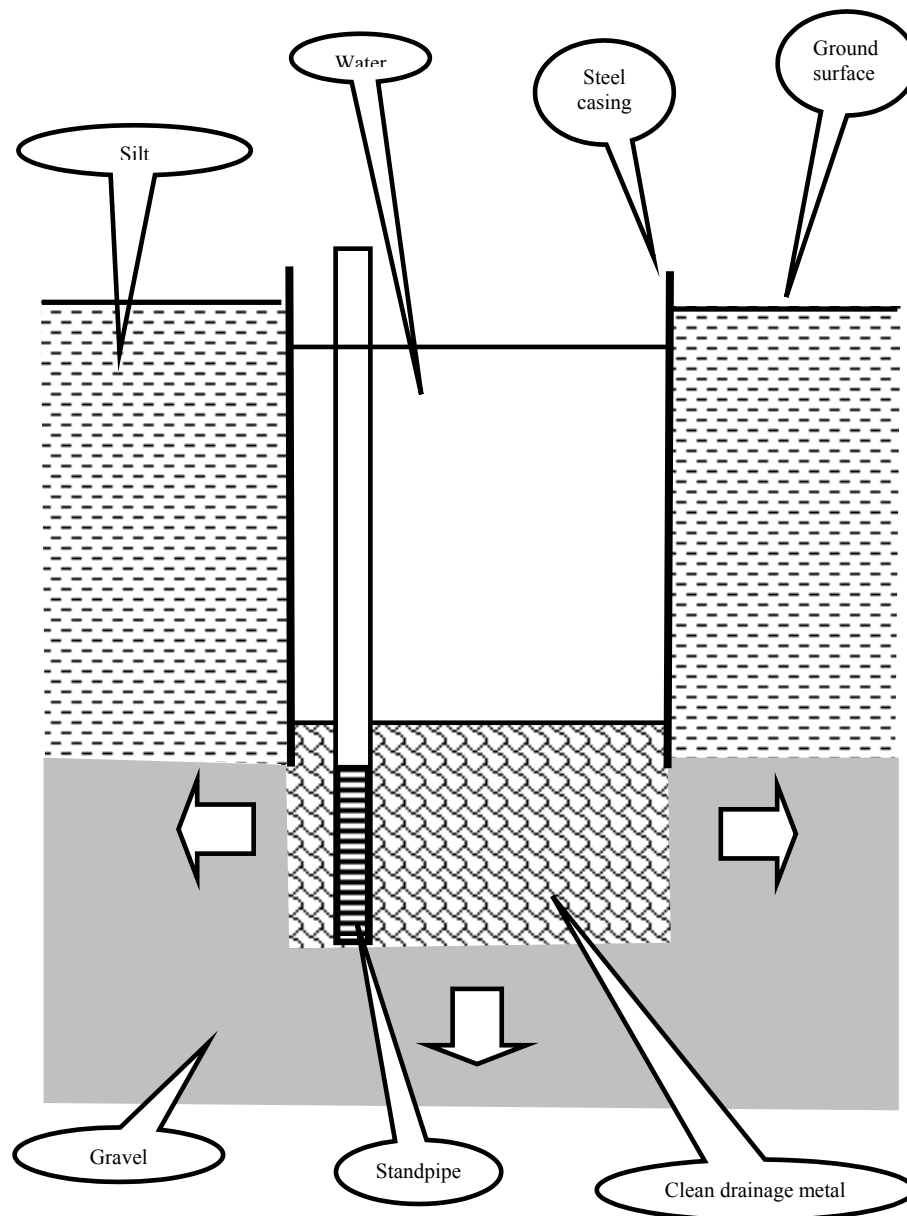
The top of the aquifer is located approximately 3 m below the existing ground level. It is therefore relatively easy to discharge to the aquifer using a soakage chamber. Having confirmed that it was possible to discharge to the aquifer, permeability testing was required to determine the parameters needed to size the soakage chamber.

The permeability testing of the aquifer was carried out using the method described below.

2.2.1 METHOD

1. A nominally 1.1 m diameter hole was drilled by auger through a confining layer of silt to gravel strata, and thence for approximately 0.5 m into the gravel strata, and a 1.05 m diameter steel casing emplaced (Figure 3, Photograph 2). During the drilling process some sand and silt material was allowed to descend to the base of the hole; this was largely removed by pumping prior to the testing procedure.
2. A 50 mm diameter slotted standpipe was placed within the casing, near the casing side (Figure 3, Photograph 2). This was protected within a sleeve consisting of a perforated 100 mm diameter plastic pipe. Approximately 0.6 m³ of 100 mm diameter clean drainage metal was placed at the bottom of the cased hole, around the standpipe assembly. The casing was retracted by 0.4 m. The drainage metal effectively supports the exposed gravel strata at the bottom of the hole when the casing is retracted (in effect acting as a screen). The standpipe allowed precise measurement of water levels within the cased bore.

Figure 3: Schematic of Permeability Test Set-Up



3. The annulus around the outside of the casing was filled with pea gravel up to a depth above the natural gravel strata and then backfilled to ground level with low permeability silt. This allowed water levels within the casing to be raised to greater than ground level.
4. The static groundwater level was measured after 30 minutes equilibration.
5. A water tanker was used to deliver a metered supply of water to the cased hole at three different flow rates. The equilibrium level of water in the cased hole was measured with a water depth probe, usually after about 30 minutes. The metered flow was checked using a bucket-stopwatch method.
6. After the final test, the water supply was turned off and the recovery of the water level within the casing monitored for approximately 100 minutes, during which time the water level in the cased hole descended towards the original static level.
7. The numerical data were analysed.

Photograph 2: Permeability Test Set-Up



2.2.2 RESULTS

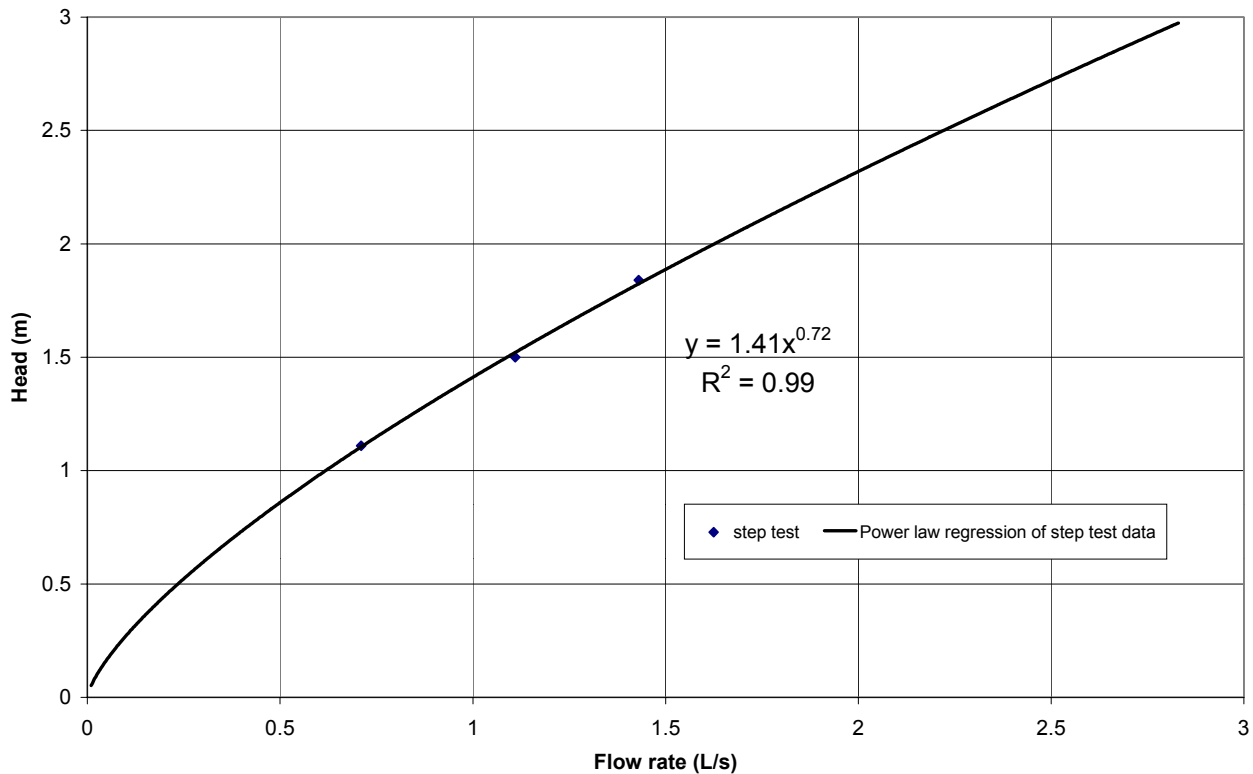
The results of the three constant discharge tests were analysed (Figure 4). The constant discharge tests were modelled using a simple Darcian flow technique whereby the relationship between water pressure and surface area of infiltration relate to the hydraulic conductivity of the gravel strata. The three tests furnished three separate measurements of hydraulic conductivity.

Two related assumptions have been made regarding the estimation of hydraulic conductivity:

- a. The vertical and horizontal hydraulic gradients have been estimated for the analysis of the constant discharge tests. Normally in an infiltration test, the vertical gradient is assumed to be unity. A vertical gradient of 1 is assumed and a horizontal gradient of 0.3. Whilst these values are not known precisely, provided the basin is designed so that similar, or greater gradients are achieved then the values determined for the analysis are valid.
- b. The analyses also assume that vertical and horizontal conductivities are identical. In small scale environments, this is probably reasonable where there are few fine-grained strata within the gravel layer chosen as the disposal medium.

Notwithstanding these assumptions and the foregoing remarks about how the measured values might relate to actual conditions, the assessment methods have produced results that are close in magnitude.

Figure 4: Step Infiltration Test Data



The three constant rate discharge tests were analysed by using a modified Darcy Law relationship that accounted for both radial and vertical flow out of the cased hole. The tests gave a mean hydraulic conductivity of the gravel strata at the bottom of the cased hole of 5.7×10^{-4} m/s. The values for hydraulic conductivity are close to the lower part of the range expected for gravel strata of 10^{-3} to 10^{-1} m/s as quoted in Freeze and Cherry (1979).

3 DESIGN OF INFILTRATION BASIN AND SOAKAGE CHAMBER

3.1 SIZING OF INFILTRATION BASIN AND SOAKAGE CHAMBER

From the testing of the soils the preliminary design of the infiltration basin was made so that it could be included into the model used to design the final size of the infiltration basin and the soakage chamber.

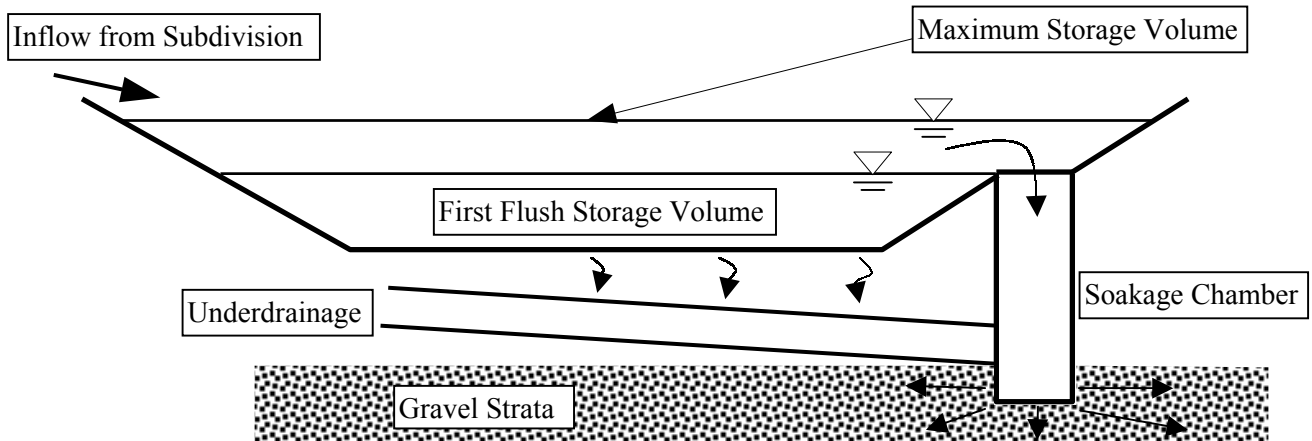
The requirements of the resource consent are that the infiltration basin should treat the runoff associated with the first 12.7 mm of rainfall, and that the rate of infiltration in the basin should be between 50 and 20 mm/hr.

The soakage chamber is required to discharge the remaining flow in excess of the capacity of the infiltration basin for storm events of up to the 2% AEP (50 year return period) storm. For more extreme events CCC permit overland flow onto neighbouring land for the flow in excess of the capacity of the infiltration basin and soakage chamber.

As discussed in Section 2 the infiltration rate of the subsurface materials and the topsoil are both below the minimum rate of infiltration acceptable in the resource consent. To size the infiltration basin the infiltration through the surface was assumed to be a minimum of 20 mm/hr.

In situations where the infiltration rate of the subsurface materials is below 20 mm/hr then the consent permits the use of an under drainage system. This was utilised in this instance. The water that is collected in the underdrainage system is then discharged into the soakage chamber. This underdrainage flow needed to be included in the sizing of the soakage chamber. A conceptual layout of the infiltration basin and soakage chamber used in the modeling is shown in Figure 5.

Figure 5: Conceptual Layout of Infiltration Basin For Modelling Purposes



3.1.1 STORMWATER MODELLING

The developer reported discussions held with CCC with respect to runoff from the subdivision and surrounding land. The result of these discussions was that the stormwater treatment system needed to account for the runoff from the subdivision plus an additional one hectare of rural land to the west of the subdivision that historically discharged overland flow over site.

The runoff from the subdivision, plus the additional rural land, was modelled using the both the HEC-HMS and MOUSE computer models.

The list of inputs into the model included

- i. Rainfall – 1 in 50 yr return period, 24 hr duration storm which was determined as approximately the critical duration for the conceptual design presented in the original application, with a hyetograph as described in CCC (2003).
- ii. Soil Infiltration Rates within the subdivision – 12 mm/hr Initial, 6 mm/hr Ultimate
- iii. Impervious Area – as measured for roads and footpaths, 45% for lots
- iv. Soakage Basin Infiltration Rate – As the CRC981968 permits the use of subsoil drains, a basin with a system designed with an ultimate infiltration rate of 20 mm/hr has been assumed.
- v. A maximum discharge rate from the basin to groundwater based on the observed hydraulic conductivity of the aquifer.

Ideally to minimize the area for detention storage the volume of storage required should just meet the requirements to infiltrate the first flush of the runoff. The remaining stormwater would discharge directly to ground by way of the soakage chambers. In this instance the permeability of the aquifer was relatively low and the model indicated that a large soakage chamber was required to take the additional flow over and above the first flush volume. It was not considered practical to construct such a system. As the developer had initially sized the area for the infiltration basin for detention storage there was storage capacity available to attenuate post first flush flows. As a result a solution was found that provided for first flush infiltration, detention storage above the first flush storage requirement and a more practicable sized soakage chamber to handle the over flow.

The proposed design was taken to the Christchurch City Council for discussion. One of the first comments was that it was preferred if the infiltration basin could infiltrate the runoff associated with the first 25 mm of rainfall (described as the first flush). The infiltration basin and overflow chamber were resized to take this additional infiltration into account. Note this results in an increase in the volume of water that is treated by way of infiltration as opposed to that which may be discharged directly to ground in the soakage chamber. An analysis

of the rainfall records at Christchurch Airport from 1960 to 2003 indicate that 77% of rainfall is either from events of less than 12.7 mm or 12.7 mm of a larger event, compared with 91% of rainfall which is from events of less than 25 mm or is 25 mm of a larger event. i.e. 14 % more rainfall is treated using a infiltration basin with a capacity of treating the first 25 mm of runoff compared with treating only 12.7 mm of runoff.

CCC also required that the soakage device be sized for 3 times the predicted flow to allow for clogging of the soakage chamber over time. This resulted in an extremely large soakage chamber based on the earlier calculations of the combination between infiltration basin size and overflow rate.

After taking into account the requirements of CCC in the model the following infiltration basin characteristics were determined for the critical 24 hour duration 2% AEP storm:

Total stormwater runoff	3875 m ³
Total discharge from Infiltration basin during storm	Infiltration -175 m ³ Discharge via Overflow-1300 m ³
Maximum Storage Required	2400 m ³

3.2 FINAL DESIGN OF INFILTRATION BASIN AND SOAKAGE CHAMBER

Once the size of the basin had been determined it the final design and layout of the system was discussed with CCC.

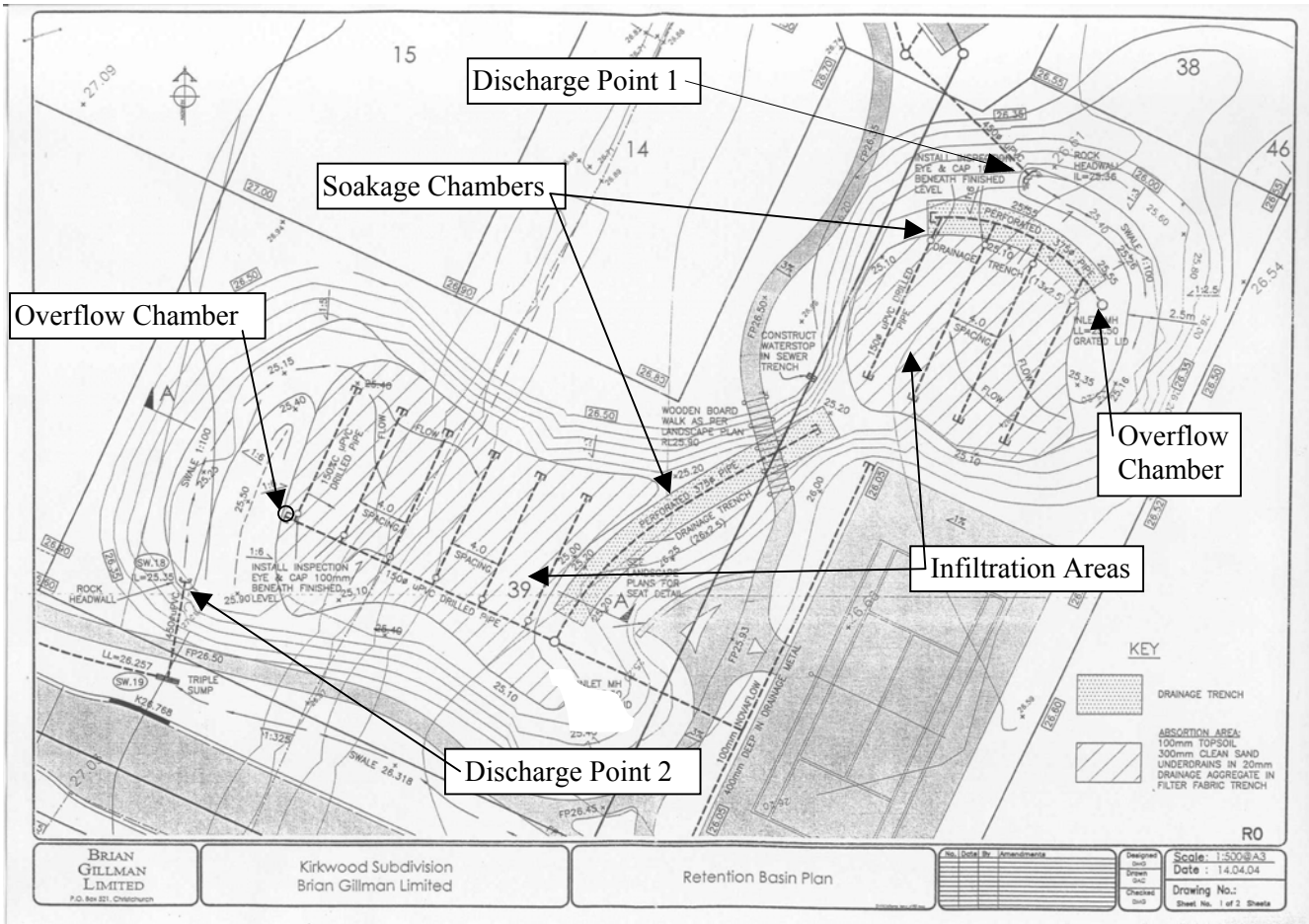
In the resource consent it was assumed that the overflow discharge to the soakage chamber was located at the end of the infiltration basin away from the inlet. This would result in some mixing of the runoff in excess of that from the first flush. CCC staff preferred that the runoff after the first flush did not mix with the first flush so in the detailed design the overflow chambers which discharges water directly to the soakage chambers are located close to where stormwater discharges into the infiltration basin. As the soakage chambers do not have the capacity to discharge the peak storms without attenuation storage, what happens with stormwater runoff for this pond is that:

1. The first flush discharges into the infiltration basin (91% of average annual rainfall)
2. When the first flush volume is full the additional storm runoff discharges to the overflow chambers until the rate of flow exceeds the capacity of the chambers
3. The remaining runoff then flows into the infiltration basin area increasing ponded water levels within the whole basin.
4. Once the storm ceases the water ponded above the over flow chambers inlet level discharges directly to the underlying gravel strata while the water below the chamber inlet level discharges by infiltration through the soil.

The final layout of the infiltration basin and soakage chamber is shown in Figure 6. As can be seen the flow into the infiltration basin is split into two discharge points at either end of the basin. The design was altered by request of CCC so that there were two overflow chambers each discharging into a separate soakage chamber. The infiltration area was also split into two with one set of underdrainage pipes discharging to one soakage overflow chamber and the other set discharging to the second chamber. This has advantages to the operation and maintenance of the infiltration basin as it means that should, for whatever reason, one side of the infiltration area, or one of the overflow chambers block then the other one should still be operating, and when the infiltration surface needs remediating then it can be done in two stages while allowing the basin to remain operational.

As indicated in section 2 the infiltration rate of the natural soil was expected to be substantially lower than required in the preliminary design and to achieve an appropriate rate it was decided to modify the topsoil by mixing it with sand. From previous work by CCC a ratio of two thirds topsoil to one third sand has been used to provide an infiltrative surface above swale subsoil drains. This ratio was adopted for the topsoil mix on the infiltration basin. The infiltration rate that has been achieved is discussed in Section 4.1.

Figure 6: Final Design of Infiltration Basin



Photograph 3 shows the as-built infiltration basin looking to the north-east. Note that the tennis court will be inundated in storms of greater than 10 year return period.

Photograph 3: Infiltration Basin



4 MONITORING RESULTS

The conditions of the resource consent detail the monitoring required of the infiltration rate and the groundwater. These conditions are:

- “9 *The stormwater infiltration rate through the swales and the base of the soil adsorption basins as determined using a double ring infiltrometer and the method "Double Ring Infiltrometer Test" attached to this consent, shall not exceed 50 millimetres per hour.*
- 10 *The infiltration rate through at least two swales and soil adsorption basins shall be measured at least once every consecutive twelve month period, to ensure compliance with condition (9). The results of this monitoring of infiltration rates will be submitted to the Canterbury Regional Council on request.*
- 11 *The first basin to be installed and two subsequent representative basins shall include the installation of a monitoring borehole to sample groundwater within 50 metres downgradient of the rapid overflow soakage chamber. Stormwater discharging down the rapid overflow soakage chamber and groundwater from the monitoring borehole shall be sampled and analyzed four times in the first year of operation and thereafter annually for the following compounds: Total Petroleum Hydrocarbons, Zinc (both solid and dissolved forms), Faecal Coliforms, Suspended Solids. The laboratory carrying out these analyses shall be accredited to ISO Guide 25, for those analyses. The results of these tests, the date and time that the samples were taken and an interpretation of the results in relation to effects on groundwater quality, shall be presented in a report which shall be made available when requested by the Canterbury Regional Council. “*

4.1 INFILTRATION TESTING

Two double ring infiltrometer tests were carried out on the infiltration basin in November 2004, approximately 3 months after the basin was completed and became operational. These are shown in Figure 7. The results give infiltration rates of 40 and 99 mm/hr. It is possible that these are not the ultimate saturated infiltration rates, as shown by the slightly declining slope at the end of the graphs, despite having run the tests for between 3.5 and 4 hours. One test indicates compliance with the conditions of the resource consent, but the other does not. The different results are probably due to two reasons,

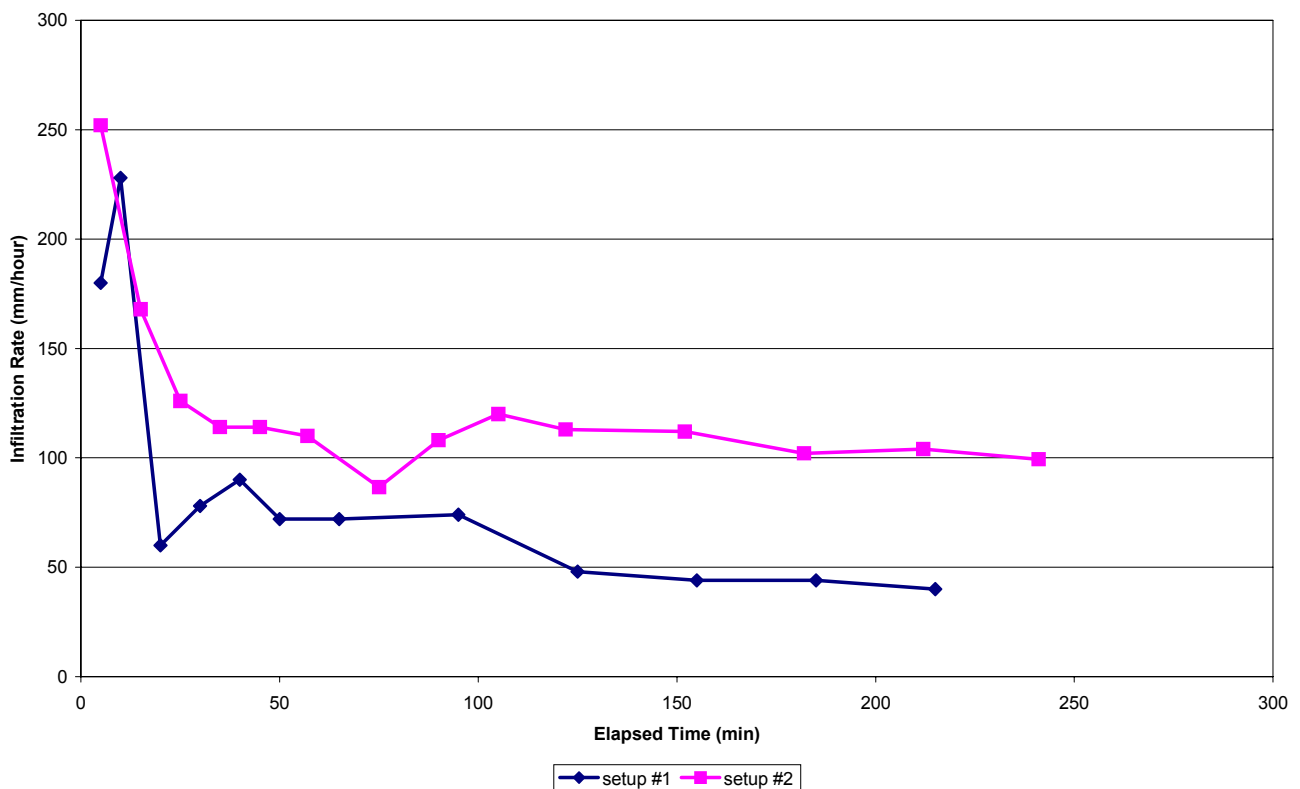
- The difficulty of obtaining a good seal between the infiltrometers and the surrounding soil potentially resulting in short circuiting of water and measurement of higher infiltration rates,
- The soil in the basin was created by mixing top soil with sand meaning that there is the potential for some areas to have more sand, and some areas to have less sand which would result in variable infiltration rates.

The USEPA (1981) reported on a comparison between the actual field infiltration rate and the rate measured by single and double ring infiltrometers. One extensive test of 357 measurements on a homogenous field showed that the infiltrometers overestimated the field infiltration rate by about 40%, indicating that small diameter cylinders will consistently overestimate the true vertical infiltration rate. It is there likely that the actual infiltration rate of the basin is lower than measured using the double ring infiltrometers.

The results that were obtained indicated, that while these did not necessarily comply with the conditions of the resource consent, the mixing of the sand with the soil successfully created a freer draining material than using the existing top soil on the site by itself, and that the infiltration rate was at the higher end of the acceptable range allowing for some progressive clogging over time so that the base should maintain acceptable infiltration rates for an extended period. It is considered that it would be prudent to leave the surface as it is rather than trying to remediate it to get a consistent infiltration rate over the whole surface.

No infiltration testing has been carried out on the swales. This is not considered as critical as the infiltrative surface available in them is relatively small (compared with the infiltration basin) and the primary means of treatment provided in the swales is filtration through the leaves of the grass grown in the swale.

Figure 7: Infiltration Test Results



4.2 GROUNDWATER AND STORMWATER SAMPLING

At the time of preparing this paper a single sample has been taken of the groundwater prior to rainfall, and one sample of the stormwater discharging to the soakage chamber and of the groundwater immediately after rainfall.

As indicated above the following parameters were required to be monitored:

Total Petroleum Hydrocarbons

Zinc (both total and dissolved)

Faecal coliforms

Suspended Solids

In addition E. Coli, Total Kjeldahl Nitrogen (TKN), Total and Dissolved Copper were also measured because in the case of E. Coli it is now the recognized determinand of faecal contamination of groundwater in New Zealand, and that nitrogen and copper are recognized as contaminants of stormwater.

The groundwater was sampled from the monitoring well on 10th February 2005 after a period of approximately 30 days with little or no rain. Sampling took place on 15th February 2005 after approximately 12 mm of rainfall. At the time of this sampling the rain had stopped. The rainfall had not been sufficient to cause direct overflow from the infiltration basin into the sump prior to the soakage chamber. The water in the sump was water that had passed through the surface of the infiltration basin to the underdrainage. At the time of collection most of the water had infiltrated from the basin and there was only a trickle of flow from the underdrains into the sump. Table 3 shows the results that were obtained.

Table 3: Results of Water Sampling from Infiltration Basin

Determinand (g/m ³ unless stated)	Groundwater		Stormwater in Sump Prior to Discharge to Soakage Chamber
	Before Rain	After Rain	
Total Suspended Solids	1290	1200	11
Total Kjeldahl Nitrogen	2.4	3.1	1.2
Nitrate-N	0.014	-	-
Copper Total	0.026	0.0358	0.0042
Copper Dissolved	0.001	0.0012	0.0032
Zinc Total	0.12	0.164	0.010
Zinc Dissolved	0.024	0.018	0.009
Total Petroleum Hydrocarbon	<0.2	<0.2	<0.2
Faecal Coliforms (CFU/100mL)	16	<9	680
E. Coli (MPN/100mL)	10	10	580

A third groundwater sample taken on 30th March 2005 was negative for E. Coli. This was taken after approximately 12 mm of rain over the previous two days.

There are several points of interest and clarification of these results:

1. The suspended solids concentration is very high in the groundwater in the monitoring well. Observations during baling of the well prior to sampling showed the presence of a brown gelatinous type material indicative of chemical precipitation involving iron from the groundwater. The sampling technique included baling out approximately 6 times the volume of water in the well before the sample was taken, so despite removing a significant portion of the casing water there was still suspended material present, indicating it is a natural component of the strata.
2. Given the likely source of the suspended solids concentration of the samples taken from the monitoring well, it is possible that there will never be any way of determining that the discharge of stormwater is causing an adverse effect on the concentration of suspended solids in the aquifer.
3. Both groundwater samples in February recorded the presence of faecal bacteria, yet the one in March did not. The potential sources are contamination during the sampling, leakage from the new sewers of the subdivision or septic tank discharge from houses further upgradient of the subdivision. It is considered that it is most unlikely that there contamination is as a result of leakage from the new sewers as these were pressure tested when installed. The results indicate that the contamination is intermittent.
4. The sump from which the stormwater sample was taken has an open meshed lid which potentially allows direct contamination of the stormwater from bird droppings so the result may not reflect filtration of stormwater through the infiltration basin.
5. The faecal bacteria present in the stormwater have not resulted in an observable change in the faecal bacteria in the groundwater.
6. The infiltration basin is filtering out the suspended heavy metal so that the only the dissolved component reaches the groundwater. This is evidenced by the similar concentrations of total and dissolved metals in the sump sample.
7. The initial sampling results indicate that the dissolved copper concentration reaching the groundwater is higher than that in the groundwater by a factor of 3 while the dissolved zinc concentration is approximately one half to one third of the background concentration.

As it was not possible to obtain a sample of the stormwater then the efficiency of treatment achieved by infiltrating the stormwater cannot be determined. Note that the resource consent does not require sampling of the stormwater, only that water which enters the soakage chamber.

The subdivision has 36 residential allotments (including the existing house). At the time of the initial sample 7 houses had been completed and 7 houses were under construction. As a result it is likely that the concentration of

contaminants such as the metals and faecal bacteria in the stormwater runoff is lower than in a mature subdivision.

5 CONCLUSIONS

The construction and installation of the first of the infiltration basins using the resource consent obtained by Christchurch City Council has proved to be a successful project, however it has demonstrated that having a minimum standard, as set out in the consent, does not mean that this will be acceptable for subdivision engineering consent from Christchurch City Council. The resultant design should provide a more robust infiltration basin, with better environmental outcomes than is provided by the conceptual designs included in the resource consent.

The preliminary monitoring results showed that the groundwater seems to be contaminated from sources other than stormwater and that the addition of stormwater from the subdivision did not seem to adversely affect the groundwater.

It is still early days in the monitoring and future monitoring will determine if the effectiveness of the system is maintained.

ACKNOWLEDGEMENTS

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