PERFORMANCE OF BIORETENTION AREAS – THE CALIFORNIA EXPERIENCE

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ABSTRACT

In the last 15-years, the inclusion of stormwater treatment measures to passively treat rainfall runoff from developed areas in the State of California, the United States of America has become widespread. Stormwater treatment measures are intended to reduce impacts to downstream receiving waters to the maximum extent practicable for typical urban constituents such as; metals, fertilisers, and hydrocarbons that may comingle with rainwater during storm events and would otherwise be transported downstream.

In California, bioretention areas have become the preferred method of treating urban stormwater. Bioretention areas use planted media to slowly filter urban rainwater runoff and remove typical urban pollutants through uptake of nutrients, adsorption, microbial activity, decomposition and volatilisation before ultimately discharging into downstream receiving waters. Although originally intended to meet broad “Maximum Extent Practicable” stormwater performance standards, there has recently been greater interest in understanding how bioretention installations perform in regard to treatment of selected stormwater constituents, necessitating sampling runoff from constructed bioretention facilities. This paper summarises the findings of four case studies performed throughout the State of California in regard to removal efficiency of typical urban stormwater constituents based on variables such as size of installation, size of catchment, type of runoff, and catchment land use. The locations of the bioretention facilities are listed below:

- Serramonte Library, Daly City. Traditional Bioretention Facility at a Public Institution: One year of rainfall sampling performed by San Francisco Estuary Institute.
- Bayport, Alameda. Small Proprietary Bioretention Facility in a Residential Housing Development: Five years of sampling performed by ENGEO Incorporated.
- San Francisco-Oakland Bay Bridge. Regional Bioretention Facility for a State Highway: Three years of sampling performed by the California Department of Transportation.
- Heritage Fields, Irvine. Regional Bioretention Facility for a Residential Housing Development: One year of sampling for dry weather flows (urban non-stormwater runoff) by Irvine Ranch Water District.

Finally, this paper provides recommendations for policy makers and potential improvements to existing bioretention technology, based on the results of the study, in addition to wider applicability for bioretention utilisation in New Zealand.

KEYWORDS

Bioretention, Stormwater, Water Quality

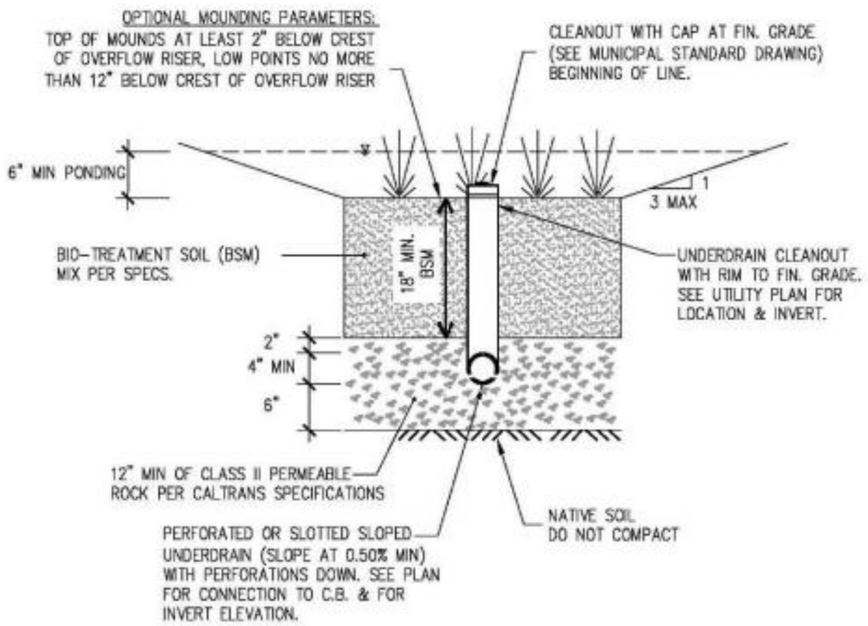
1 INTRODUCTION

Rainfall runoff from urbanized areas including streets, parking lots and rooftops is known to cause adverse water quality impacts in receiving water bodies (Dietz and Clausen 2006) and according to the United States Environmental Protection Agency (USEPA) is the leading cause of impairments to the nation's waterways (USEPA 2002), deteriorating water quality at local and regional spatial scales. For approximately 15-years, the introduction of low impact development (LID) stormwater infrastructure into new urban development projects has begun in the State of California, the United States of America, in order to mitigate concerns related to downstream receiving water impairment. Compared to traditional flood control engineering solutions that usually only address peak flow rates, LID and redevelopment infrastructure can be used to mitigate runoff velocity, runoff volume, and water quality across a range of flow rates (Dunnett and Clayden 2007), depending on the design of the stormwater facility.

Although various types of LID stormwater infrastructure can be implemented in new development, bioretention has become the preferred method of treating, and sometimes reducing, runoff for projects in the State of California. Bioretention areas were originally developed in the State of Maryland in the late 1980's to improve the quality of rainfall runoff discharging into the Cheasepeake Bay along the Atlantic Ocean. Bioretention areas use a planted sand media to slowly filter urban rainwater runoff and remove typical urban pollutants through uptake of nutrients, adsorption, microbial activity, decomposition and volatilisation. In areas where infiltration may occur, the facility may be designed to capture rainfall runoff and provide a source of groundwater recharge by letting stormwater directly percolate into the ground below the installation. However, for most applications, a subdrain is installed underneath the bioretention area in order to collect treated water underneath the planted sand media and discharge it into the downstream receiving water. Compared to wet ponds and engineered wetland LID systems, the ability of the bioretention facility to completely drain provides an easier maintenance protocol over the long-term, and reduces risk of vector issues or unintended creation of habitat for sensitive species.

A typical section of a bioretention area is shown below:

Figure 1: Typical Bioretention Section View (SCVURPPP C.3 Stormwater Handbook, April 2012)



Note that the bioretention soil mix specification used in the State of California is 85-90% sand, less than 5% clay, and less than 5% silt. The soil also includes 4 to 6 % (by dry weight) organic compost. The intended field infiltration rate is 5-inches per hour (127 mm per hour). The mulch layer is generally specified as an organic non-buoyant mulch. A widely accepted sizing method in California is to divide the maximum specified design storm intensity of 0.2-inches per hour for a flow through system by the 5-inch per hour soil mix infiltration rate, and multiply this ratio (4%) by the area of impervious surface in the catchment to be treated. This would yield a 40 m^2 bioretention area to treat a catchment area containing 1,000 m^2 of impervious surface. However, if erosion is a concern in downstream receiving waters, larger ratios can be specified.

Although their usefulness under a wider variety of conditions and over the longer term has yet to be studied comprehensively, results of water quality testing performed on several bioretention systems are beginning to become more available. This paper compares results of four pilot studies conducted in the State of California on bioretention demonstration projects, each with a slightly different objective. Deviations from the standards noted above in the pilot projects are noted accordingly. The goal of the study is to compare the results for several different independent variables (catchment size, land use type, etc), and provide any useful conclusions that may be used in a wider applicability for similar projects in New Zealand.

2 SELECTED CALIFORNIA PILOT STUDIES

2.1 SERRAMONTE LIBRARY, CITY OF DALY CITY, SAN MATEO COUNTY, CALIFORNIA

2.1.1 SETTING

This demonstration project was located at a library in Daly City, San Mateo County, CA, and included a 4,600 ft^2 (427 m^2) bioretention system comprised of four small cells which treat stormwater runoff from an up gradient parking lot and several sport courts. It was financed by San Mateo County through a local vehicle registration fee increase as one of a series of countywide stormwater demonstration projects. Additional funds were contributed from the City of Daly City, with the desire to beautify the library area. The project was built in September of 2009. The site is heavily used year round with an estimated 20,000 visitors per month. This high use rate and the library facility give the project high public visibility and provide a platform for outreach and education.

The project drainage area is approximately four acres (1.62 hectares) and includes a parking lot (70% of the drainage area) and recreation area (basketball and tennis courts and a community area that together account for 30% of the drainage area), all of which are impervious. Following local guidance provided by the San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook (San Mateo Countywide Water Pollution Prevention Program 2009), the bioretention system has a footprint size of approximately 4% of the impervious surface area located within the catchment and is divided into four separate cells (rain gardens) that receive runoff from different sections of the parking lot and adjacent recreation area. Note that storms with rainfall intensities greater than 0.2-inches per hour bypass the system and drain directly into the downstream storm drain system, as is typical for all of the projects included in this paper.

The bioretention areas constructed slightly varied from others studied herein, in that the surface layer consisted of an inorganic layer of pea gravel as opposed to an organic mulch layer used in the other pilot projects. This decision was largely made for two reasons: 1) The need to have a low maintenance facility where replacement of mulch would be infrequent, 2) The maritime weather pattern of the location, where temperatures seldom rise above 25 degrees Celsius; above this temperature the surface gravel layer may begin to absorb heat and affect plant health in the biofilter.

2.1.2 SUMMARY OF SAMPLING PROCEDURES

The project was sampled by the San Francisco Estuary Institute for two storm seasons in order to assess the efficacy of the system in removing several typical constituents of rainfall runoff from urban parking lots, including metals, total suspended solids (TSS), diesel and motor oil. Approximately 7 samples were collected in the downstream receiving water prior to the project being implemented and 12 samples were taken in the same location after full implementation of the system. Full results were published in a paper entitled Bioretention Monitoring at the Daly City Library, dated March 2011.

2.2 BAYPORT DEVELOPMENT, CITY OF ALAMEDA, ALAMEDA COUNTY, CALIFORNIA

2.2.1 SETTING

The Bayport Development project located in the City of Alameda, California, is located nearly adjacent to the San Francisco Bay. As part of informal agreement with the San Francisco Bay Regional Water Quality Board (SFBRWQCB), who oversee post-construction stormwater standards in the San Francisco Bay Area of California, the project applicant installed two Filterra™ units along a residential street and monitored them for five years starting in 2009. Filterra™ units are a commercial product, installed at the back of curb at storm drain catch basins, that mimic traditional bioretention post-construction stormwater best management practices. The units are designed to intercept low flows collected by a curb and gutter system up to a rainstorm intensity of 0.2-inches per hour. Larger flows bypass the system and are collected in the drainage inlet. The watersheds that are tributary to these units include rooftops, driveways, lawns and feeder streets that provide a variety of source stormwater constituents from a residential neighborhood. These locations were selected due to the relatively large tributary watershed areas at these particular drainage inlet locations.

The Filterra™ Units were sized according to the manufacturer's recommendation. Catchment areas were approximately 10,000 square feet (929 square metres) for each unit tested, and each catchment area contained approximately 80% impervious area.

The Filterra™ Unit uses a proprietary biofiltration mix which drains at a rate of approximately 100-inches per hour (2.5 metres per hour) as opposed to the much slower rate of 5-inches per hour used in a traditional bioretention stormwater system. This makes the system much smaller in footprint size since it operates much faster hydraulically. However, the Filterra™ Unit is fairly expensive as compared to a traditional system, and therefore these units are not considered economical for many projects.

2.2.2 SUMMARY OF SAMPLING PROCEDURES

Two Filterra™ Units were sampled by ENGEO Incorporated for five storm seasons (2008-2013) in order to assess the efficacy of the system in removing several typical constituents of rainfall runoff, such as metals, TSS, and nutrients from residential housing developments. Approximately 50 samples were collected in total from the upstream and downstream receiving water after project implementation. Results were furnished to the SFBRWQCB and compared to traditional bioretention systems based on available data collected locally, including the Serramonte Library project.

2.3 INTERSTATE HIGHWAY 80, CITY OF OAKLAND, ALAMEDA COUNTY, CALIFORNIA

2.3.1 SETTING

As part of the San Francisco-Oakland Bay Bridge Seismic Safety Retrofit project, which replaced a portion of the subject bridge after the 1989 Loma Prieta Earthquake, the California Department of Transportation (Caltrans) installed two bioretention areas alongside portions of the highway system in Oakland, California. Due to the locations of the units adjacent to the San Francisco Bay, a pump system was required to hydraulically lift storm drain runoff collected in a storm drain system below the highway up to a discharge point where it could flow through the systems and ultimately discharge into the Bay. The catchment area for the basins were both approximately 50-acres (20-hectares), about 90% of which is impervious area, typical of a highway system. The basins were sized at approximately 4% of the impervious area within the catchment using guidance from the SFRWQCB, such that the basins treat storms up to an intensity of 0.2-inches per hour (5.1 mm per day).

The bioretention areas were constructed in conformance with Caltrans standards and contain a minimum of 18-inches (0.46 metres) of biofiltration material below 2-inches (0.05 metres) minimum of planted mulch.

2.3.2 SUMMARY OF SAMPLING PROCEDURES

Sampling was conducted by Caltrans and the pilot project is on-going as of 2015. However, an interim report containing sampling data from two storm seasons in 2010 and 2012 has been released with seven total rain events being sampled for influent and effluent concentrations. The intent of the sampling program is to verify removal of heavy metal, nutrients, trash, pathogens, sediments, and hydrocarbons through the use of bioretention. It is noted in the Caltrans study that some of the water being passively processed in the bioretention systems is saline due to the close proximity to the San Francisco Bay.

2.4 HERITAGE FIELDS, CITY OF IRVINE, CITY OF IRVINE, ORANGE COUNTY, CALIFORNIA

2.4.1 SETTING

The Heritage Fields project is located in the City of Irvine in Orange County, California. The project is currently converting a former military air station into a mix of residential housing and commercial uses. In this portion of Orange County, a previously existing regional stormwater management plan for the Irvine Ranch Water District covered portions of the Heritage Fields project. According to the regional stormwater plan which has already been implemented in several developments, engineering wetland systems were the proposed method for treating stormwater and dry-weather runoff. As a demonstration project, the Heritage Fields project installed one bioretention area in lieu of a previously proposed engineered wetland system in order to assess its efficacy compared to the existing wetland systems in other portions of the regional stormwater master plan. The bioretention system was complete as of November 2014.

The tributary catchment area to the bioretention system is approximately 46 acres (19 hectares), of which 58% is considered to be impervious. Parks, streets and residential homes are located within the catchment area. The bioretention system was sized using a flow and volume sizing method making the footprint size a total of 0.5-acres (0.2-hectares), with the ability of the system to pond approximately 1-foot (0.3-metres) before discharging into a standpipe. This treats the volume of an 85th percentile rain event by either directly flowing through the sand media, or by ponding above the sand media after the sand is completely saturated and then flowing through the sand media as the pond draws down. Unlike the other two traditional bioretention installations included in this study, the Heritage Fields Project used a 24-inch (0.61-metre) depth of sand media per local requirements.

2.4.2 SUMMARY OF SAMPLING PROCEDURES

Sampling was conducted for the bioretention area by the Irvine Ranch Water District during the first year of operation. Due to concerns of impaired water bodies downstream, sampling was limited to dry-weather flows which, in this area, consist of excess irrigation water being used in landscape installations for the project and general irrigation. A total of six sampling events comparing influent and effluent were collected.

2.5 SUMMARY OF PILOT STUDIES

Table 2.5-1 summarises the pilot studies evaluated in this paper based on bioretention area and catchment characteristics.

Table 2.5-1 Summary of California Pilot Projects

Pilot Study	Size of Catchment	Biofiltration mix	Sizing method	Land Use of Catchment
Daly City	4 acres (1.62 hectares)	2-inches (51-mm) pea gravel over 18-inches (457-mm) biofiltration mix.	4% of catchment tributary impervious surface area.	Institutional Parking Facility
Bayport	10,000 s.f. (929 m^2)	2-inches (51-mm) organic mulch over 18-inches (457 mm) proprietary biofiltration mix.	Per manufacturer's recommendation. Less than 1% of catchment tributary impervious area.	Residential
Highway-80	50 acres (20.23 hectares)	2-inches organic mulch (51-mm) over 18-inches (457-mm) biofiltration mix.	4% of catchment tributary impervious surface area.	Highway
Heritage Fields	46 acres (18.62 hectares	2-inches (51-mm) organic mulch over 24-inches (610-mm) biofiltration mix.	Approximately 2% of catchment tributary impervious surface area with 1-foot (305 mm) of additional ponding.	Residential / Commercial

2.6 STORMWATER IN AUCKLAND, NEW ZEALAND (NOTES TAKEN FROM TP10 AND TR35)

In Auckland, New Zealand, it has long been recognized that stormwater runoff is a significant contributor to water quality and stream and coastal ecosystem health. The first "Stormwater Treatment Devices Design Guideline Manual" (TP 10) was developed in 1992 in response to issues related to stormwater runoff quality. Since then multiple updates have been made as increasing knowledge of impacts and methods of control have improved, resulting in the latest version published in 2003.

In August 2013, the "Auckland Unitary Plan stormwater management provisions: technical basis of contaminant and volume management requirements" (TR 2013/035) was published. This document reconsiders the performance requirements for the management of stormwater quality to include a broader range of constituents including metals (copper and zinc) and temperature in addition to total suspended solids (TSS). Additionally, rather than stipulating a removal percentage, design effluent quality requirements (DEQRs) have been identified based on the performance that can reliably be expected from stormwater treatment devices. Similar to California, bioretention has become one of the preferred methods for meeting the stormwater quality requirements within Auckland.

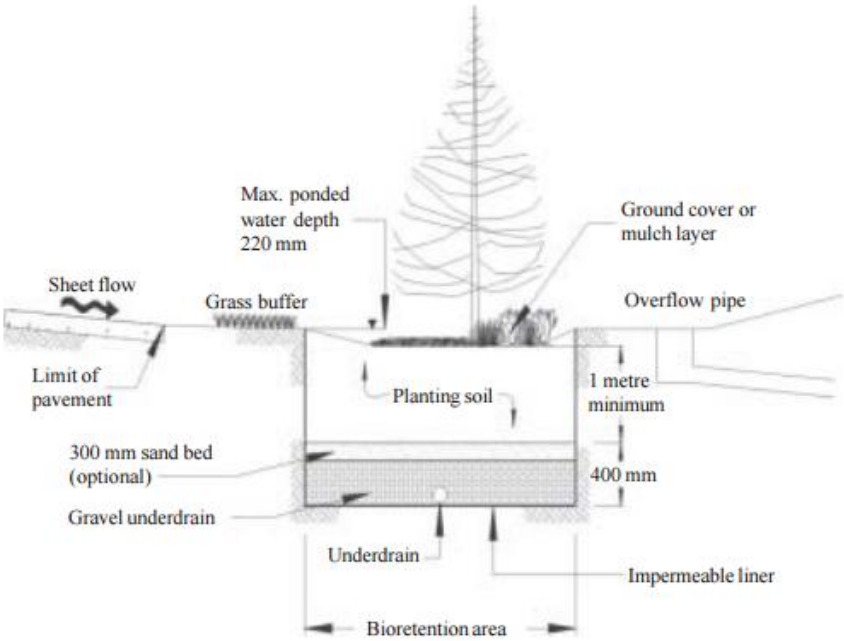
The current DEQRs listed in TR 2013/035 are provided in the Table 2.6-1 below.

Table 2.6-1: Stormwater Device Design Effluent Quality Requirements (TR 2013/035)

Name	Design Effluent Quality Requirement
Sediment	TSS < 20 mg/L
Metals	T Cu < 10 µg/L, T ZN < 30 µg/L
Temperature	Temperature < 25°C

While DEQRs have been revised recently, the bioretention design standards currently used are those outlined within the revised Technical Publication #10 published in 2003. That current design is shown on Figure 2 below.

Figure 2: Typical Bioretention Section View (Auckland Regional Council, TP 10)



It should be noted that there is a significant difference between the Auckland standard bioretention design and the California standard bioretention design. Table 2.6-2 below summarises some of these differences.

Table 2.6-2: Typical Bioretention Detail

Category	Auckland TP 10	California Typical Design
Planting soil depth	1 meter	0.46 meters
Gravel layer depth	400 millimeters	305 millimeters
Planting soil content	35-60% sand, less than 25% clay	85-90% sand, less than 5% clay, less than 5% silt; 4 to 6 % (by dry weight) organic compost
Recommended maximum drainage area	Less than 1,000 m^2	n/a

The recommended maximum drainage area specified in the Auckland TP10 document is 1,000 m^2. Of the pilot studies summarised in Section 2.6 above, only the Bayport project has a catchment area which meets this requirement. Additionally, the depths of the bioretention areas included within this study are all significantly less than what is specified within the Auckland TP10 document.

3 CONCLUSIONS

3.1 SUMMARY OF RESULTS

Table 3.1-1, 3.1-2 and 3.1-2 below summarises the results of the studies performed in California, referenced above, for three stormwater constituents of interest in New Zealand: Total Suspended Solids, Total Copper and Total Zinc.

Table 3.1-1 Summary of Results – Total Suspended Solids

Study	**Reduction Influent vs. Effluent (%)**	**Average Concentration Effluent (mg/L)**
Serramonte Library – Daly City	84	15
Bayport - Alameda	77	11
Highway 80 - Oakland	64	20
Heritage Fields - Irvine	80	3.15

All bioretention areas performed well in terms of removals of Total Suspended Solids (TSS), although only the traditional system studied in Daly City and the regional system studied in Irvine removed greater that 80% on average, which is a typical threshold used to evaluate the efficacy of stormwater systems (USEPA 2005). However, the average results from the propriety high flow system studied in Alameda were close to that value. The highway study suggested that a higher concentration of dissolved metal intake may occur in a catchment area comprised solely of a busy transportation corridor, and thus a proportionally less amount of sediment would be trapped in the bioretention area, reducing overall TSS reduction. In terms of comparison to recently considered Auckland standards, all bioretention systems would be at or below the 20 mg/L water quality objective for TSS regardless of size, soil mix material, or catchment area land use.

Table 3.0-2 Summary of Results – Total Copper

Study	**Reduction Influent vs. Effluent (%)**	**Average Concentration Effluent (μg/L)**
Serramonte Library – Daly City	83	7
Bayport - Alameda	78	6
Highway 80 - Oakland	66	9
Heritage Fields - Irvine	50	16

Much like TSS, all bioretention areas studies removed considerable amounts of Total Copper in each study. However, the studies with smaller catchment sizes performed slightly better. In terms of comparison to recently considered Auckland standards, only the regional bioretention area in Irvine was over the 10 µg/L water quality objective.

Table 3.0-2 Summary of Results – Total Zinc

Study	Reduction Influent vs. Effluent (%)	Average Concentration Effluent (µg/L)
Serramonte Library – Daly City	93	46
Bayport - Alameda	82	15
Highway 80 - Oakland	73	20
Heritage Fields - Irvine	73	12

In terms of total Zinc, all bioretention areas studied removed considerable amounts of Total Zinc. Interestingly, the Daly City project had a very high zinc reduction but still had the highest overall average concentration of total zinc effluent. Because the project served an institutional parking lot, the study suggests that parking lots are very high generators of zinc as compared to other land uses, including highways. In terms of comparison to recently considered Auckland standards, only the parking lot study area in Daly City exceeded the 30 µg/L water quality objective.

3.2 DISCUSSION

The paper attempted to compare four relatively different studies of bioretention areas in the State of California to provide any useful conclusions in regards to performance of the systems based on different independent variables. We note several conclusions based on this study.

1. Overall, the size of the catchment area does not appear to have a significant effect on the removal efficacy of the constituents studied above.

2. Proprietary bioretention areas appear to perform about as well as traditional system for the constituents studies.

3. Land uses may have an impact on the ability to meet Average Concentration Effluent objectives.

When comparing the bioretention designs used in the pilot studies to the standard detail currently used in Auckland, significant differences are evident in the depth of the bioretention area, the content of the soil mix, and the size of catchment areas. Considering the revised requirements for the management of stormwater contaminants in the Auckland Region, it is reasonable to assume that changes to the existing Stormwater Treatment Devices Design Guidelines will soon follow. While differences in rainfall patterns must be considered, this study shows that a reduction to the total bioretention area depth, changes to the planting soil composition, and an increase in the catchment area size may be made to the existing standard detail while still meeting the DEQRs outlined in TR 2013/035.

ACKNOWLEDGEMENTS

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