

GEOG402

A Future for the Avon River

Improving water quality and management



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Abstract

The Avon Otakaro network is a community driven organisation who wish to see the land within the Avon Residential red zone become a successful ecological and recreational reserve. The Avon River, a significant feature within the red zone, has become a key focus, with particular attention being drawn to improving water quality. Following their establishment in the late 19th century, the Christchurch Drainage Board split the city's wastewater and stormwater into two separate components, where the wastewater was sent to Bromley for treatment, whilst stormwater was simply piped into the nearest river source. As a result of this split and a growing city, Christchurch's waterways, particularly the Avon River, have become increasingly polluted. Subsequently, the main focus of this study was to assess the potential of and likely land requirements for constructed wetlands in the Avon red zone as a means of treating stormwater before it enters the river, thus improving water quality and ecological health in the river environment. Consideration was also given to examining wider community support for and opinions surrounding the project. Various methods were utilised including: modelling to assess size and location requirements for potential wetlands, some use of GIS and focus groups to engage with the community.

Introduction

Following the establishment of the Christchurch drainage board and the division of Christchurch's wastewater and storm water, where the storm water was piped straight to the nearest river source whilst waste water was sent to Bromley for treatment, pollution of Christchurch's urban waterways has continued to become a growing issue (Wilson, 1989). As a consequence of the devastating earthquakes that struck Christchurch in 2010 and 2011, the Avon Otakaro network was formed; a network of people and organisations throughout Christchurch who wish to see the red zone land along the Avon River become a successful ecological corridor. One of the key objectives of the network, alongside establishing an ecological corridor within the red zone, is to make improvements to the health and water quality of the Avon River.

Consequently, the Avon Otakaro Network wished to identify the types of treatment options that could be incorporated into the Avon corridor and the likely associated land requirements. As a result, the focus of this study was to assess the potential for constructed wetlands in the red zone, including the assessment of factors such as feasibility, land requirements and community support. A variety of methods were used to do this, including wetlands modelling to estimate the required size of the wetlands to treat Stormwater before it enters the river, GIS to examine where these wetlands will lie spatially within the red zone, and finally community consultation to assess support for the wetlands concept within the red zone.

Background and Context

Avon Residential Red Zone

Following the earthquakes that struck Christchurch during 2010 and 2011, a substantial amount of land surrounding the Avon River was deemed not economically viable to rebuild on; thus the Avon residential red zone was formed (Figure 1). As residential development is no longer permitted in this area, and most of the previous residents have now left, the biggest concern should now be turned to flood risk and the impacts flooding could have on the communities surrounding the red zone. Consideration of these impacts is also important when planning for future land use within the red zone. Basic infrastructure such as storm water and waste water pipes in the area are now no longer serviced and surplus to requirement; consequently these pipes would either need to be left unused or removed and utilised for a different purpose.

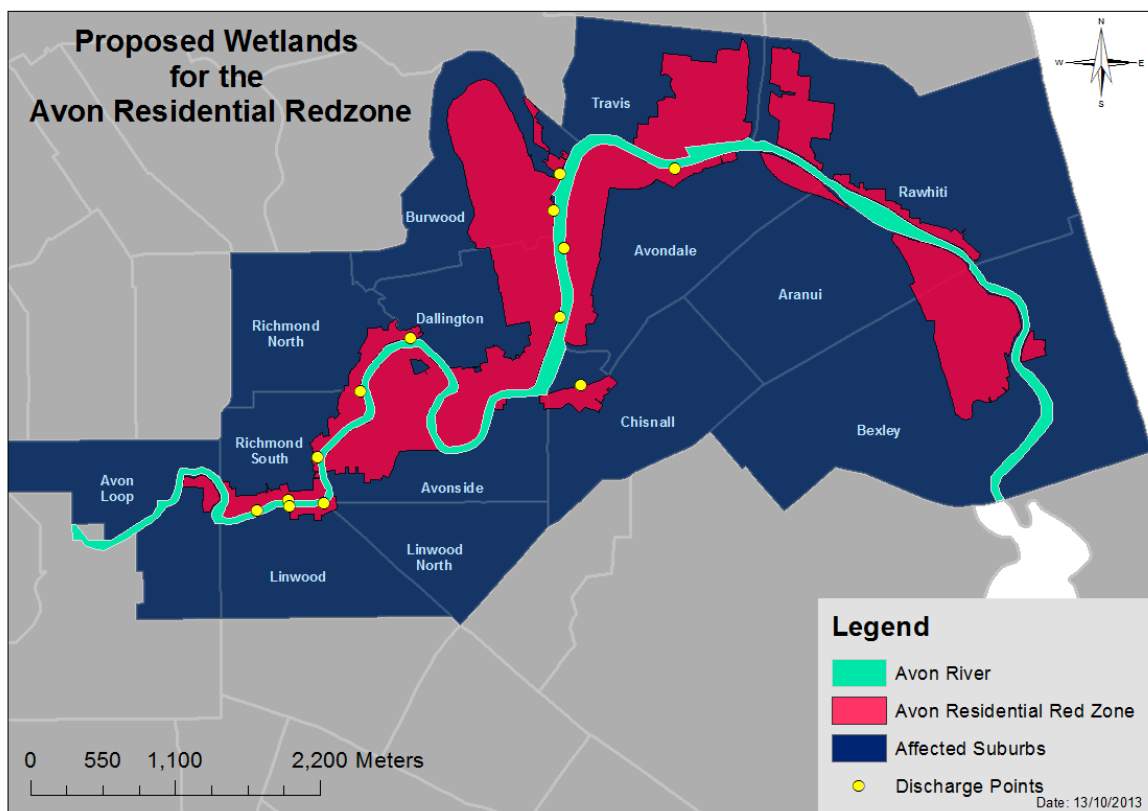


Figure 1: Map of the Avon Residential Red Zone and affected suburbs

Note: The discharge points that can be seen on the map above represent points where storm water is currently piped directly into the Avon River

Avon Otakaro Network

Subsequent to the establishment of the Avon River red zone, the Avon Otakaro Network was formed; a network of Christchurch residents and organisations committed to seeing the Avon River red zone become a successful ecological corridor and recreational reserve (Avon Otakaro Network, 2011). Through working in conjunction with other groups throughout Christchurch and consulting with organisations such as the Christchurch Earthquake Recovery Authority (CERA) and the Christchurch City Council (CCC), their key aim is to help shape the future of the land surrounding the Avon River (Avon Otakaro Network, 2011).

Flood Risk in the Red Zone

One of the key reasons for the establishment of the Avon Residential red zone, aside from the likely cost of residential redevelopment, was the increased flood risk in the area following the earthquakes. Figure 2 summarises the flood risk within the area as well as the location of the red zone, outlining the importance of understanding these risks when making land use decisions for the red zone land. Whilst improving the water quality and health of the Avon River is undoubtedly important, it is also vital to address the potential flood risk within the Avon residential red zone, and identify ways to either mitigate or minimize the impacts flooding would have on the area. The Dudley creek catchment would also need a large amount of upstream treatment systems to remove contaminants before they enter streams. These could include rain gardens or infiltration strips that could treat contaminants, particularly those coming off roof surfaces.

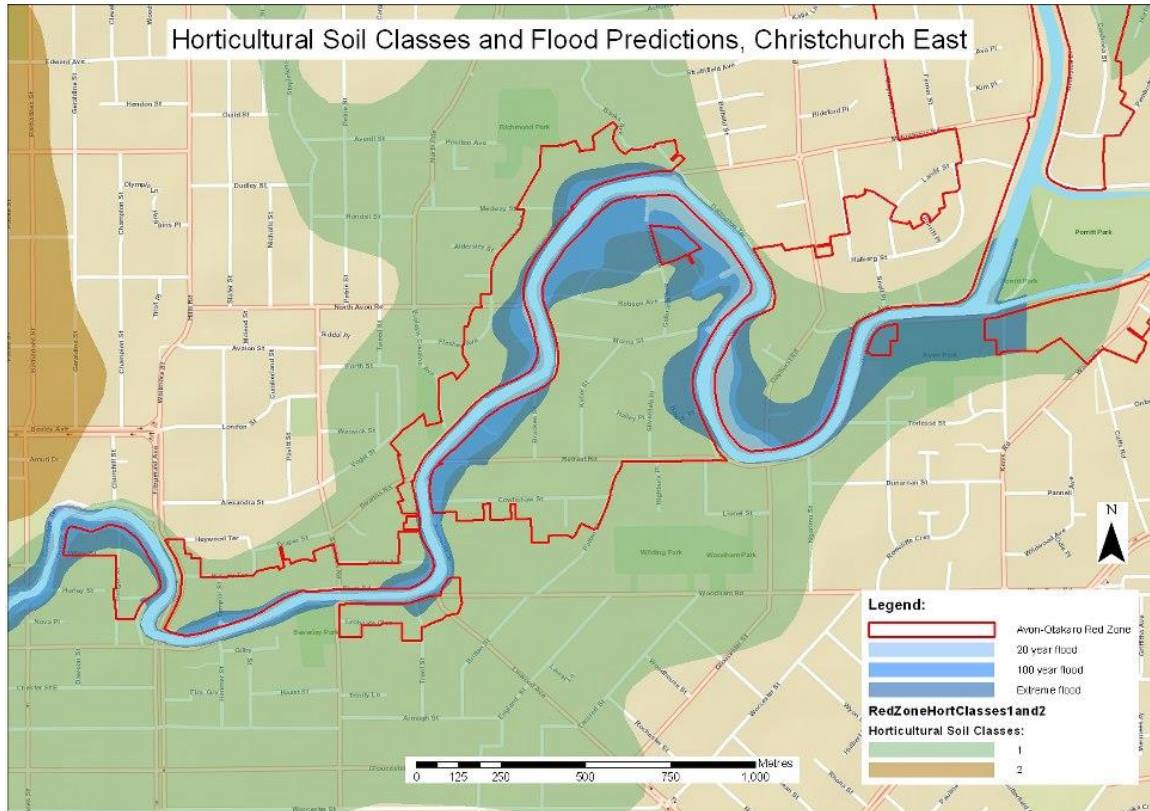


Figure 2: Flood predictions for Christchurch east following a 20 year, 100 year and extreme flood

Source: Paul Goodhue

Contaminant Concerns

In the late 19th Century, the Christchurch drainage Board was established to minimise the impact of flooding and health risks throughout Christchurch that were occurring due to a lack of water treatment and drainage (Wilson, 1989). The drainage board split waste water and storm water into two separate components; wastewater was sent to Bromley for treatment, whilst storm water was simply piped to the nearest river source. As the city’s population grew, an increase in housing and roads significantly contributed to an increase in the quantity of stormwater seen throughout the city. Consequently, Christchurch now has urban waterways that are highly polluted, particularly with heavy metals as a result of increased roof and road stormwater runoff. However, following the establishment of the residential red zone, there is the potential to use the vacant land to treat the stormwater before it enters the river, thus to a certain degree remediating some of the damage that has occurred in the past.

A Greener Christchurch

Following the earthquakes in Christchurch, urban revitalisation and regeneration have become terms frequently used and heard; a key component of which is the incorporation of more biophilic elements throughout the city. The 'Share an Idea' campaign got a strong response in terms of people wanting to see the city become greener; suggestions such as: "integrate nature within the urban form: expand riverside greenspaces, link with green pockets elsewhere, re-create native ecosystems" were common (Christchurch Central Development Unit, 2012). Beatley (2011) drew attention to the fact that biophilic cities treasure the nature that already exists within a city, but also put a substantial amount of effort, energy and time into repairing and restoring what has been degraded or lost. With this in mind, it is imperative to highlight the importance of the work the Avon Otakaro network is putting in towards restoring the Avon River corridor and the contribution this would make to Christchurch becoming a biophilic city. Restoration through means such as the implementation of constructed wetlands would not only contribute to improving the health of the Avon River, but also cultivating the biophilic image of Christchurch and satisfying public requests expressed through the share an idea campaign, particularly in terms of the re-creation of native ecosystems.

Ecosystem services

Defined as "the conditions and processes through which natural ecosystems, and the species which make them up, sustain and fulfil human life" (Daily, 1997), ecosystem services comprise an important component of the ways in which humans interact with surrounding natural environment. Ecosystem services can be broadly categorised into four different groups: those used for provisioning, such as food, water, fuel and fibre; regulating services which encompass the prevention of soil control and flood mitigation and management amongst others; supporting services including soil formation, nutrient cycling and the formation of oxygen from photosynthesis; and finally cultural services such as recreation and spiritual values and sense of place (Tallis & Kareiva, 2005). Although ecosystems services are an important constituent in the sustaining of human life, until recently they have certainly been taken for granted. It is now thought that well over half of the world's ecosystems that provide services have become significantly degraded as a result of unsustainable use (Tallis & Kareiva, 2005). It has been suggested that the relationship between human beings and nature lies at the core of sustainability (Edwards, 2005). Humans heavily depend upon nature survival (Edwards, 2005); thus including nature and the preservation of ecosystem services within planning, development and management frameworks is fundamental to the notion of sustainable development.

Although the services in which ecosystems provide can be broken up into four categories, in most cases a single ecosystem is able to provide a number of services from the various different classifications. Whilst the values of the individual services may be minor in some cases, when synthesised there is certainly potential for the total value of the ecosystem to be significant (Bolund & Hunhammar, 1999). Figure 3 below outlines the different services several ecosystems can provide, which can lead to conclusions being drawn surrounding the value of each ecosystem. It should be noted, as it is particularly important to the context of this research, that wetlands appear to be the most valuable ecosystem as they can contribute to all services, whereas the other ecosystems investigated cannot. Furthermore, a recent study undertaken by Lincoln University that sought to place economic value on the different components of the proposed river park and corridor, found that constructed wetlands within the Avon Residential red zone would have substantial economic value. Measured on the annual value of benefits to Christchurch residents, it is expected that the incorporation of ecosystem services within the red zone would likely have a value of approximately \$8.8 million per year; this was based on services such as improvements to water quality, flood mitigation and stormwater management (Vallance & Tait, 2013).

	Street tree	Lawns/parks	Urban forest	Cultivated land	Wetland	Stream	Lakes/sea
Air filtering	X	X	X	X	X		
Micro climate regulation	X	X	X	X	X	X	X
Noise reduction	X	X	X	X	X		
Rainwater drainage		X	X	X	X		
Sewage treatment					X		
Recreation/cultural values	X	X	X	X	X	X	X

Figure 3: Urban ecosystems generating various different services (Bolund & Hunhammar, 1999)

Objectives

As discussed above, the pollution of urban waterways throughout Christchurch, particularly the Avon River has become an increasing concern since the formation of the Christchurch drainage board. The Avon Otakaro Network wished to identify treatment options and associated land requirements that could be incorporated into the wider Avon River corridor to both reduce contaminant loads as well as reduce flood peaks. Consequently, the following objectives became the focus of this project:

1. Assess potential for proposed wetlands in the residential red zone
2. Investigate likely land requirements and locations for wetlands
3. Seek community feedback surrounding wetlands in the red zone

Methods

Various methods were used to complete this research, including both quantitative and qualitative analysis. Methods included wetlands modelling, some use of GIS and focus groups for community consultation. To begin with, wetlands were sized using data obtained from the CCC and CCC wetland design guidelines. Further information can be found in the appendices. The wetlands were designed to try and reduce initial heavy metal loading to below the ANZECC 80% trigger guidelines; levels that can sustain a certain level of natural aquatic life remaining based on the new contaminate load. These values can be found in the Appendix B. Following this, shapefiles of the wetlands were created in ArcMap 10.1, which could then be used to show the spatial location, distribution and land requirements for the wetlands for each of the catchments assessed. Subsequent to the completion of the quantitative analysis, focus groups were utilised to assess the public perception of and support for the implementation of constructed wetlands with the Avon residential red zone; the results of this can be found below. It is important to note that this research was limited to the Avon Loop area as can be seen outlined in orange in Figure 4. The reason for this was the data provided by council for the initial information was only complete for this area and allowed the project to be at a scope the council were happy with (Brookland, 2013). Figure 4 also provides some context of the red zone area, which may aid in interpreting the results below.

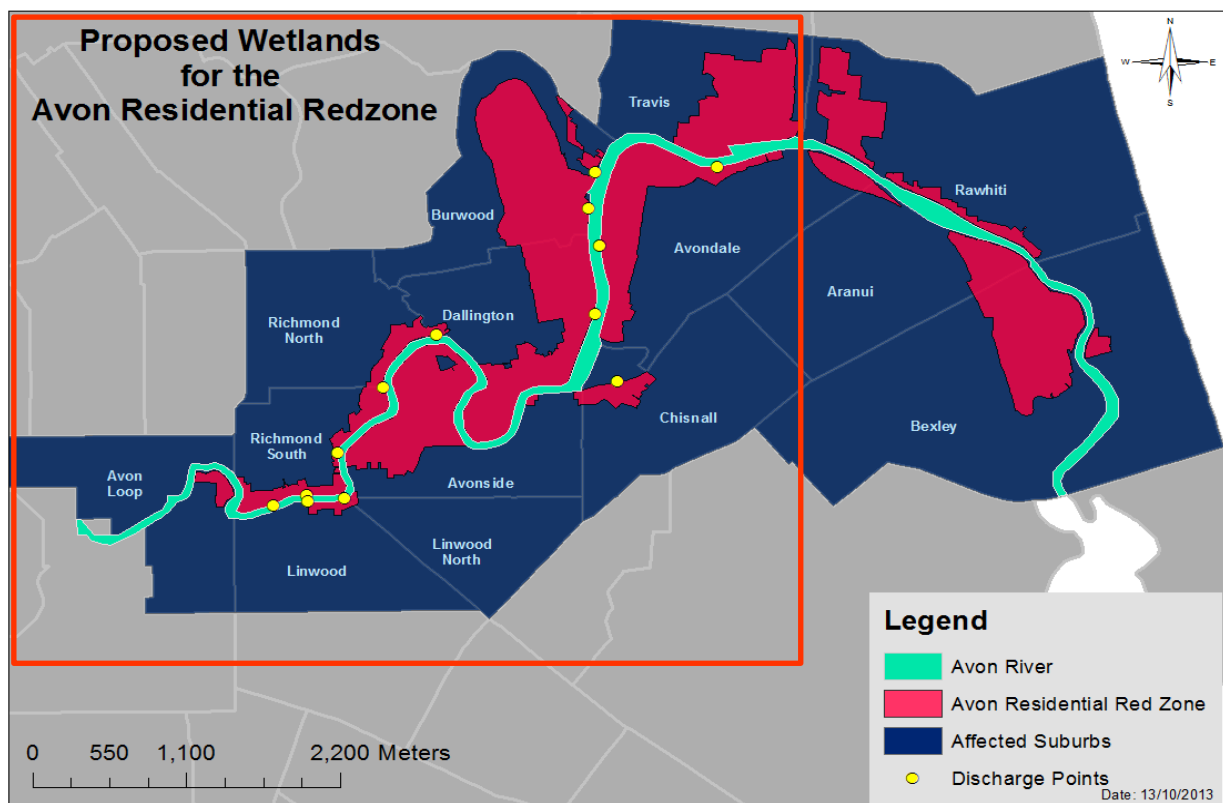


Figure 4: Avon residential red zone: the Avon Loop study area can be seen within the orange box

Wetland Potential and Design

It has been identified that wetlands provide a wide range of services with a large number of benefits, including flood alleviation, recreation and aesthetic services. (Georgiou, Turner, & Fisher, 2008).

Wetlands are currently, the most feasible option for treating heavy metals within the red zone before they enter the Avon River is to assess the catchments that contribute directly to the Avon River within the red zone and investigate the potential for constructed wetlands. There are 9 catchments in total within and around the red zone which feed into the Avon River (Figures 4 and 5).

The Horseshoe lake catchment is the largest of the nine catchments assessed. Based on the CCC's wetland design guidelines, the available red zone land that could be used to construct a wetland for this catchment is too small to adequately treat the metal loads found within the catchment. Conversely, this catchment does nevertheless have a wetland system large enough to treat the catchment; however it has suffered significant damage as a result of the earthquakes. Proper restoration and development of the pre-existing wetland would allow for adequate treatment of heavy metals within the catchment as well as drastically reducing flow rates and should therefore become a top priority within the red zone redevelopment.

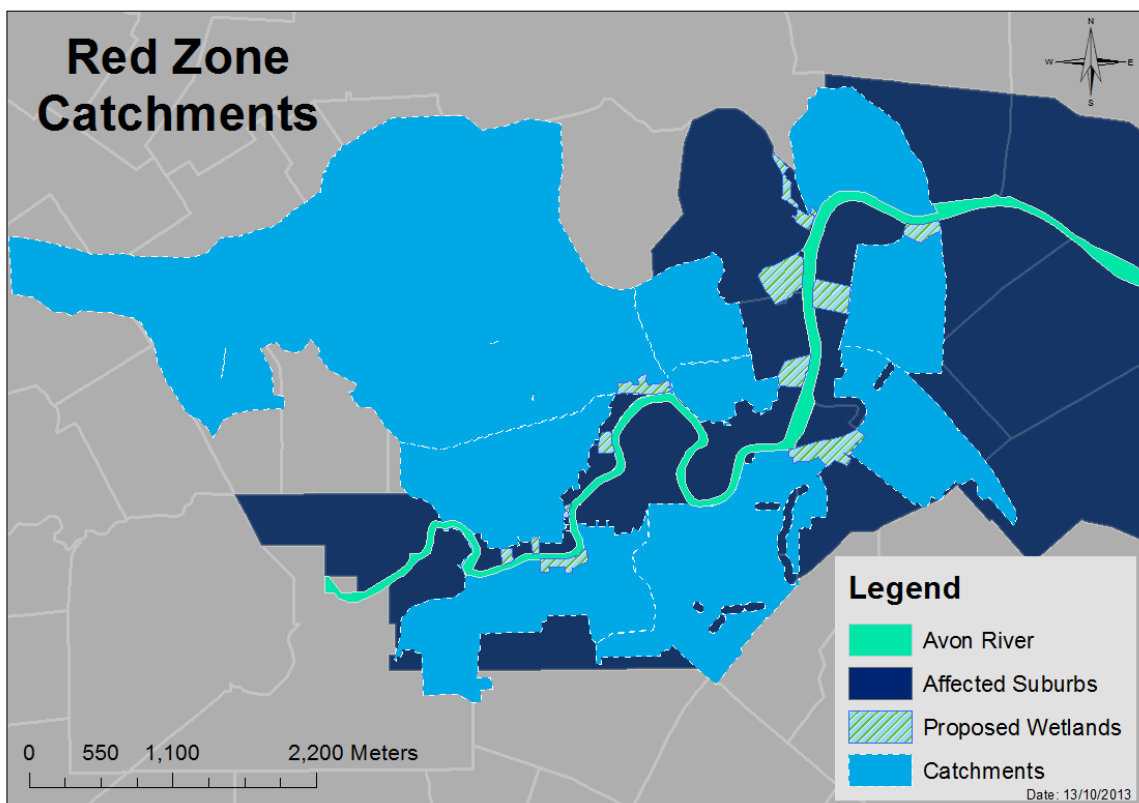


Figure 5: 8 of the catchments that can be found within the Avon residential red zone for which wetlands have been designed

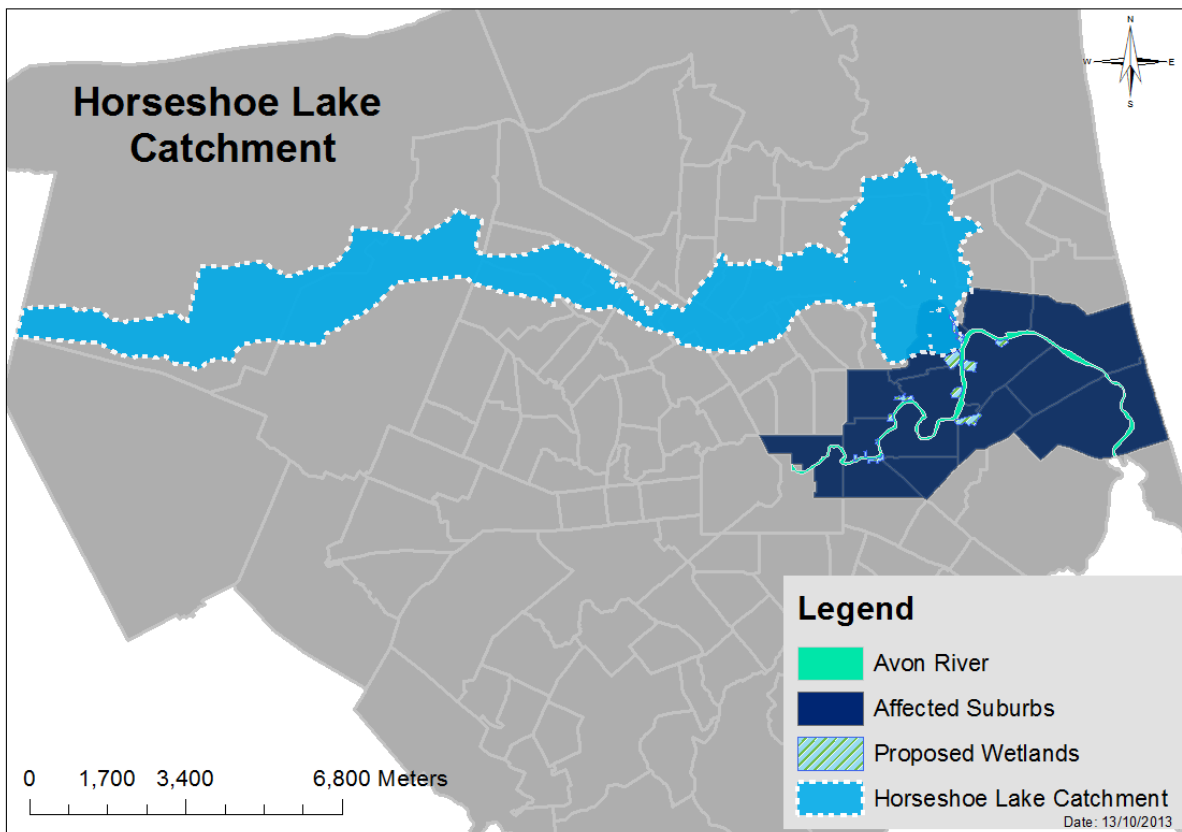


Figure 6: Horseshoe Lake Catchment, which is by far the largest of the catchments investigated

For the most part, the catchments that can be seen in blue in Figures 5 and 6 all have enough available red zone land surrounding them to design wetlands to treat storm water, based upon CCC wetland design guidelines. These guidelines are outlined in the technical design publication for storm water treatment options. They are simply a guide to assist with general designs of wetlands, not a strict building code. Wetlands for these catchments would begin at the end of existing storm water outlet points (Figure 1) and end right at the edge of the Avon River. Development of wetlands for these catchments should also be a high priority, second only to the restoration of the pre-existing wetland in Horseshoe Lake catchment. Reconfiguration of the storm water infrastructure already present within these catchments would not be required for the application of wetlands.

The catchments that can be seen in Figure 6 below do not have storm water systems within the red zone, but instead have vacant red zone land adjacent to them that could be used for the development of constructed wetlands. In saying this however, the implementation of constructed wetlands in these areas would require significant redevelopment of storm water systems in the red zone to redirect storm water from these catchments into wetlands (particularly for the Travis Catchment that can be seen in orange in Figure 6). Consequently, it would only be economically viable to implement constructed wetlands in the Travis catchment if the entire storm water system

required improvements, which is unlikely; as a result the Travis catchment should be earmarked as the lowest priority for wetland construction.

The Dudley Creek catchment (seen in Green in Figure 7) encompasses a significant area of over 700 hectares. High concentrations of Copper, Zinc and Lead are an issue within this catchment, thus a wetland far larger than the available red zone land would be required to adequately treat the quantity of storm water likely to come from the catchment. It is recommended that a dry basin be applied in this area as an alternative, allowing for the settling of suspended solids before storm water enters the Avon River. Additionally, this would also lead to some variation in the types of storm water treatment options throughout the red zone, which could be said to have the potential to enhance aesthetic variance within the red zone area.

For those catchments where wetlands are a suitable option for the treatment of stormwater, results of wetland modelling can be found in Figure 8. The distribution of the wetlands throughout the red zone can be seen, along with an indication of the likely land requirements. For the most part wetlands are certainly a viable option for most catchments within and around the red zone, with the exception of those outlined above, and could certainly be successfully integrated into the wider river park and ecological corridor concept.

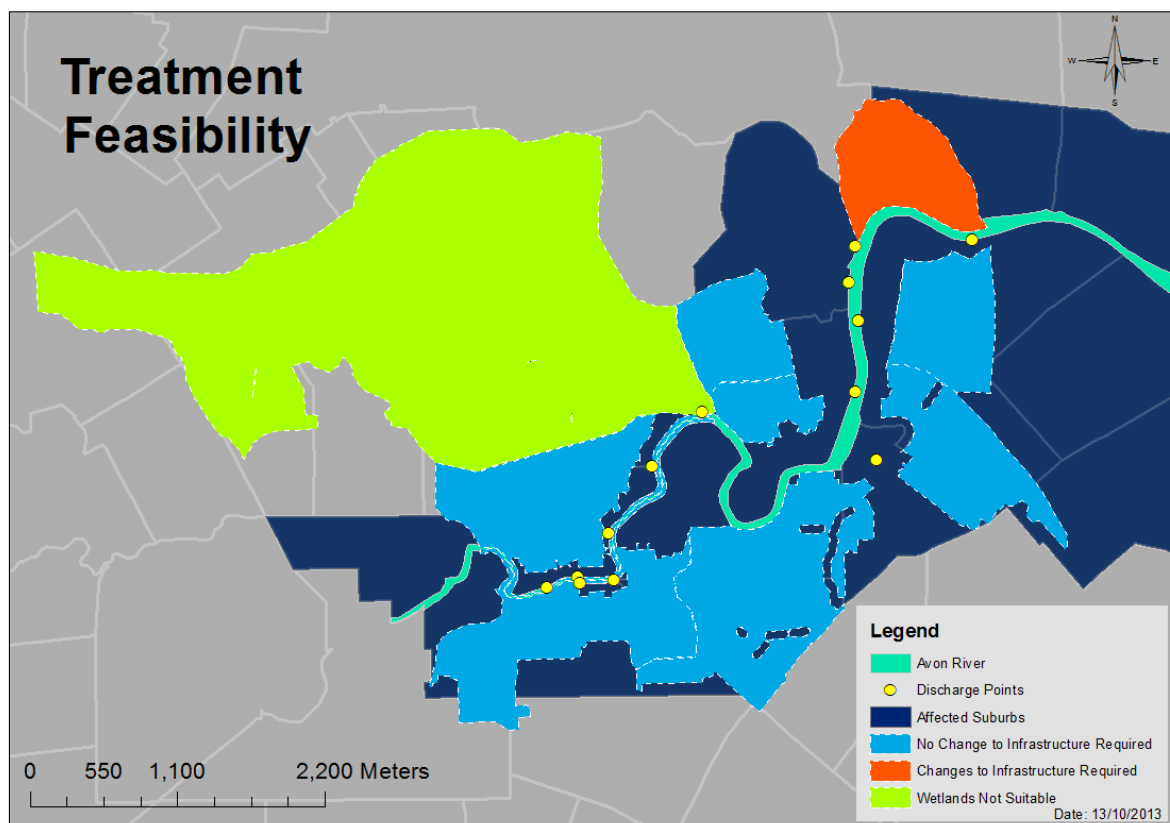


Figure 7: An indication of catchments for which constructed wetlands are a less suitable solution; Dudley Creek can be seen in green and Travis in Orange

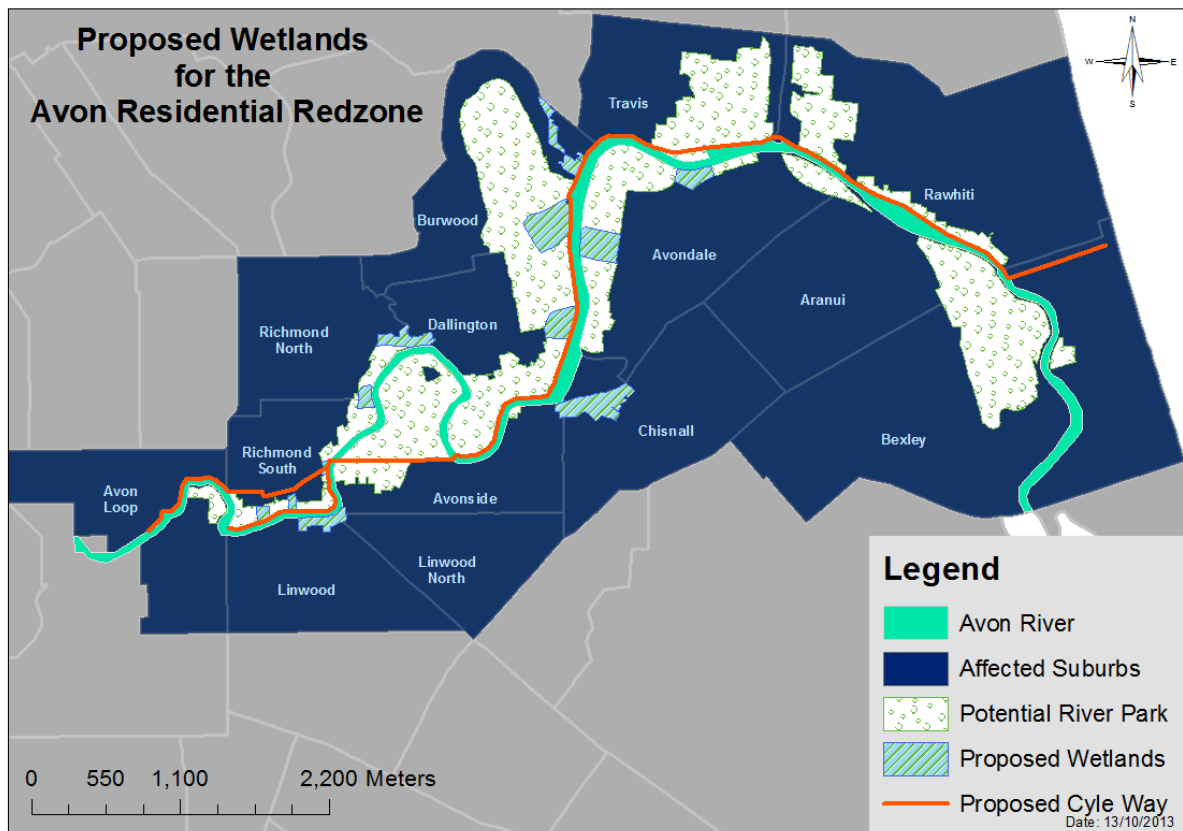


Figure 8: Map provides an indication of where wetlands would need to be located in the red zone, and how they will fit into the wider river park concept spatially

To further enhance the benefits of constructed wetlands with the residential red zone, reducing the quantity of heavy metals entering the waterways through the stormwater system is recommended. In order to do this, ‘at source’ treatments options are suggested; including swales, permeable pavements, green roofs and rain gardens, all of which are mechanisms that can be useful in catchments where wetlands are not suitable. Additionally, the sources of these heavy metals should be addressed and supplementary measures taken to reduce the impacts that they have upon the quality of Christchurch’s urban waterways.

Community Feedback

In order to gauge community perspective on the implementation of constructed wetlands within the residential red zone, a focus group was undertaken with residents of the affected and surrounding areas; participants were from a range of areas including Dallington, Avondale, Burwood and Brooklands. Various factors related to the proposed wetlands were addressed within the focus group, including, but not limited to, the following:

- Assessing the level of awareness of the Avon Otakaro Network and their work within the red zone area and eastern suburbs
- Exploring prior knowledge of constructed wetlands and their uses concerns and opinions surrounding the development of constructed wetlands
- Gauging any concerns they have surrounding the constructed wetlands proposal
- Identifying any alternatives or additional urban design features they would like to see within the redeveloped red zone

Communities within and around the red zone are well aware of the Avon Otakaro Network, openly acknowledging the work and effort that the group has put into pushing for the restoration of the Avon River and surrounding areas. Many of the community members seemed to have some knowledge surrounding constructed wetlands and their features; however misconception is certainly present with wetlands often described as swamps and marshes by participants. Most participants were unaware of the benefits wetlands can have, including the filtering of sediments to improve water quality and reducing flood risk. This mirrors their concerns associated with the locations of wetlands near their homes, which included the increase of water volumes to levels that are likely to cause flooding and the further spread of pests (rats and mosquitoes), including the associated impacts that this would have on both human and environmental health. Some participants rated river water quality as an important issue, but consider other options including natural river flows and natural parks & reserves as better possibilities for improving the river water quality and health.

Furthermore, it appears that some members of the wider community are largely unaware of specific policies associated with the construction and management of wetlands. It was highlighted during the focus group that if there are current policies on wetlands, there is lack of enforcement and the Christchurch City Council needs to look at better enforcing policies and regulations. A summary of key concerns and suggestions surrounding urban design features made by focus group participants can be seen in Table 1.

Table 1: Summary of key concerns and findings from the focus group with red zone residents

KEY CONCERNS	ALTERNATIVES/POSSIBILITIES
<ul style="list-style-type: none"> • The Red Zone area is already swampy with river flow and water loadings; this may lead to more flooding in the area. • The location of the wetlands needs to be a substantial distance away from people’s homes and properties. • Health impacts of the spread of pests such as mosquitos and rats need to be addressed • The increased spread of pests (e.g. water rats, frogs, weasels, stoats and wild cats) which can have impacts upon and pose threat to other habitats and ecosystems, such as native birds, require consideration • Questions were raised surrounding the management of the wetlands – who will be responsible for their upkeep and maintenance • Impacts upon the value of neighbouring properties • Potential impacts on groundwater resources 	<ul style="list-style-type: none"> • No forests – prefer more of a park environment (The Groynes was given as an example) • Picnic areas • Incorporation of cycle ways • Cafes along the waterfront • Sports parks • Horticultural Gardens • Golf courses • Emergency facilities such as telephones • River Sports • Fencing the area to protect nature habitats from wild cats and other predators

Findings from the focus group highlighted the need to further increase community awareness of constructed wetlands, specifically surrounding the functions and benefits of such an initiative. It is certainly apparent that the community has a substantial amount of enthusiasm and passion when it comes to the future of the Avon residential red zone; thus through further education, and increased awareness, their full support could lead to a successful river park and ecological reserve.

Case Studies

When assessing the focus group results, it became clear that some members of the community were a) not convinced that the red zone would never be used for residential development again and b) not fully aware of the impacts flooding could have in the area if residential development was to occur within the red zone in the future. As a result, case studies were explored that could be used to highlight the importance of no future residential development occurring within the Avon residential red zone; examples from South Dakota and Colorado can be found below.

Rapid City, South Dakota

On June 9 – 10 1972, Rapid City in South Dakota experienced a devastating flood, caused by a dam failure upstream of the town which led to a surge that destroyed all houses on the flood plain (Costa, 1978). Urban planning policy at the time was to simply allow for the flood plain of Rapid Creek, which passed right through the middle of the city to be built on; the result of which following the flood was extensive property damage, 238 fatalities and over 3,000 injuries (Costa, 1978). Subsequent to the flood, the council decided to re-zone the land for non-residential and commercial use only. Consequently, the risk of damage for a future flood is now very low. Although the Avon River will most likely never have the same human risk to life as Rapid City, the economic damage from a flooding event would be similar. Through only allowing certain types of development on the flood plain, Rapid City has reduced economic risk to virtually zero as well as enhanced the city through allowing the flood plain to be developed into numerous golf courses and nature reserves (Costa, 1978), a concept that could also be enormously successful in Christchurch's residential red zone.

Denver, Colorado

In another example of the risk that surrounds residential development on flood plains, Denver Colorado utilised large structures to mitigate the risk of flooding in the Denver city centre, a component of which was a dam upstream of Cherry Creek. The construction of this dam created a false sense of security regarding the safety of the flood plain downstream of the dam, resulting in rapid development on the flood plain which subsequently considerably increased the risk associated with a dam breach (Costa, 1978).

However, the main issue associated with this concept is in that the dam was designed to spill flood water down another catchment and therefore bypass the city, with no planning framework in place to protect the flood plain from urban development. Consequently, the planned catchment where

flood water was to be diverted is now home to major residential growth, thus rendering the goal of the dam development redundant (Costa, 1978).

From the two examples given above, it is clear that there is significant risk and loss associated with residential development on flood plains. It certainly became apparent following the focus group that these risks need to be reiterated to the wider community to ensure that residential development does not occur on the flood plain of the Avon River. Whilst the land could be utilised for commercial purposes and features that will be integrated into the Avon corridor, it is likely that the consequent risks associated with future residential development in the red zone far outweigh the potential benefits.

Recommendations

Following community consultation, it became apparent that there is a significant knowledge gap between the experts and the general public in relation to constructed wetlands, their uses and the potential benefits. In order to further increase community support associated with the wetlands, this gap needs to be addressed. Whilst the community definitely understood that there is currently serious water quality issues associated with the Avon River and its tributaries, they were not supportive of the wetlands concept as a solution. With additional education, it is likely that community support could be further developed. It is also recommended that further public consultation be undertaken in order to ascertain just how widespread this knowledge gap and consequent lack of support is.

In order to develop additional understanding and support, the broader river park concept requires further development. If the community can see how wetlands could be incorporated to the wider red zone redevelopment, then it is likely that support for the wetlands proposal could be improved. Currently it appears that community cannot see how the wetlands could be integrated into the wider concept, but instead believe that they would be somewhat of an impractical eyesore. Through changing this perception, wetlands could be a successful solution for the Avon River.

Finally, it appeared from the focus group results that many members of the wider community did not fully understand the impacts that floods within the red zone could have, particularly if residential development should occur within the area. In order to increase knowledge of these impacts and discourage residential development, case studies such as those outlined above could be utilised to help increase understanding surrounding these issues.

Conclusions

Currently the main goal of the Avon Otakaro network is to redevelop the Avon residential red zone into an ecological corridor and recreation reserve. As a result, the scope of this project was to assist with the stormwater management aspect of this vision, through assessing the potential of constructed wetlands to treat stormwater that is currently piped directly into the Avon River, causing a number of issues surrounding water quality and river health.

As can be seen above, the treatment of stormwater through the use of constructed wetlands is certainly feasible for the vast majority of catchments within the red zone. As mentioned, whilst the Travis catchment would need reworking in terms of infrastructure, there is enough red zone land in the catchment to construct a wetland that could adequately treat the heavy metals to an acceptable standard. Dudley creek however will require alternative means treatment, such as “at source” treatments such as swales and rain gardens, due to the large scale infrastructure change that would be required to make wetlands a feasible option. All of the remaining catchments have space available for the construction of wetlands that could adequately address the heavy metal treatment needs of each catchment.

Whilst wetlands as a treatment option are certainly viable throughout the red zone, it appears that at this point, a significant amount of focus should be turned towards gaining the support of the wider community surrounding the wetlands proposal. Whilst focus group participants were certainly supportive of the wider river park and ecological, corridor concept, a lack of information in the public domain surrounding the purposes and functions of constructed wetlands has led to a large knowledge gap and consequently a lack of support for the wetlands concept.

To conclude, constructed wetlands are undoubtedly a viable method of treating storm water contaminants found within the red zone and Avon River. However public perception associated with wetlands and their benefits needs to be addressed, and changes seen, if the wetlands concept is going to be a successful component of the wider red zone redevelopment.

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Appendix A: Example Wet-pond Design

The following method outlines the design of wetlands that were sized using the CCC guidelines. The general design of both this wetland design and plug flow wetland designs consist of the following.

- A permanent wet pond which also has storage capacity above it to handle storm events.
- This storage system and wet pond design then feeds into a wetland system.

TOTAL VOLUME ASSESSMENT:

The area of a catchment is determined. This will be denoted by the symbol A. The percentage district type was then determined. This was achieved by determining the percentage composition the catchment was with Table 2.

Table 2: Christchurch City Council Impervious Surface Composition Reference Table

District Zone	Effective Impervious area	Impervious Contribution	% C_{eff}	Discharge Coefficients C_d	Composite Coefficients C_{ff}	FF
L1	0.5	0.9	0.9	0.9	0.41	
L2	0.55	0.9	0.9	0.9	0.45	
L3,L4,L5	0.7	1	0.9	0.9	0.63	
LH	0.45	0.95	0.9	0.9	0.38	
Business	0.9	1	0.9	0.9	0.81	

The Composite First Flush Rainfall Constant for the catchment is simply a weighted average of the percentage composition of the catchment. For example if a catchment was 50% L2 and 50% Business the C_{ff} of the catchment would be:

$$C_{ff} = 0.5 * 0.45 + 0.5 * 0.81 = 0.63$$

A design rainfall event is then used to size the treatment system. For both wetland designs a 25mm first flush rainfall (d_{ff}) was then used to size the treatment system. This rainfall event was selected as it is the design rainfall event that must be used when developing a Greenfield site.

The first flush volume is then determined by the following formula:

$$V_{ff} = 10 * C_{ff} * A * d_{ff}$$

The wet pond system can now be sized. CCC state a 1.2 metre depth for particulate settling and 1.5 for settling. The wet pond/water storage system will therefore have a 1.2 metre depth. The following design guideline constraints were also used and outlined in Table 3.

Table 3: Design parameter used for the wetland catchments. These are based of the Christchurch City Council design guidelines.

Constraint	Unit	Value
Length to Width Ratio		4
Planting Buffer	m	5
Freeboard	m	0.2
porosity (100% as no planting)	-	1
Horizontal to Vertical ratio		4
detention time of Pond	days	4

The following cross section can then be developed:

The only dimension which can be changed is x. The size of x determines the entire volume of the wet pond system. As a result the size of x needs to create a wet pond volume that is equal to the V_{ff} volume. This was how all wet pond systems were designed for this report.

Appendix B: Wetland Design (Christchurch City Council)

The wet pond will release the water to the wetland over a period of four days. Therefore the flow of water into the wetland is simply:

$$Q = \frac{V_{ff}(m^3)}{4 (days)}$$

The CCC guidelines indicate that the water entering and residence time should, be two days, with the wetland only having a depth (d_w) of 0.25 m, a length to width ration of 10, and a porosity (n) of 75%.

As a result the wetland footprint area of the wetland is simply:

$$A_f = \frac{Q * HRT}{d_w * n}$$

Appendix C: Wetland Sizing Plug Flow Reactor Method

Locations of metal concentration readings along the Avon River were provided by Christchurch city council. Anzecc guidelines also provide values of what the minimum concentration level should be in a stream that allows for a certain percentage of the natural species to still survive in that habitat. For this analysis 80 percent Anzecc guidelines were used to design these Wetlands. Table 4 displays the initial concentration for each of the locations as well as the target treatment concentrations. Only the Horseshoe Lake and Dudley Creek wetlands were able to be designed with this method due to a lack of data for the other catchments. The table shows that Horseshoe Lake wetland can successfully treat most max heavy metal concentrations.

Table 4: Heavy metal contaminant information from CCC data

Location	Maximum measured Zn (mg/l)	Target Anzecc Zn (mg/l)	Maximum measured Pb (mg/l)	Target ANZECC Pb (mg/l)	Maximum measured Cu (mg/l)	Target Anzecc Cu (mg/l)
Dudley Creek	0.083	0.031	0.033	0.0094	0.011	0.0025
Horseshoe Lake	0.015	0.031	0.0015	0.0094	0.0054	0.0025

The plug flow wetland design method can be used to design a wetland system that can treat an influent metal concentration down to a user specified concentration, in this case, 80 percent. The following method outlines how the design works:

Appendix A provides details about the volume of water that will enter the plug flow wetland this water volume is known as the first flush volume and is denoted by the symbol V_{ff} . The concentration of the metals will also decrease by 75% after the wet pond as it settles out 75% on the contaminants.

To remove the remaining contaminants the Hydraulic Residence Time is calculated using the plug flow reactor formula of:

$$HRT = \frac{\ln\left(\frac{C_o}{C_e}\right)}{k_t}$$

Where C_o is the concentration of contaminants entering the wetland, C_e is the concentration of the contaminants leaving the stream. Kt is the rate constant of the reaction (units of days^{-1}), this is temperature dependent however CCC have a guideline value of 0.38. This was the value used for this wetland design method.

The wet pond will release the water to the wetland over a period of four days. Therefore the flow of water into the wetland is simply:

$$Q = \frac{V_{ff}(\text{m}^3)}{4(\text{days})}$$

The calculated HRT of the wetland is then combined the CCC guidelines of the wetland only having a depth (d_w) of 0.25 m, a length to width ration of 10, and a porosity (n) of 75%.

As a result the wetland footprint area of the wetland is simply:

$$A_f = \frac{Q * HRT}{d_w * n}$$