A COUPLED WETLAND BIOFILTER : THE BEST OF BOTH WORLDS

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ABSTRACT

This paper describes an innovative stormwater treatment solution that combines the low head loss, large catchment properties of a treatment wetland with the high treatment efficiencies of a biofilter to achieve a reduced footprint solution.

The future of our cities will see development encroaching into more and more constrained areas as they regenerate and intensify. The application of the solution proposed in this paper could be of considerable interest for highly urbanised areas where there are challenges of high contaminant loads from catchments with high imperviousness combined with limited space for stormwater infrastructure. The paper describes the design philosophy of the system and systems being constructed. It then sets out the design, assessment and consenting phases of a New Zealand brownfield application to demonstrate how the solution could be applied in a local context.

The treatment system includes forebays and wetlands to provide some treatment as well as volume above the wetland that increases the temporary storage volume that can pass through biofilters. This also allows the biofilters to be located higher, thus, potentially allowing filtration treatment to be achieved in areas that do not have enough hydraulic grade for a more conventional filtration approach. This aspect is particularly helpful when considering a future where climate change induced sea level rise is reducing the head available for treatment in coastal areas. The other advantage of having biofilters above and separated from the wetlands is that it prevents them from being subject to constant low flows that would see algae growth reducing infiltration rates. This can provide for better long-term performance and lower maintenance requirements for future asset operators.

The New Zealand application presented is a retrofit designed to treat 600 hectares of commercial development discharging to the Māngere Inlet in Auckland. According to the MUSIC modelling undertaken, the coupled wetland and biofilter devices can achieve 75%TSS removal in in an area equivalent to 0.9% of the contributing catchment. This is less than half the space required for a conventional wetland treatment system using current Auckland guidelines. Further, the devices can treat a range of other contaminants, including intercepted leachate from adjacent landfills and they have been designed to integrate into a landscaped environment. The proposed application was designed as part of the NZ Transport Agency's East West Link project in collaboration with Auckland Council. It was part of a successful application for resource consents with the Board of Inquiry decision noting that the stormwater measures incorporated for the wider catchment would be *"expected to enhance the mauri of this water body and help to restore the mana of the wider area"*.

KEYWORDS

Water quality, MUSIC, wetlands and biofiltration

PRESENTER PROFILE

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1 INTRODUCTION

Many of our urban areas and stormwater management systems were developed long before stormwater quality treatment was common practice leaving legacy water quality issues. Retrofitting stormwater quality treatment into historically developed areas has a different set up challenges than incorporating treatment into a greenfield development

1.1 LEGACY WATER QUALITY ISSUES

Stormwater quality effects occur when particles from car exhausts, tires and brakes, silts and oils from urban activities collect on roads and hard surfaces and are washed off during rain events. Historically there were few barriers placed between contaminant sources such as roads or industrials sites (subject to say, hydrocarbon accumulation at refueling pads) and the pipe network that deliver runoff to the receiving environment.

Water quality can be affected by contaminated groundwater making its way into stormwater pipe networks. This can often occur through aged, cracked pipes. Historic activities may have led to areas of contaminated land. These areas could be poorly managed or uncontrolled landfills, major spills or the sites of old industries where chemicals were stored or used in processes. The types of potential contaminants can be very broad and may, for example contain metals or phosphorus. Degrading or unpainted galvinised steel roofs, as were once common in many New Zealand industrial buildings can contribute to elevated zinc concentrations in stormwater. Further, older areas are more likely to have wastewater cross connections, overflows and illegal connections which contribute to fecal coliform and ammonia contamination in stormwater.

Accumulation of contaminants in receiving waters and changes to the chemical make-up of stormwater affect water and sediment quality and can then have a significant effect on aquatic ecosystems.

1.2 CHALLENGES WITH TREATING DEVELOPED AREAS

Limited space is key. Water quality treatment devices all need space to operate; both horizontally and vertically and typically land area in developed parts of cities are highly sought after and well used leaving little space for stormwater quality devices.

Typical stormwater treatment devices currently installed in Auckland can range in area between 2% of the contributing catchment up to as much as 10%. These are devices such as biofilters (also known as raingardens), ponds, wetlands and swales, infiltration trenches. The total area a treatment device takes up is typically greater than that required for the treatment itself due to factors such as providing safe maintenance access, accessible and stable batter slopes or retaining structures and providing for bypass flows.

Most treatment devices need hydraulic grade (or driving head) to operate. Biofilters and most proprietary filtration devices rely on runoff being driven down through media and can typically requite half a metre to a metre of head. Swales rely on gravity to operate and infiltration trenches rely on storage volume being available above groundwater levels. Only ponds and wetlands require low head to operate but they still do need a depth of water for storage to allow settlement of contaminants and support plant growth

It is rare to find unoccupied space at a suitable level to support treatment devices in a developed catchment. What makes it particularly challenging is that space, where available, must be located in the right place; that is, downstream of contaminant sources and at suitable levels. Many of the contaminant sources are diffuse (groundwater borne contaminants, un-recorded wastewater cross connections), the right place is often right at the bottom of a catchment. This is also where there is likely to be little hydraulic grade available.

The challenges of retrofitting stormwater quality treatment are not only technical. Many developments and industrial operations have what amounts to existing-use rights meaning the obligation to treat or otherwise manage stormwater contaminants is not likely to be triggered unless a change in activity occurs that requires a resource consent. Land that is privately held cannot always be accessed easily either for temporary or permanent occupation for stormwater works. Obtaining funding for retrofit solutions may not be so straightforward as in new developments where local authorities can use development contributions or direct developer funding.

1.3 THE FUTURE OF DEVELOPED AREAS

There is a trend towards regeneration or intensification of residential urban areas in many parts of Auckland. While intensification can put additional strain on stormwater infrastructure through increased runoff, it can also offer the opportunity or resource consent triggers to promote stormwater solutions or to incorporate better source control measures. Housing New Zealand and HLC's Auckland Housing Programme is an important example in which some 18,000 homes will be added to developed areas in the Auckland Isthmus over the next decade or two. Industrial and commercial areas in Auckland do not have the space to intensify that residential areas do. What can be expected over time is that changes in use can trigger better onsite management practices however this tends to be on a piecemeal fashion.

Climate change is predicted to impact on many of Auckland's urban areas. Sea level rise will see a reduction in the hydraulic grade available in stormwater systems near the coast, exacerbating the constraints of low head available in existing networks to retrofit treatment devices.

2 THE WETLAND BIOFILTER CONCEPT

2.1 BIOFILTER

Biofilters (often called raingardens) are commonly used in Auckland and many other urban areas. They are vegetated soil filtration systems that provide efficient sediment and nutrient removal from stormwater. Stormwater flow is directed down through filtration mediate (for example loamy sand) which also supports vegetation. Treated runoff is collected in perforated subsoil drains in the base of the biofilter to be conveyed to discharge points. Contaminants are retained in the system through enhanced sedimentation, fine particle filtration, biological uptake in the vegetation and associated biofilms and biological processes in the soil profile.

They are surface fed devices and are best suited to dispersed or sheet inflow. Inflows need to be to spread out across the media surface to make best use of it and point flow can cause local erosion or scour problems within the device. They do require a driving head to operate.

Biofilters require some reasonably frequent inflow to retain plantlife but they do not stand up well to continuous inflows which can result in surface clogging and filming. To get the right cycle of wetting and drying for a biofilter, contributing catchments are best kept to less than 20 or 30 hectares and individual devices to less than 1,000m^2.

Biofilters are relatively small footprint devices in the right conditions and are effective for a wide range of contaminants. Auckland Council's current water quality treatment device guidelines result in biolfilters that are 2% of the area of the contributing catchment.

2.2 WETLAND

Wetlands are permanent shallow water bodies that are extensively planted. They are configured to slowly pass flows over 2 to 3 days using controlled outlets. Wetlands are shaped with internal bunds or even walls to provide relatively long flow paths. Length to width ratios are greater than 7 to 1. Some 80% of the wetland area is vegetated with depths undulating to provide suitable conditions for a range of plants. Plants are arranged in band perpendicular to the main flow paths and use a diversity of plants.

Forebay ponds are provided at the head of the wetland, often with gross pollutant traps and or other mechanisms to trap littler and floatable debris as well as remove an amount of the coarser solids entrained in stormwater. These measures protect the downstream vegetated portion of the wetland to achieve a longer life. Forebays also offer the opportunity for spills (such as hydrocarbon spills on roads draining to the wetland) to be contained before reaching and damaging the main body of the wetland.

Wetlands have the advantage of being low head devices. They do require a reasonable sized catchment to maintain a permanent pool of water so don't suit catchments smaller than 20 or 30 hectares. Wetlands have a surface area of at least 2 to 3% of the contributing catchment with the total required area including allowances for access and safe batters.

2.3 COUPLED WETLAND BIOFILTER

2.3.1 CONCEPT

The coupled wetland biofilter is designed to have both the low head properties of a wetland and the small footprint, high performance of a biofilter. It is essentially a wetland and a biofilter constructed immediately adjacent to each other with the two devices separated with a bund, timber weir or similar. Figure 1 is sketch plan showing the concept in early stages of development.

Figure 1: Sketch plan showing development of coupled wetland biofilter concept

Figure 2: Coupled wetland biofilter cross section

Stormwater enters the wetland forebay where coarse sediment settles out. Flows continue on through the main body of the wetland. Baseflows and small storm events will be treated this way, bypassing the biofilters. In larger rainfall events, water levels build up in the wetlands. When it gets high enough it spills over into the biofilter areas. As water levels continue to build up, water can pond across both the wetland and biofilter becoming a shared storage area for both devices which both operate until water levels recede.

By using the wetland to build up water levels, a head is created to drive runoff through a biofilter. This can make biofiltration a viable mechanism for treatment in a situation where a surface fed gravity flow into biofilters is difficult to achieve. The wetland keeps baseflows out of the biofilter reducing surface clogging and film buildup in the biofilter. The system is capable of turning a point inflow into the wetland into a spread weir flow in the biofilter, thereby avoiding the performance and scour problems associated with point inflows in biofilter.

Of particular importance for treatment efficiency is the space above the wetland as ponding storage for the biofilter. This effectively makes the biofilter work harder during and soon after storm events. Treatment through a wetland generally takes 2-3 days whereas a biofilter can treat flow in a matter of hours. Therefore, during a storm event, when the system is full, the vast majority of ponded water flows out through the biofilter receiving efficient treatment. Using this technique the total footprint of the treatment system can be smaller than either wetlands or biofilters acting in isolation.

2.3.2 PERFORMANCE

Performance of a coupled wetland biofilter system can be assessed using a simulation tool such as The Model for Urban Stormwater Improvement Conceptualisation (MUSIC).

A continuous modelling approach simulates the effect of antecedent rainfall patterns, interactions between the different treatment systems (that is, when the wetland overtops to the bioretention) and to simulate the processes of treatment that occur with frequent rainfall events. It is the frequent rainfall events that carry the majority of annual pollutant loads. The model assumes typical contaminant loads from industry understanding of stormwater quality taking account of the different types of land-use in the catchment. MUSIC simulates the interaction between treatment devices and pollutant generation and removal at each time step to provide a thorough assessment of the pollutant removal process. MUSIC has been developed over more than a decade as is based on thorough research results from the last 18 years on the pollutant removal performance of different treatment systems.

In order to compare the performance of a coupled wetland biofilter to other methods common in Auckland, a Total Suspended Solids (TSS) removal rate of 75% has been considered. Concept designs developed for the Māngere Inlet foreshore as described in Section 4 were simulated in MUSIC as were conceptual conventional wetlands. The results suggest that the total footprint of the coupled wetland biofilter could be less than half the size of wetland alone (Figure 3) or less than 1% of the contributing catchment compared to 2% for a conventional wetland alone.

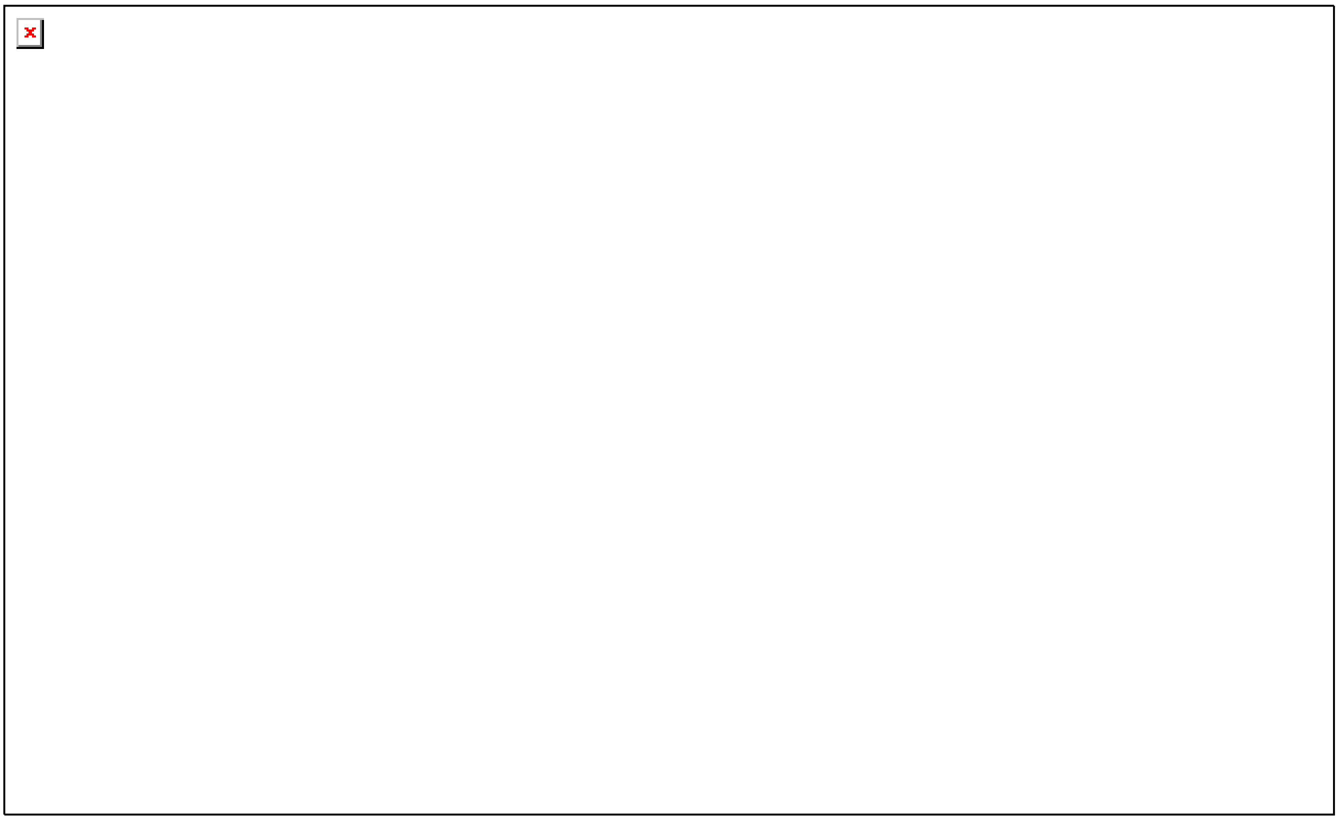

Figure 3: Predicted TSS removal

3 EXAMPLE INSTALLATIONS

3.1 COMMONWEALTH VILLAGE, GOLD COAST

The Commonwealth Games village in the Gold Coast which was constructed for the 2016 games includes a large biofilter that shares extended detention storage with a large sediment pond. The system is made more effective by using the extended detention storage over the pond for treatment through the biofilter. This system appears to be operating effectively but no water quality testing has been performed.

Figure 4: Large biofilter at the Gold Coast commonwealth games village where extended detention is shared with an inlet pond and biofilter surface

3.2 UNITY PARK, ADELAIDE

A similar installation of biofilters in Unity Park, Adelaide has been operational for more than eight years and has had extensive monitoring performed. Refer to Kerrigan et al. (2014) for more details. The biofilters process much more water put through it compared to a conventional biofilter because it is part of a stormwater harvesting scheme. The system has a sediment pond that captures flow during storm events and then releases the flow slowly into a series of six $200m^2$ biofilters. In this way, the biofilters are acting in the same manner as the coupled wetland biofilter treatment system described in this paper.

The performance of the system has been monitored with continuous flow and turbidity sensors coupled with regular storm event and grab samples. The results show that the biofilters have continued to treat the stormwater to consistently less than 5 NTU and have flows rates in the order of 4-7 L/s per $100m^2$ of biofilter (more than 20 times faster than wetlands).

The system continues to be monitored as it is part of an aquifer injection scheme and therefore is subject to stringent environmental regulation. The system continues to show good performance for both water quality improvement and flow throughput. The continued success of the Unity Park system provides evidence that the concept of passing more water through a biofilter compared to a conventional biofilter does not compromise its treatment performance.

Figure 5: Unity Park biofilters

Figure 5: Unity Park biofilters Water quality results (TSS and turbidity) from six biofilter cells at *Unity* P*ark*, Adelaide (labelled H, L, HS, LS, HSC & LCS) *with more loading than conventional biofilters*

4 MĀNGERE INLET NORTHER FORESHORE

4.1 EXISTING STORMWATER SYSTEM AND QUALITY

Onehunga and Penrose are long established urbanised catchments of industrial and commercial activities that currently drain through pipes directly into the Māngere Inlet without treatment. There are few stormwater treatment devices in the catchment with most of the stormwater runoff currently untreated. The overall catchment potentially discharging to the foreshore area is approximately 1350 Ha. Of this, approximately half drains to soakage. The remaining half is serviced by the stormwater pipe network which drains to 11 outfalls sitting at about mean sea level (current climate) along the foreshore as shown on Figure 6. Opportunities to provide stormwater treatment for the Onehunga and Penrose catchments are limited.

Information available indicates that stormwater quality is likely to be at least typical of an untreated developed catchment in Auckland and potentially worse in terms of the stormwater contaminant type and load such as TSS and metals. Elevated faecal coliforms and ammoniacal nitrogen levels indicates wastewater cross connections and overflows within the stormwater network and potentially leachate ingress. There is a widespread legacy of contamination, including several coastal reclamation sites that were historically used for landfills and uncontrolled filling. There is a possibility that some of the legacy landfills along the foreshore are leaking leachate into the stormwater network (as well as into groundwater system) and to Māngere Inlet.

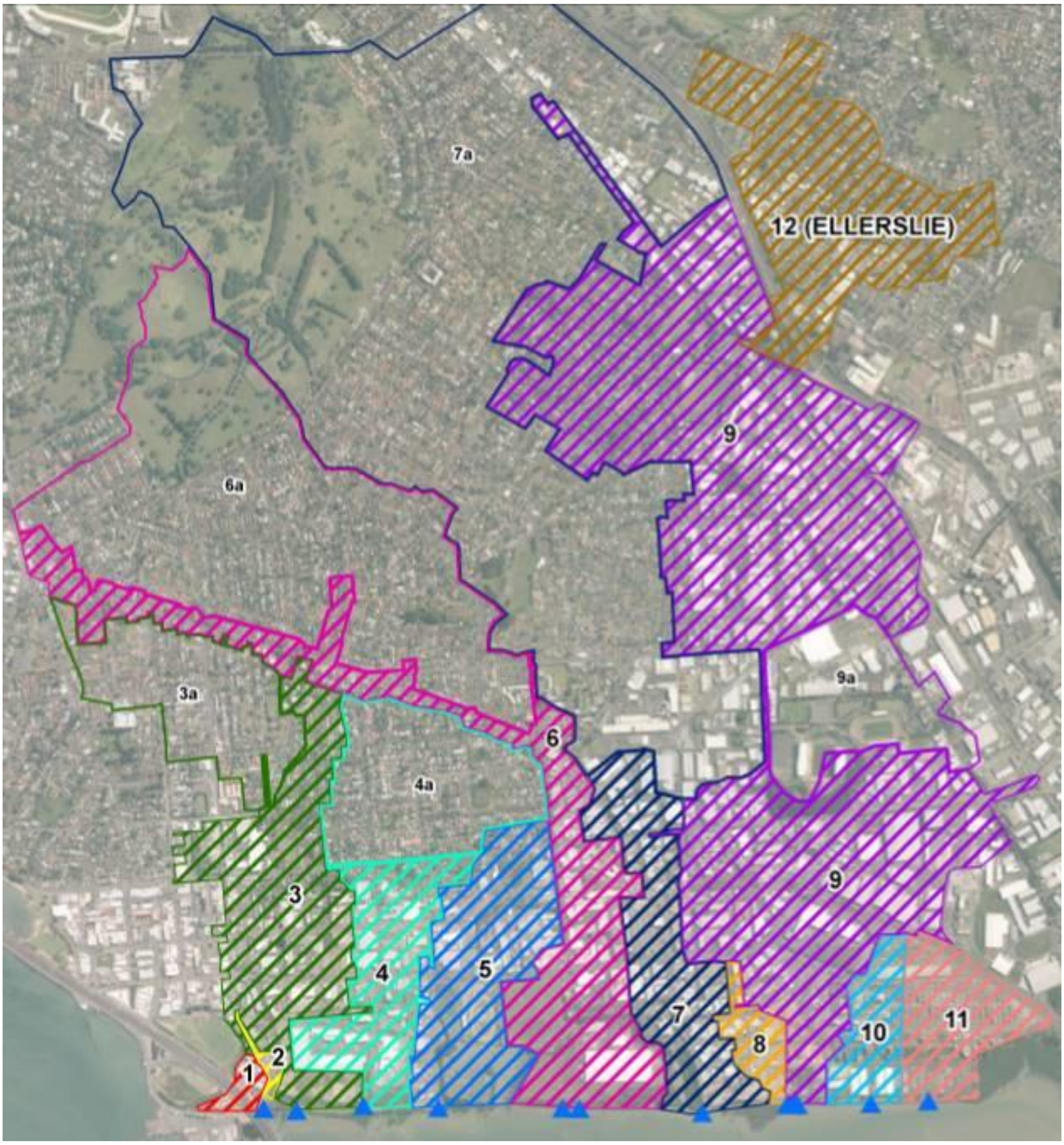

Figure 6: Māngere Inlet Northern Foreshore stormwater catchments

4.2 EAST WEST LINK

The East West Link is a potential road connecting State Highways 20 and 1 that skirts along the Māngere Inlet foreshore. Locating the road embankment along the foreshore presented a unique opportunity for stormwater runoff from the wider Onehunga - Penrose catchment to be captured and treated. An agreement in principle between the New Zealand Transport Agency (who would construct and operate the road) and Auckland Council was made to include treament in the East West Link Project for those upstream catchment flows as an overall environmental benefit. The stormwater treatment systems presented in this paper were designed as part of the East West Link project and were part a successful application for resource consent for that project.

4.3 MĀNGERE INLET CONCEPT TREATMENT SYSTEM

Stormwater treatment systems were designed to be integrated into a landscape edge treatment that restored a naturalised shape and provide public access to the foreshore. The treatment areas are located and shaped to avoid areas of higher existing natural character and ecological value, principally the two volcanic outcrops which remain along the foreshore and Ann's Creek.

Figure 7: Māngere Inlet concept plan showing foreshore stormwater treatment areas

The concept system comprises approximately 6 hectares of treatment area which caters for the 657 hectare contributing catchment. Three lined stormwater treatment areas on reclaimed land in the coastal marine area comprise freshwater treatment wetlands and biofiltration systems. An outer bund around each provides separation between the freshwater treatment system and marine environment. There are also two lined stormwater treatment areas on the landward side of the reclamation. These are the conversion of Miami "Stream" to a treatment area comprising a freshwater wetland biofiltration system, and a forebay and biofiltration system in the "triangles" formed at the intersection of Galway Street and the East West Link alignment.

Figure 8: Māngere Inlet concept treatment area integrated with coastal landscaping

MUSIC modelling shows the system would result in in significant reductions to the quantity of suspended solids, metals, hydrocarbons and coliforms discharging via stormwater with respect to current discharges. For the approximately 657 hectares affected, the following changes to long term annual average contaminant discharge are predicted:

- A reduction in total suspended solids from 870 to 210 tonnes per year (a 75% reduction);
- A reduction in total nitrogen from 19 to 10 tonnes per year (a 47% reduction);
- A reduction in total zinc from 2.67 to 1.17 tonnes per year (a 56% reduction); and
- A reduction in total copper from 0.24 to 0.08 tonnes per year (a 66% reduction).

In addition, the treatment systems offer treatment of wastewater contaminants that enter the stormwater pipe network, increased resilience to contaminant spills in the catchment, reduction in contaminants reaching Māngere Inlet through groundwater as it attenuated through the road embankment and the opportunity to passively treat intercepted leachate from closed landfills which is now being pumped to the wastewater system.

While the hydraulic barriers created between the land and coast provide the means to contain and treat stormwater, they do introduce a challenge in terms of discharging flood waters as does the need to prevent saltwater entering the freshwater treatment areas. To manage this, a system of pipe networks with internal weirs, gate valves and pumps for water quality flow is proposed to manage the range of runoff and tidal events anticipated. The system is to be constructed so that it can be adapted for climate change (in particular, sea level rise) over time.

5 CONCLUSIONS

A coupled wetland biofilter system can present advantages over standalone wetlands and biofilters including smaller footprint, lower driving head requirements and suitability for large catchments (unlike biofilters). These attributes can provide increased treatment opportunities in developed catchments where space is limited and where hydraulic grade is limited and being reduced by climate change sea level rise.

Assessment of a concept system for the Māngere Inlet northern foreshore demonstrates that coupled systems can achieve 75%TSS removal in in an area equivalent to 0.9% of the contributing catchment; less than half the space required for a conventional wetland treatment system.

The main components to consider in design and implementation are how extended detention volumes are shared across both wetland and biofilter components within the site depth and head limitations as well as keeping baseflows out of the biofilters. This requires careful consideration of wetland outlet configuration and appropriate sizing of the overall footprint. In coastal applications, avoidance of saltwater intrusion is important.

Figure 1: Artists impression of the northern foreshore of Māngere Inlet with East West Link Road the stormwater treatment systems in place.

ACKNOWLEDGEMENTS

New Zealand Transport Agency

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