Sustainable management of Christchurch's waterways and wetlands using stormwater soakage disposal

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Abstract The western margins of Christchurch City, New Zealand, are located on a large alluvial flood plain including areas of free draining gravel strata. In settings such as this, the disposal of stormwater via ground soakage will minimize the disruption that urban development causes to the hydrological cycle. The gravel strata also forms part of a productive aquifer used by wells to provide the city water supply. The discharge of stormwater into a drinking water aquifer, rather than a surface aquatic environment, indicates that faecal coliforms are likely to be the main contaminant of concern, along with protection against chemical spillages. Removal of suspended sediments is also important to maintain the soakage capacity of the disposal system. An appropriate treatment and disposal system involves separate soakage of roof stormwater, reticulation of other stormwater using vegetated swales, and disposal via soil adsorption basins and rapid soakage overflow chambers. The location and shape of these components are designed with appropriate landscape and planting considerations to create an aesthetic enhancement to the urban environment.

INTRODUCTION

Stormwater in Christchurch City (Fig. 1) has traditionally been discharged into the city's surface waterways. These spring fed streams are adversely affected by stormwater discharge due to the introduction of suspended and floating solids and chemical contaminants to the waterway along with the creation of flooding problems. Prior to urban development in this area, most rainfall infiltrated directly to the underlying groundwater resource. Using the guiding principle that urban development should aim to minimize disruption to the hydrological cycle the use of ground soakage is now being promoted for the total management of urban stormwater within newly developed catchments.

HYDROGEOLOGICAL SETTING

Christchurch City is located on the eastern (coastal) margin of an extensive alluvial floodplain. The western areas of the city are built over unconsolidated deposits formed from alluvial gravel, sand and silt. The strata is quite variable with near surface

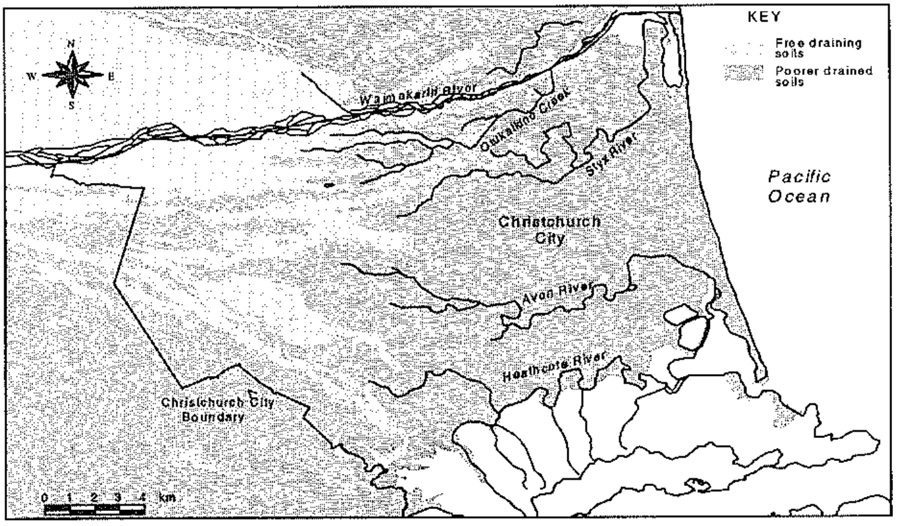

Fig. 1 Christchurch City showing areas of free draining and poorer drained soils.

hydraulic conductivities ranging from 5×10^{-5} m s^{-1} (silt overbank deposits) to 1×10^{-2} m s^{-1} (gravel in former river channels). The water table occurs at depths of around 10 m below ground level to the west of the city but becomes progressively shallower towards the sea coast with saturated conditions frequently occurring at depths of less than 1 m in many areas of the central and eastern city.

Due to these variable conditions, site specific investigations are required to assess the viability of any particular site for consideration of ground soakage. However, there are many areas in the western city where gravels occur within 5 m of the ground surface and the water table always occurs below a depth of 1 m. Under these circumstances ground soakage disposal of stormwater is quite feasible.

TREATMENT REQUIREMENTS

The free draining gravel strata forms a valuable groundwater resource. The unconfined aquifers of the western city are vulnerable to contamination and also provide recharge to a vertical sequence of confined aquifers to the east. Both the confined and unconfined aquifers are used extensively to provide the city's drinking water supply. The aquifers are highly permeable (with measured transmissivities up to 15 000 m^3 day^{-1}) and of good quality such that the water can be abstracted directly into the reticulation mains without treatment.

STORMWATER QUALITY ISSUES

It is expected that stormwater quality from new residential developments in the western City area will be of relatively good quality due to:

- Low urban density (residential units typically have a minimum section size of 450 m^2 with buildings occupying no more than 35% of this area).
- Flat catchments (typical ground slope less than 1 in 200).
- Low level of industrial and commercial activity.
- Separate sewerage system.

Table 1 shows the expected range of contaminants compared to environmental guidelines for both drinking water supply and surface aquatic ecosystems. It can be seen that for the traditional stormwater discharge to surface waterways the stormwater quality parameters of concern include suspended solids, hydrocarbons, nutrients, metals, and bacteria. However, when considering a ground soakage discharge into an aquifer, the main concern is with bacterial pollution and elevated suspended sediment concentrations, which will clog the soakage systems. The risk of chemical spillages resulting from accidents is also a matter of concern.

A further change in approach for ground soakage systems is the use of event mean concentrations (EMCs) to characterize stormwater quality impacts rather than peak concentrations that are sometimes used in surface water assessments. This is more realistic due to the storage characteristics of the receiving groundwater resource and the use of a storage basin to allow soakage so occur. The EMC is the flow-weighted mean concentration which is calculated by dividing the storm (the "event") mass by the storm volume (Williamson, 1993).

Table 1 Stormwater quality and environmental standards.

Stormwater parameter	Expected quality of Upper Heathcote stormwater	NZ drinking water standards (MoH, 1995)	Fresh water aquatic ecosystem guidelines (ANZECC, 1992)
Suspended solids ($g\ m^{-3}$)	50–200	2.5 NTU[a]	<10% change in seasonal mean concentration
Hydrocarbons ($g\ m^{-3}$)			
Total hydrocarbons	5	-	-
PAH	0.007	e.g. Benzo[a]pyrene 0.007[h]	0.003
BTEX	<0.003	e.g. Benzene 0.01[h]	0.3
Toxic organics ($g\ m^{-3}$)	<0.004	variable	variable
Nutrients ($g\ m^{-3}$)			
Nitrate-nitrogen	1.9–3.5	11.3[h]	
Kjeldahl-nitrogen	2.0	-	Total-N
Ammonia-nitrogen	0.6	1.5[h]	0.1–0.75
Dissolved reactive phosphorus	0.6	-	-
Total phosphorus	0.4	-	0.01–0.1
Total metals ($g\ m^{-3}$)			
Lead	<0.05	0.01[h]	0.001–0.005
Zinc	0.1–0.8	3[a]	0.005–0.050
Copper	0.02	1[a]–2[h]	0.002–0.005
Bacterial pollution (MPN 100 ml) Faecal coliform	1070–8000	1[h]	200

[a] Aesthetic based criteria.

[h] Health based criteria.

IMPLEMENTATION OF GROUND SOAKAGE SYSTEMS

Previous use of ground soakage in Templeton Township

Templeton is a small residential township on the southwestern outskirts of Christchurch City covering an area of 65 ha (Pattle Delamore Partners Ltd, 1998a). The earliest subdivisions were developed around 30 years ago, with roof water being disposed via small individual soakage pits on each property. Other stormwater was collected in roadside curbs and channels which discharged to larger soakage chambers located under roadways or in parks. Over time, most of the older private roof water soak pits have failed due to siltation and this water now discharges via the chamber overflow pipes into the roadside curb and channel.

The soakage chambers for curb and channel stormwater are simple vertical shafts and the stormwater receives no treatment prior to being piped directly to the soakage chamber. These chambers experience reduced infiltration capacity due to siltation and maintenance is required to break up layers of silt and debris that accumulate at the base of the chamber. In 1992, new subdivisions in Templeton were developed using soil adsorption basins. Based on past experience in the township, private roof soakage was not utilized and all stormwater is piped to an inlet which spreads the inflow across a soil adsorption basin, with rapid soakage overflow chambers at a raised elevation at a level which corresponds to inflows greater than 12.7 mm of rainfall over the catchment for each storm event (a typical value used to quantify first flush stormwater, which corresponds to 57% of Christchurch rainfall).

These soakage systems are working well, although their rectangular shape and concrete capping for the overflow chambers gave a very utilitarian appearance. This has been softened in recent years through landscape planting.

Future use of ground soakage–The Upper Heathcote catchment

The Upper Heathcote catchment occupies an area of around 2300 ha and comprises three main sub-catchments referred to as numbers 13, 14 and 15 (Pattle Delamore Partners Ltd, 1998b). A 50 year development scenario has been used to assess the likely effects of flood damage. The expected changes in stormwater runoff under this development scenario are listed in Table 2.

To preserve surface water quality and to avoid a worsening of flooding problems it is planned to deal with all stormwater disposal via ground soakage. Christchurch City Council stormwater reticulation systems are designed to cope with all runoff generated

Table 2 Upper Heathcote stormwater flows.

Subcatchment number	Percentage of impervious area: Present	50 year development scenario	Peak flow for 1 in 50 year storm: Present	50 year development scenario
13	31%	36%	3.7 $m^3 s^{-1}$	4.2 $m^3 s^{-1}$
14	12%	22%	4.9 $m^3 s^{-1}$	8.2 $m^3 s^{-1}$
15	22%	35%	5.0 $m^3 s^{-1}$	7.5 $m^3 s^{-1}$

by a 1 in 5 year storm. Therefore, groundwater soakage systems will be designed to routinely dispose of water from these storms. Catchments will also be designed to have secondary storage to contain runoff from larger storms and allow it to discharge to ground soakage after the storm peak recedes.

Based on the experience of Templeton, the following improvements are proposed:

- Private on-site roof soakage will not be utilized. Roof water will either be discharged to mix with other stormwater, or it will be collected into a separate reticulation system, which excludes other stormwater, to discharge into a Council maintained soakage chamber.
- Swales will be used as much as practicable to transport stormwater, providing infiltration, filtration and storage at the same time.
- Soil adsorption basins provide a storage area for stormwater which allows it to pass through a designed filter bed to provide adequate treatment of possible contaminants including metals, hydrocarbons, bacteria and suspended sediment. The filtered runoff then drains down to the water table. If the natural strata underlying the basin is not free draining then the filtered runoff can be collected by an under-drain system and passed to soakage chambers, where the treated runoff infiltrates into the groundwater system below the poor draining layer. Figure 2 shows the size of basin for various proportions of stormwater treated by soil adsorption (assuming 20 mm h^{-1} infiltration). It is proposed that basins will be sized to store the first 12.7 mm of stormflow before direct discharge to rapid soakage overflow chambers commences. Basin design will incorporate significant input from landscape architects with regard to their shape and planting.
- Overflow chambers are utilized when storms exceed the basin treatment design capacity. They include tamper proof lids which only allow direct inflow via an underflow weir, thereby providing protection against litter and floating contaminants.

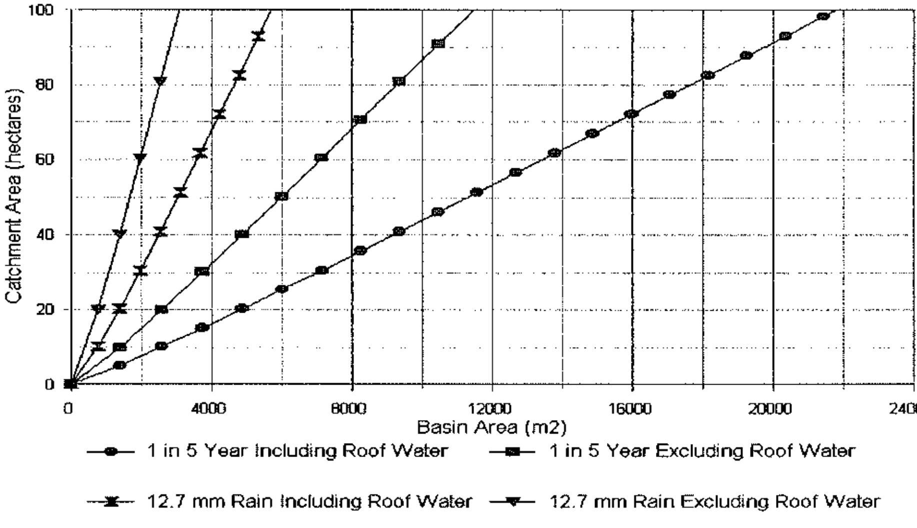

Fig. 2 Catchment area *vs* basin area for different treatment options.

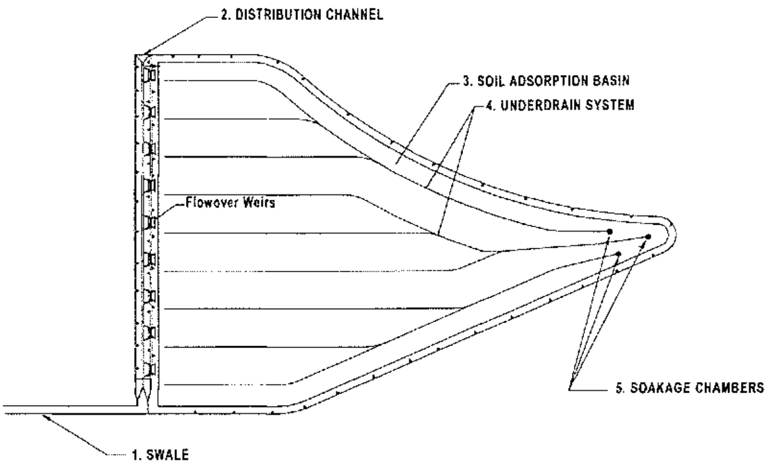

Fig. 3 Stormwater treatment and disposal system.

Figure 3 shows an example layout of these components. Each soil adsorption basin can be landscaped to provide a unique and aesthetically pleasing area, with the soakage chambers constructed as a raised mound which can be accessed from the side of the basin.

Site selection is a critical aspect for the successful implementation of these ground soakage systems. Guidelines for site selection encourage the following locations:

- Areas of free draining gravels and deeper water tables (as determined by investigative boreholes and field percolation tests).
- Areas where the basins can contribute to the catchment landscape and habitat plan, which encourages the creation of "green corridors".
- Sufficiently sized areas to allow easy access for maintenance.

The following areas will be avoided:

- Close proximity to water supply wells (to avoid contamination risks).
- Former landfill areas.
- Areas of low permeability and/or high water table.

The protection of public water supply wells has been assessed using groundwater contaminant modelling. This showed that faecal coliforms as an indicator bacteria was the critical parameter of concern due to direct entry into overflow chambers during low intensity (1.45 mm h^{-1}), long duration (72 h) storms. This could result in overflow discharges of up to 65 l s^{-1} for 63 h from a 100 ha catchment. Any contaminants which enter the aquifer system are attenuated within the receiving aquifer through the processes of dilution, dispersion, filtration, adsorption and decay. Provided sufficient separation is available to allow these attenuating factors to occur, then potential adverse effects can be avoided. A downgradient safe separation buffer of 800 m has been specified for the 100 ha catchment area scenario.

CONCLUSION

The alluvial plains of western Christchurch provide an opportunity to develop a comprehensive stormwater management system based on ground soakage. The separation of roof water and the treatment of remaining stormwater via swales and soil adsorption basins allows the stormwater to be used for aquifer recharge whilst mitigating flooding and surface water quality problems. With appropriate design and plantings, these systems can also contribute to the aesthetic enhancement of the urban environment.

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