TURNING THE RED ZONE GREEN – REGENERATIVE STORMWATER DESIGN IN THE ŌTĀKARO AVON RIVER CORRIDOR

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ABSTRACT

Christchurch's Ōtākaro Avon River flows for approximately 26 kilometres from its spring-fed source to its mouth at Te Ihutai / Avon Heathcote Estuary. The lower reaches of the river are located within the red zone, land that was previously residential but deemed unsuitable to rebuild on following the 2010/11 Canterbury earthquakes and was acquired by the Crown. This land is now owned by Christchurch City Council (Council). The river corridor has historically been an area of cultural and ecological significance; however, ongoing development in addition to earthquake damage has reduced the overall ecological habitat, water quality, vegetation cover and hydraulic capacity.

The Ōtākaro Avon River Corridor (ŌARC) Regeneration Plan was developed by Regenerate Christchurch in consultation with mana whenua, the Crown, Council and the wider community to support the regeneration of ŌARC area within the red zone. It sets out the vision, objectives and green print for the 602-hectare ŌARC and was approved by the Minister for Greater Christchurch Regeneration in August 2019. The objectives are:

- Create a restored native habitat with good quality water so there is an abundant source of mahinga kai, birdlife and native species
- Support safe, strong and healthy communities that are well connected with each other and with the wider city
- Provide opportunities for enhanced community participation, recreation and leisure
- Create opportunities for sustainable economic activity and connections that enhance our well-being and prosperity now and into the future.

In 2022, Council engaged Beca to undertake stormwater investigations and design for the ŌARC Wainoni and Bexley areas, with a combined area of approximately 80 hectares. The purpose of this project is to provide flood resilience and stormwater management in these areas, consistent with the Regeneration Plan, the Iwi Management Plan and Council's six values approach to surface water management (the six values are: ecology, drainage, culture, heritage, landscape and recreation) (Christchurch City Council, 2003). Stopbanks and flood walls will be used to provide flood resilience, while wetlands and swales will treat and convey stormwater runoff before it is discharged to the Ōtākaro / Avon River. The sites present several challenges:

- The ground is low lying with high groundwater and is susceptible to liquefaction and lateral spreading in seismic events
- Areas of contaminated land are present
- The proximity to the estuary will result in increased river levels which will increase flood risk and groundwater salinity
- The existing stormwater networks are low lying relative to water levels in the river

- There remain some residential properties within the red zone
- Space is constrained in some areas by the river and State Highway 74 (SH74)
- New excavations for basins or wetlands in liquefaction-prone land, if unmitigated, may increase the land instability and risks to SH74, private property and the proposed stopbank.

This paper discusses how the project has balanced these challenges during the concept design phase to achieve a successful outcome using innovative design and collaborative efforts across a wide range of disciplines and several organisations (including Council, Beca, Rough Milne Mitchell, Aurecon, WSP and GHD). The design is subject to ongoing development informed by Council discussions with mana whenua and other stakeholders.

KEYWORDS

Wetland, stopbank, Ōtākaro Avon River, regeneration, red zone

PRESENTER PROFILE

Hamish Cotter is a civil engineer in the water resource team in Beca's Christchurch office. He has four years of experience and has recently been focusing on stormwater and river jobs in Canterbury and throughout New Zealand.

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1 INTRODUCTION

The 2010-11 Canterbury earthquakes and subsequent aftershocks caused extensive ground failure in areas of Christchurch, including liquefaction and lateral spread, which resulted in significant damage to infrastructure and buildings. In some locations, the damage was so severe that the land was deemed unsuitable for residential redevelopment and was subsequently acquired by the Crown. A continuous 602-hectare tract of this land lies adjacent to the Ōtākaro / Avon River on the eastern side of Christchurch and is now known as the Ōtākaro Avon River Corridor (ŌARC) (Regenerate Christchurch, 2019) (Figure 1).

Historically, the ŌARC was part of an extensive network of riparian margins and wetlands that supported ecosystems with high cultural and ecological values. However, development of the area in the past century, combined with the damage sustained from the earthquakes has led to a reduction in the overall ecological habitat and water quality. The area is also vulnerable to flooding due to a combination of ageing infrastructure, proximity to the adjacent river and climate change (Christchurch City Council, 2015).

To address these issues, Regenerate Christchurch developed the ŌARC Regeneration Plan, which sets out a vision and objectives for the ŌARC area. The objectives of the plan are centered around creating a restored native habitat with high-quality water, supporting healthy communities, providing opportunities for community recreation and leisure, and creating opportunities for sustainable economic activity and connections.

In 2022, Christchurch City Council (Council) engaged Beca to undertake investigations and design work on the Wainoni and Bexley project areas, which encompass a combined area of approximately 80 hectares within the ŌARC. The project's primary aim is to provide flood resilience and stormwater management in these areas, consistent with the ŌARC Regeneration Plan, the Iwi Management Plan and Council's own six values approach to surface water management. The Council's six values are: ecology, drainage, culture, heritage, landscape and recreation.

The project builds on earlier investigations and designs by others (including GHD, WSP, and Jacobs) and is being carried out in parallel and in close liaison with the landscape and ecology design for these areas. This paper examines how the project balanced numerous challenges presented by the Wainoni and Bexley areas of the ŌARC, detailing the options considered and the solution adopted for flood resilience and stormwater management.

Figure 1. Ōtākaro Avon River Corridor

2 BACKGROUND

2.1 CATCHMENT AND PROJECT AREA

The Ōtākaro / Avon River is a significant watercourse in Christchurch, stretching for 26 km from its source in Avonhead to its mouth in Ferrymead (Figure 2). The river's catchment covers approximately 89 km^2, which includes a number of spring-fed streams in the upper catchment, as well as a number of tributaries in the lower catchment. In addition to these streams and tributaries, the river receives water from 74 km of stormwater drains (Christchurch City Council, 2016).

The Ōtākaro / Avon River catchment has undergone significant modification over the past 150 years. Extensive urbanisation has increased impervious areas, drained natural wetlands, and increased pollutants from commercial / industrial activities in the area. Consequently, the quality of the water in the river is generally documented as fair to poor (Christchurch City Council, 2016).

The focus areas of this paper, Wainoni, and Bexley, are located in the lower Ōtākaro / Avon River catchment and are flat, low-lying suburbs with poorly draining soils and high groundwater levels (Figure 2). Filling for residential development and the demands for drainage have resulted in the piping of many waterways in the area, such as Wainoni Drain. Pumping has also been installed to assist drainage. The performance of existing stormwater infrastructure in the area has decreased as a result of land subsidence from the 2010-2011 Canterbury Earthquake Sequence and is continuing to decrease as sea levels rise.

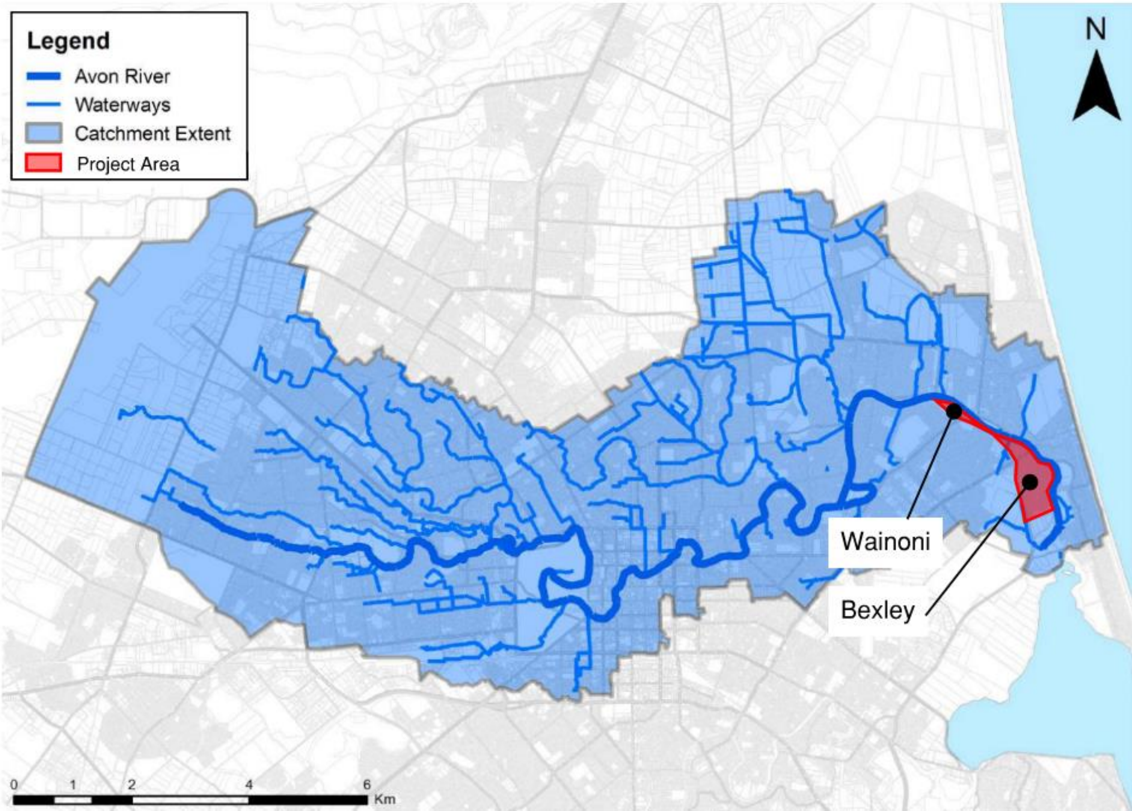

Figure 2. Ōtākaro / Avon River Catchment and Project Area (Council: Ōtākaro /Avon River Catchment)

2.2 CANTERBURY EARTHQUAKES AND RED ZONE

On 4 September 2010, a 7.1 magnitude earthquake struck Christchurch, with its epicentre located 10 km southeast of Darfield at a depth of 11 km. Although there were no reported fatalities, the earthquake caused widespread damage to the city's infrastructure, including water, power, and sewerage services. Several months later, in February 2011, a 6.3 magnitude earthquake, considered an aftershock of the September event, hit 10 km south-east of Christchurch at a depth of 5 km, causing 185 deaths, as well as extensive damage to buildings and infrastructure. This series of earthquakes is collectively known as the 2010-2011 Canterbury Earthquake Sequence (2010-2011 CES).

The ŌARC was among the areas most severely affected by the earthquake sequence. The area suffered from significant ground movement, including liquefaction and lateral spread, resulting in ground cracking, settlement, and lateral movement throughout the area (New Zealand Geotechnical Society, 2021). The ground settlement left the area more susceptible to flooding from the adjacent river, necessitating the construction of temporary stopbanks (GHD, 2018). Following the earthquake sequence, residential areas were assessed to determine the extent of damage, and residents were informed whether their properties were safe to inhabit and/or rebuild. In some areas, the damage was so significant that the land was considered unsuitable for rebuilding. This area is known as the residential red zone. From August 2011, the Crown made voluntary offers to purchase red zone properties.

Residents located within the red zone were provided nine months to consider the offers before a decision had to be made. By December 2015, 5,442 property owners in the ŌARC had accepted the Crown's offer, however, some opted to decline and retain their properties. All properties acquired by the Crown were subsequently demolished. Two of the properties retained in private ownership are located in the project area, one in the Wainoni site and one in the Bexley site.

2.3 REGENERATION PLAN

The demolition of the red zoned properties in the ŌARC left a large area of land unutilised for several years. With a vision to restore the area's historic, cultural and ecological significance, the ŌARC Regeneration Plan was developed by Regenerate Christchurch in consultation with mana whenua, the Crown, Council and the wider community. The Regeneration Plan was approved by the Minister for Greater Christchurch Regeneration in August 2019. It provides a vision and objectives for future land use and opportunities in the area.

The plan aims to regenerate the area by creating a restored native habitat with good water quality, supporting safe, strong and healthy communities, providing opportunities for enhanced community participation, recreation and leisure, and creating opportunities for sustainable economic activity and connections that enhance well-being and prosperity now and into the future. The green print provides a spatial framework for the future development of the area, including the restoration of ecological habitats, the creation of walking and cycling tracks, and the development of community facilities. Figure 3 below illustrates the 'Green Spine' which will form the core of the regeneration area and includes the Wainoni and Bexley project areas.

Several projects have already been completed as part of this regeneration plan, including a riverside landing at Dallington and new foot/cycle bridges at Snell Place, Medway Street and Avondale.

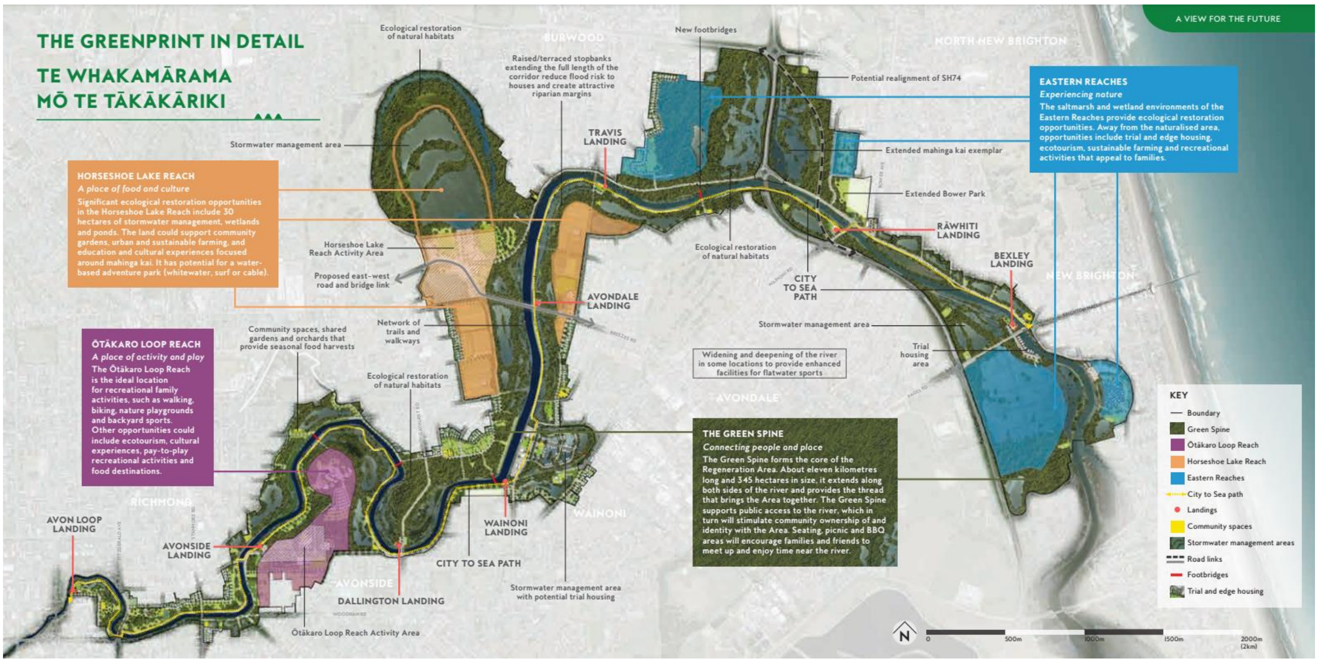

Figure 3. The Green Spine (Core of the Regeneration Area) (Ōtākaro Avon River Corridor Regeneration Plan)

3 CHALLENGES

The Wainoni and Bexley sites that are the focus of this paper present numerous design challenges that have required balancing and coordination between multiple disciplines. The key challenges are expanded on below.

3.1 SPATIAL CONSTRAINTS

Although both the Wainoni and Bexley sites are ultimately spatially constrained by the Ōtākaro / Avon River and Anzac Drive / State Highway 74 (SH74), there are additional features specific to each site that cause further spatial constraints.

3.1.1 WAINONI

The Wainoni site extends from where Anzac Drive / SH74 crosses the Ōtākaro / Avon River to approximately 1.3 km downstream where it ties into the Waitaki project area and the stopbank currently under construction. The site is intersected by Wainoni Road, which splits the site into two distinct areas. Figure 4 shows the delineation of the two areas within the site and identifies other features that cause spatial constraints.

The northwestern area contains one of the privately owned properties mentioned in Section 2.2. The property is located on the landward side of the existing temporary stopbank and has existing service connections for wastewater, water, power and Vodafone. The design is required to either maintain or relocate the existing service connections and provide, as a minimum, the same level of flood protection offered by the existing temporary stopbank. This reduces the footprint available for the stormwater management design.

In the southeastern area, there is a pinch point between the Ōtākaro Avon River and Anzac Drive / SH74, where the width between the Anzac Drive / SH74 road reserve and the river edge is as narrow as 8.0 m.

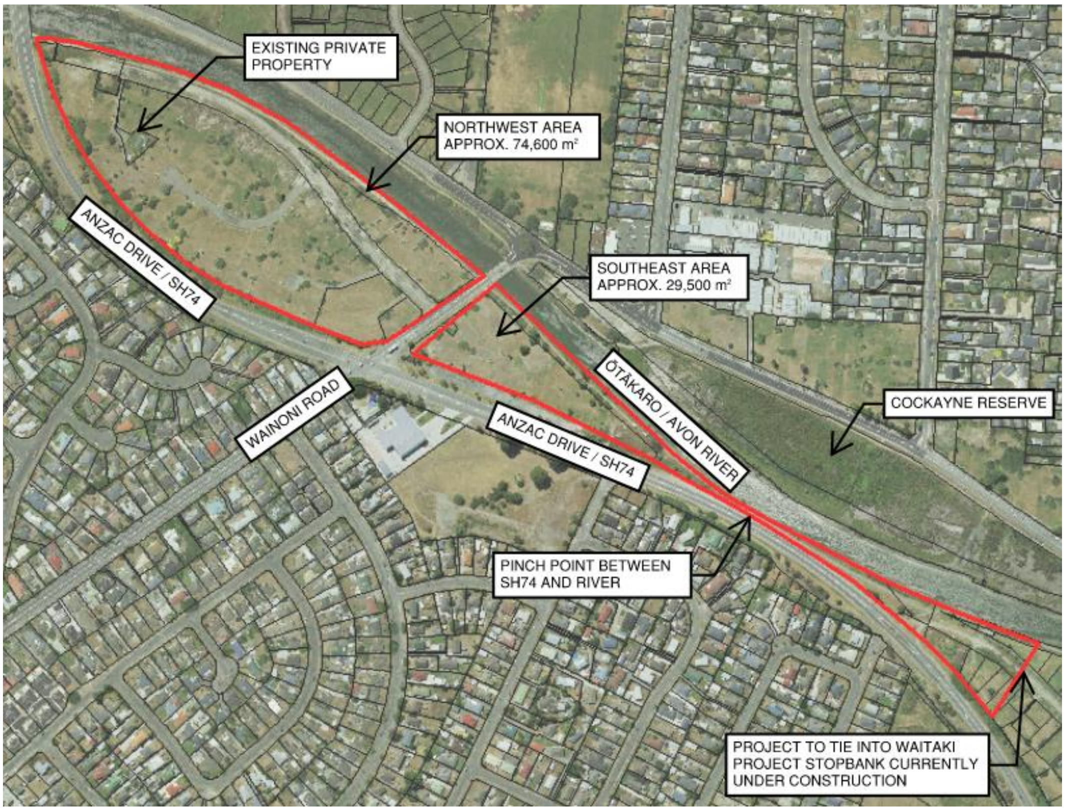

Figure 4. Existing Layout of the Wainoni Project Area

3.1.2 BEXLEY

The site boundaries for the Bexley area are largely defined by Pages Road to the north, the Ōtākaro / Avon River to the east, Anzac Drive / SH74 to the west, and the Bexley Wetland to the south (Figure 5). Note the undeveloped land to the west of Anzac Drive / SH74 is the former Bexley Landfill, which was closed in 1984, and subsequently capped.

Figure 5. Existing Layout of the Bexley Project Area

3.2 SITE LEVELS

3.2.1 GROUND LEVELS

The existing ground within the Wainoni site generally falls northeast towards the existing stopbank, with levels varying from approximately 10.3 mRL to 11.3 mRL (Christchurch Drainage Datum, CDD). The crest of the existing temporary stopbank varies from approximately 11.0 mRL to 11.6 mRL. Figure 6 shows a colour schemed elevation grid of the site and its adjacent surroundings.

Existing ground levels within the Bexley site vary from approximately 9.5 mRL to 11.3 mRL, with the southern half of site being approximately 0.5 m – 1.0 m higher than the northern half due to filling as part of a subdivision developed prior to the 2010-2011 CES. The crest of the existing stopbank varies from approximately 10.9 mRL to 11.9 mRL. Figure 6 shows a colour schemed elevation grid of each site and their adjacent surroundings. Refer to Table 1 for river levels at the sites.

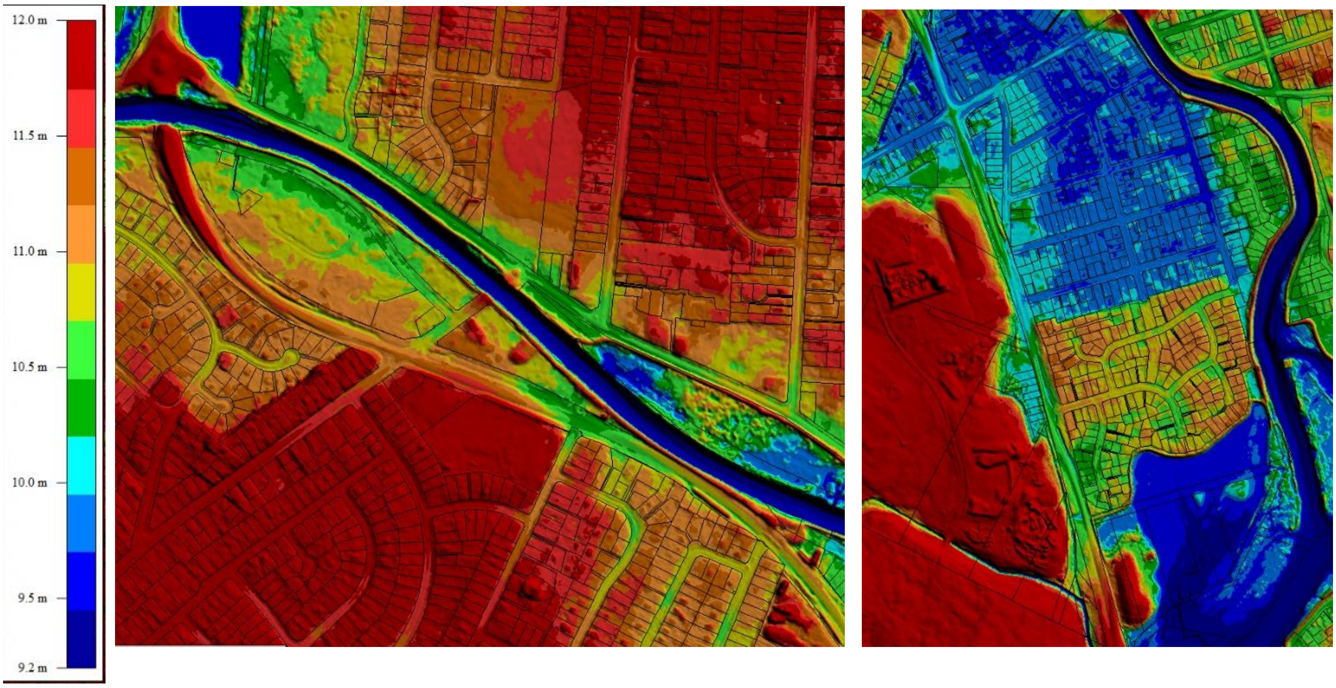

Figure 6. Existing Ground Levels of the Wainoni Project Area (left) and the Bexley Project Area (right)

3.2.2 RIVER LEVELS

Ōtākaro / Avon River levels at the Wainoni and Bexley sites are influenced by the tidal fluctuations in the Avon Heathcote Estuary, located at the mouth of the river. The low lying, flat nature of the sites makes them susceptible to flooding. Although there is an existing temporary stopbank to prevent flooding from the river, when rainfall events coincide with high tides or high river flows, the gravity stormwater drainage cannot discharge to the river.

Both sites contain existing stormwater mains that discharge to the Ōtākaro / Avon River via gravity outfalls. Figure 7 shows the existing stormwater mains located in the Wainoni site.

Figure 7. Existing Stormwater Pipes Located in the Wainoni Project Area

Flooding issues on the landward side of the stopbank will worsen as climate change continues to cause sea levels to rise, increasing tidal levels. Levels of the existing gravity stormwater outlets shown in Figure 7 range from approximately 8.40 mRL to 9.30 mRL. Table 1 shows the current and estimated future tidal levels in the Ōtākaro / Avon River at Bridge Street, which is located where the river meets the Estuary (Beca, 2023).

Table 1. Current and Future Tidal Levels in the Ōtākaro / Avon River at Bridge Street

Scenario	**2022, current sea level** **Now**	**+0.39m sea level rise** **50 years' time**	**+1.03m sea level rise** **100 years' time**
Mean High Water Springs	10.50	10.89	11.53
Mean Level of Sea	**9.46**	9.85	10.49
1yr ARI	10.721	11.11	11.75
5yr ARI	10.886	11.28	11.92
10yr ARI	10.957	11.35	11.99
20yr ARI	11.028	11.42	12.06
100yr ARI	11.194	11.58	12.22

The current mean level of sea (MLOS) partially submerges all the existing gravity outlets, with the mean high water springs (MHWS) level fully submerging all. With sea levels expected to rise by more than a metre in the next century, the gravity systems used to discharge runoff to the river will become increasingly unreliable, resulting in more frequent surface flooding.

Table 1 also emphasises the need for new stopbanks, as the existing temporary stopbank (10.9 mRL to 11.9 mRL) will offer decreasing levels of flood protection as sea levels rise.

3.2.3 GROUNDWATER LEVELS

Besides the flooding issues, both the Wainoni and Bexley areas are also facing the challenge of high groundwater levels, owing to the similarity between the existing ground and river levels. Groundwater monitoring tests undertaken by Beca show that groundwater in both sites is generally less than 1.0 m below ground level and is generally saline and tidally influenced. The anticipated rise in sea levels due to climate change is expected to exacerbate this situation. The presence of high, saline groundwater necessitates that precautions be taken during the design and construction phases to keep excavations as shallow as possible to minimise the likelihood of groundwater intrusion.

3.3 GEOTECHNICAL

As discussed in Section 2, the ŌARC suffered considerable land damage from liquefaction and lateral spreading during the 2010-2011 CES. Liquefaction occurs when soil loses its strength temporarily and behaves like a fluid, due to increased water pressure caused by ground shaking during seismic events. It generally occurs in loose sands and/or silts, below the groundwater level. Lateral spreading is the lateral movement and subsequent cracking and settlement of the ground surface that can occur following liquefaction, towards nearby riverbanks, slopes or cuttings (i.e., free faces).

The Wainoni and Bexley sites both have loose sandy and silty soils, and high groundwater levels, which makes them susceptible to liquefaction during seismic events, and both contain free faces (the river) making them susceptible to lateral spreading. Figure 8 shows the severity of liquification observed at both sites following the 2011 earthquake (New Zealand Geotechnical Database, 2013). Lateral spreading can cause settlement and longitudinal and traverse cracking of the stopbanks resulting in a reduced level of service (loss of freeboard) and the creation of seepage pathways (i.e., the loss of service). The magnitude of lateral spreading decreases with distance from the free-faces hence future stopbanks should be positioned as far from them as possible to minimise the effects of lateral spreading.

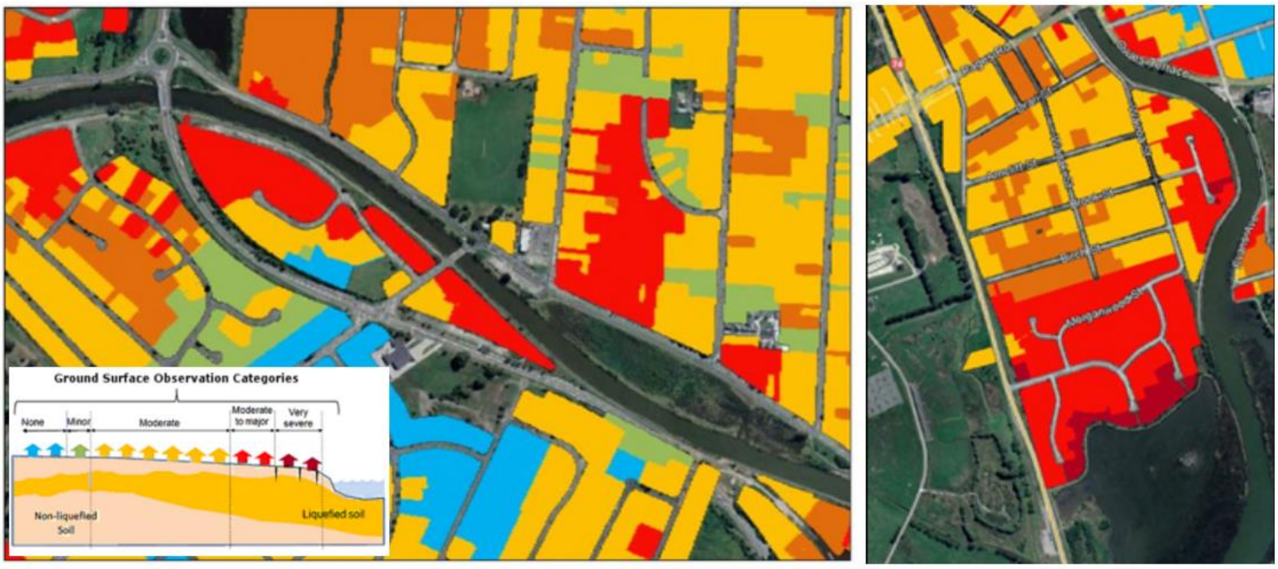

Figure 8. Severity of Liquefaction Observed at the Wainoni Project Area (left) and the Bexley Project Area (right) after the 2011 Earthquake

For both sites, the implementation of a stormwater treatment facility or management system that involves excavation, such as a wetland or a swale, will create a new free face in close proximity to existing infrastructure, including housing and roads (such as Anzac Drive), as well as the proposed stopbank. To reduce the potential impact of seismic-related land damage, adequate buffer distances should be established between new free faces and the surrounding infrastructure. Deeper excavations (i.e., higher free faces) will require larger offsets, so, again, there is a preference to keep excavations as shallow as possible.

3.4 CONTAMINATION

3.4.1 WAINONI

A preliminary desktop assessment of the Wainoni site area identified a number of historic and current land use activities on and adjacent to the site that may have impacted site soils. In response to this assessment, field testing was carried out at the site to determine the nature and extent of soil contamination. This assessment was carried out to determine if soil contamination could affect the suitability of reusing soils on the site and if it could potentially contaminate groundwater. Contaminated groundwater could, in turn, impact the treatment efficiency of stormwater facilities if they are not suited to treat such contaminants.

During the field testing, general site observations were made, which included the visual identification of coal tar in a number of test pits and frequent observations of fill and demolition materials within the site soils. These materials were likely from previous residential properties and associated structures such as sheds, garages, fences, and other structures. Approximately 30% of soil samples returned contaminants that were above published acceptable background concentrations. The predominant contaminants identified were lead and asbestos, both of which can pose significant risks to human health and the environment. However, subject to a resource consent, there may still be potential for the reuse of all soil on site, depending on the proposed use. For example, capping within the stopbank or used for surficial landscaping.

3.4.2 BEXLEY

A preliminary desktop assessment of the Bexley site area identified a number of historic and current land use activities on and adjacent to the site that may have impacted site soils. In response to this assessment, field testing was carried out at the site to determine the nature and extent of soil contamination and to assess the potential risks to human health and the environment. This included over 93 machine test pits, 395 hand excavated test pits and 12 groundwater monitoring boreholes.

Based on the results received to date, the nature of contaminants at the Bexley site is generally consistent with that of other areas in the ŌARC project, such as Wainoni (refer Section 3.4.1). The results suggest that there may be the potential for the reuse of all soil on site, depending on its proposed use. For example, capping within the stopbank or surficial landscaping. However, this will be confirmed on completion of the investigation and analysis. It is important to note that roading material is being tested for coal tar, which may limit reuse options if coal tar is present.

The impacts of contamination on the proposed design are expanded on below in Section 5.

4 OTHER VALUES

In addition to aligning with the objectives of the ŌARC Regeneration Plan, this project aims to meet the requirements of Councils own six values approach to surface water management, which are ecology, drainage, culture, heritage, landscape and recreation. Currently, the ŌARC area is considered to have a low amenity value. This is not only due to poor water quality, poor aquatic species diversity, and vegetation loss, but also the lack of protection and enhancement of cultural and historic assets.

As part of this project, Council has engaged Aurecon and Rough Milne Mitchell (RMM) to develop the design of a tidal wetland within the Bexley redzone area, which is recognised as having the highest ecological potential in the entire river corridor. The available area for this wetland is between the new permanent stopbank (refer to Section 5.2.3) and the banks of the Ōtākaro / Avon River. This will need to consider the land required for stormwater treatment of the catchments draining to the Bexley project area (refer to Section 5.2).

The primary aim of the tidal wetland is to provide saltmarsh and wetland ecological habitat opportunities while ensuring that the new adjacent stopbank remains effective in protecting the area's infrastructure. A carefully balanced and resolved design is required to ensure both goals are met.

To maintain the habitat and wetland functions over time the wetland will be contoured in a way that allows for predicted future changes, such as sea level rise. Recreation paths within the site will be designed to protect the habitat, and a natural landscape approach will balance maintenance and stability of the stopbank.

The wetland will also serve as a platform for educating the public about the importance and function of wetland habitats and celebrating the unique habitat and flora and fauna of the region. A recreational network will be created that allows people to safely visit and travel through the site while expanding the linkages of this site to the surrounding environments and the remainder of the ŌARC. The integration of these objectives will not only enhance the ecological value of the area but also improve its cultural and recreational amenity.

Other work being incorporated as part of this project to help meet the vision of the ŌARC Regeneration Plan and Councils own six values approach to surface water management are:

- Planted first flush basins and wetlands to help improve the water quality through plant filtration over time
- Landscaping north and south of Wainoni Road, including the design of the city to sea pathway.

5 PROPOSED DESIGN

A multi-disciplinary design team has worked together to propose solutions that address the challenges and constraints discussed above. The preferred designs for each discipline have often clashed with one another, so a collaborative approach has been essential in finding compromises that consider all disciplines, while keeping flood protection a top priority. The design is currently at concept stage and is subject to ongoing development by the project team, in conjunction with Council discussions with mana whenua and other stakeholders.

5.1 WAINONI

The proposed concept design for the Wainoni project area consists of a stopbank located as far from the river as possible with a stormwater treatment area located on the river side of the stopbank. A flood wall is proposed where the distance between Anzac Drive / SH74 and the river is too small to fit the standard earth embankment stopbank cross section and an earth bund is proposed on the river side of the wetland to provide flood protection of the wetland during minor tidal events. Figures 9 and 10 show the proposed plan and cross section schematics for the design.

Figure 9. Schematic Plan Layout of Proposed Concept Design for the Wainoni Project Area

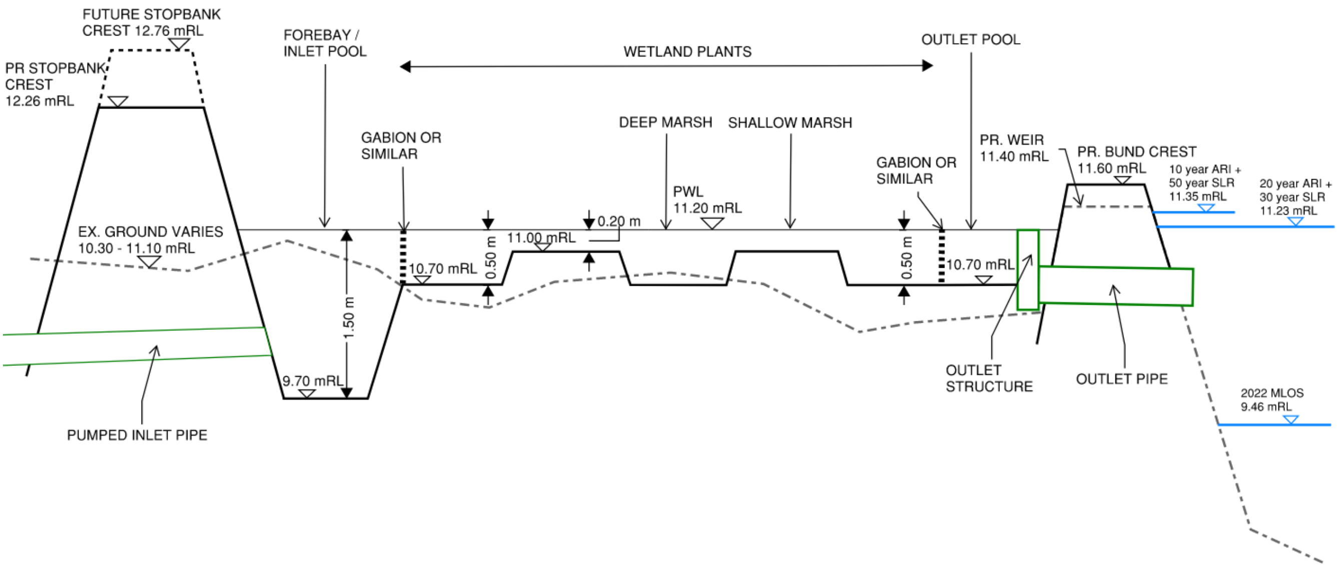

Figure 10. Schematic Cross Section of Proposed Concept Design for the Wainoni Project Area, Wetland Treatment Option

5.1.1 STOPBANK

After considering several different alignments, the stopbank location is proposed as far from the river as possible. As discussed in Section 3.3, this provides the best performing stopbank in seismic events. This means it is likely to require the least amount of maintenance and/or rebuilding over its asset life compared to other alignments, and it will provide a higher level of flood protection after earthquakes before it is repaired. The stopbank is proposed to tie into the high land adjacent to the SH74 bridge at its upstream end and the Waitaki stopbank at its downstream end.

Earth embankments with a core of low permeability engineered fill are the proposed form of stopbank wherever space allows. The core is to sit on a raft of geogrid reinforced engineered fill. This design does not minimise the effects of seismic related land damage but assists with reducing cracking of the stopbank embankment and helps facilitate managed remediation post-earthquake. Sheet pile reinforcement is proposed in sections of the stopbank that do not run parallel to the river to mitigate the risk of transverse cracking with future lateral spread.

The design crest level of the stopbank is set at 11.96 mRL, which provides flood protection up to the current 100-year ARI event with allowances for sea level rise and freeboard. The core will be built to 12.09 mRL to allow for construction and survey tolerance with the finished surface level to be at 12.26 mRL. Subject to future decisions on coastal adaptation, the design allows for the finished surface level of the stopbank to be raised to 12.76 mRL to provide further flood protection from rising sea levels. The current design provides sufficient crest width to allow for this future upgrade. The cross section of the proposed stopbank is shown in Figure 11.

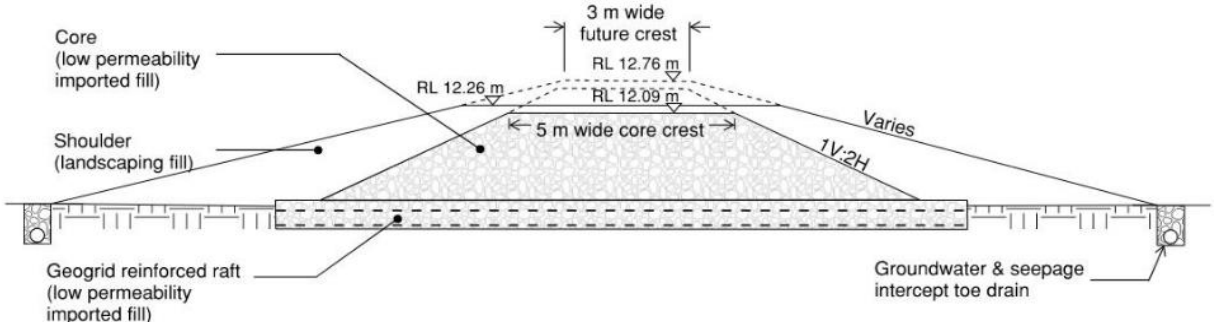

Figure 11. Standard Cross section of Proposed Stopbank

The ‘pinch point’ between SH74 and the river (refer Figure 9) does not provide sufficient space for the earth embankment stopbank, so a flood wall is proposed in this section. The flood wall consists of a single row of cantilevered steel sheet piles embedded into the ground, with the top of the sheet piles being the height of the future stopbank (12.76 mRL). The cross section of the proposed flood wall is shown in Figure 12.

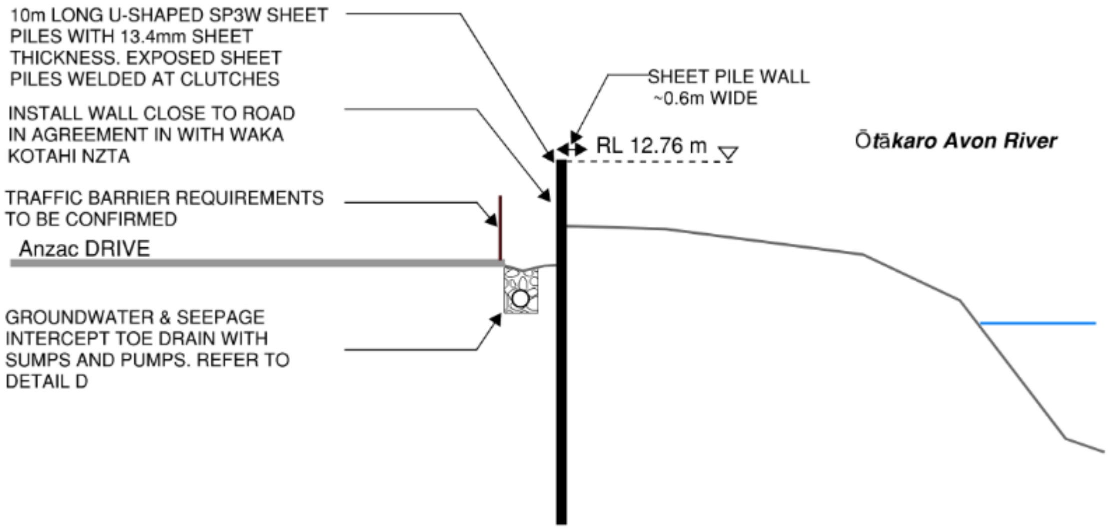

Figure 12. Standard Cross Section of Proposed Flood Wall

Toe drains will be located on the landward side of the floodwall and stopbank to help prevent groundwater flooding and reduce the risk of piping failure and instability due to permanent saturation of the embankment fill. The design of the toe drains has not yet been finalised but should consist of subsoils and/or swales.

5.1.2 STORMWATER TREATMENT FACILITY

Early in the project, Council indicated a preference for land-based treatment systems (e.g., wetlands) over proprietary treatment devices. This was largely due to the issues and costs associated with relying on suppliers for materials and parts and needing to use their preferred maintenance contractors. The Regeneration Plan also identifies wetlands and detention basins as the preferred method of stormwater treatment.

The proposed concept design includes a wetland to treat stormwater runoff from the upstream catchments (refer Figure 9) before it is discharged to the Ōtākaro / Avon River. The wetland is located on the river side of the proposed stopbank, meaning it will not receive any flood protection from the stopbank. Regular breaching of the river into the wetland would significantly reduce the effectiveness of the wetland by resuspending sediments and discharging these into the river. It could also have a negative impact on the vegetation in the wetland, either due to erosion or the salinity of the tidal river water. To reduce this risk, an earth embankment bund is proposed on the river side of the wetland (approximately on the alignment of the existing temporary stopbank) to provide flood protection up to an approximate future 10–20-year ARI tidal event. The flood protection provided by the bund would be less critical than that of the stopbank, meaning that the bund could be designed to a lower level of resilience, accepting that it will require more regular maintenance and repair.

The stopbank, bund and existing private property leave a relatively limited area available for the wetland. As mentioned in Section 3.3, offsets are required between new free faces and existing infrastructure to mitigate lateral spread risk and provide maintenance access, which further limits the area available. Ten metre offsets are provided from the bund and longitudinal section of the stopbank to the stormwater treatment facility, while 20 m offsets have been provided from the existing private property and transverse section of the stopbank to the stormwater treatment facility. The remaining area available for the wetland is 26,700 m^2.

The footprint required for a stormwater treatment facility is dependent on the size of the catchment that it is designed to treat runoff from and the design approach. There are several catchments upstream of the Wainoni site that discharge to the river. These are shown in Figure 13.

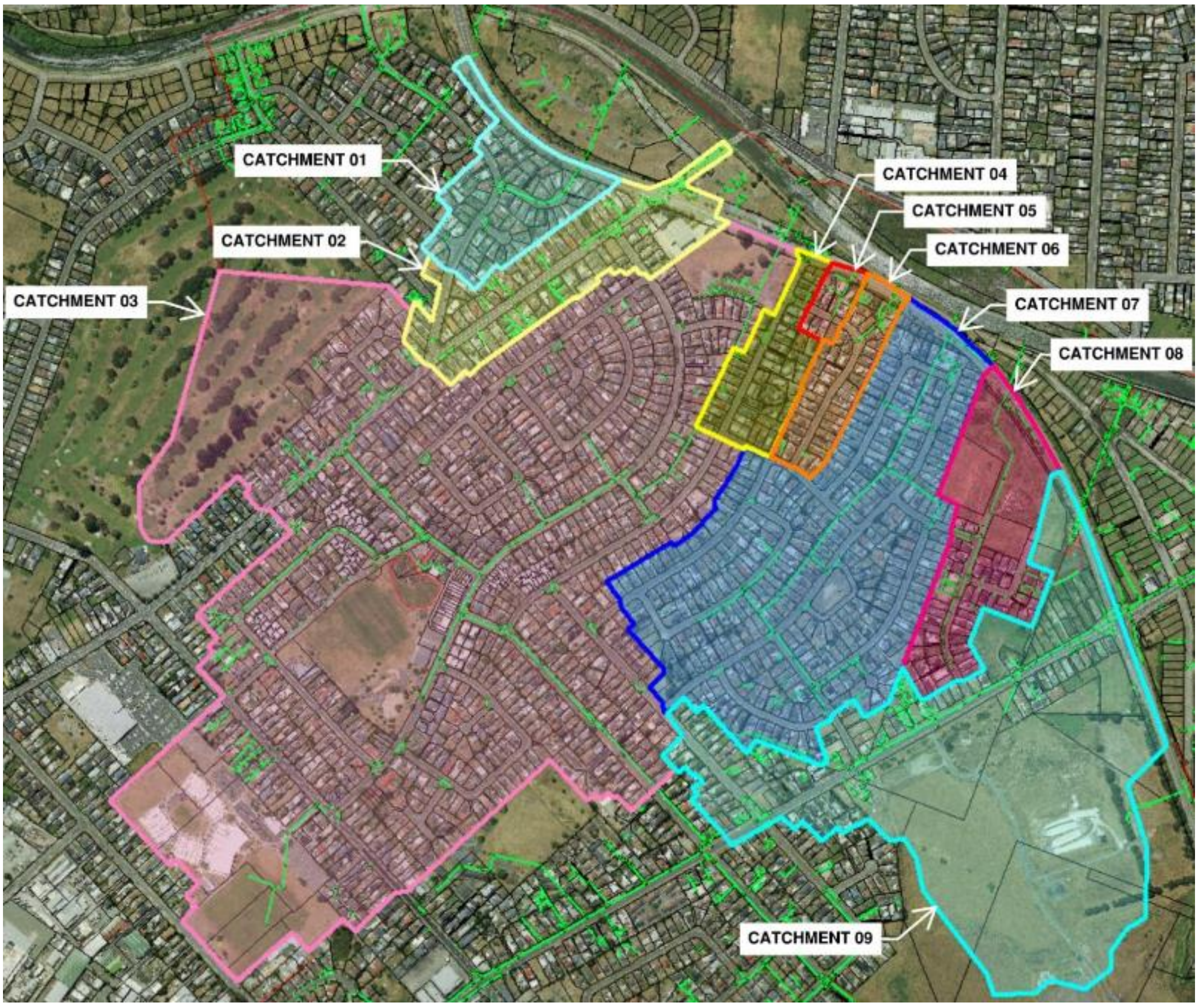

Figure 13. Existing Stormwater Catchments Draining to the Wainoni Project Area

Catchment 9 drains to the south to the Knights Drain catchment/PS232, and the water quality volumes and flows from catchments 5 - 8 were included in the Waitaki project design (refer Section 3.1.1). This means that the stormwater treatment facility in the Wainoni area is only required to treat water quality volumes and flows from catchments 1–4.

Table 2 shows the sizes of catchments 1-4 and summarises the water quality volumes and flows calculated using the standard approach in Council's Waterways Drainage Design Guidelines (WWDG).

Table 2. Existing Stormwater Catchment Areas and First Flush Volumes for the Wainoni Project Area

Catchment	Area (ha)	First flush volume (m^3)
Catchment 1	5.732	580
Catchment 2	8.521	863
Catchment 3	95.762	9696
Catchment 4	3.998	405
Total	**114.013**	**11,544**

Council's standard design approach for wetlands, as set out in the Waterways, Wetlands and Drainage Guide (WWDG), can be summarised as follows:

- A first flush depth of 25 mm

- A first flush (dry) basin that is sized to capture the first flush runoff volume from the catchment and drain this volume to the wetland over 4 days
- A 0.25 m deep wetland designed to receive discharge from the first flush basin with a two-day retention time

Council's design approach results in a wetland footprint of 42,300 m^2, more than one and a half times the available area. The significant difference between the area required as per this method and the actual area available (26,700 m^2) means that some form of compromise or alterative option is needed.

Auckland Council's GD01 approach sets out a different approach for wetland design:

- Wetland of varying depth (generally 0.2-0.5 m depth) with a permanent water volume equal to the first flush volume
- Inlet pool of 1.5 m depth, designed to hold 15% of the first flush volume
- Outlet pool of 1.0 m depth

Adopting this design approach, with the Council first flush rainfall depth of 25 mm and an average depth of 0.4 m over the wetland, results in a wetland footprint of approximately 28,900 m^2. This approach was adopted for the concept design due to being considerably more space efficient than the WWDG approach and is shown in Figure 9. However, the GD01 approach does not provide the same flow buffering and settlement time as Council's design approach with a first flush basin prior to the wetland.

At time of writing, a range of treatment options are being considered to balance flow buffering, treatment efficiency, capital and operational costs, and carbon. While Council prefers land-based treatment where possible, the options being considered include the use of proprietary devices due to the significant space constraints of the site.

5.1.3 STORMWATER PUMPING

As discussed in Section 3.2, existing ground levels in the site are relatively low compared to tidal levels in the river. As climate change continues to cause sea levels to rise, gravity-based stormwater discharges are going to become increasingly unreliable. The proposed stopbank will also prevent overland flow from the catchments upstream of the Wainoni site from draining to the river via gravity. Stormwater pumping is proposed to address these two issues.

Pumping into the proposed wetland, rather than out of it, allows for shallower excavation depths. As previously discussed, there is a strong preference to keep excavation depths as shallow as possible due to the geotechnical risks associated with deep excavations creating new free faces (increasing lateral spread risk) and the high groundwater table. The pump is designed to convey the water quality flows from catchments 1-4 to the inlet of the wetland. It is also designed to convey the 50-year flows directly to the river via a pipe that bypasses the wetland.

5.2 BEXLEY

The Bexley site area comprises three stormwater catchments; the Anzac Dive catchment, Pages Road catchment, and Estuary Drain catchment (Figure 14) which all drain to the Ōtākaro / Avon River via existing stormwater infrastructure and drains.

The concept design for Bexley considered the treatment of runoff from the three contributing stormwater catchments separately. For the Estuary Drain catchment, treatment and pumping off-site and within the site were both considered, while only treatment onsite was considered for the Pages Road and Anzac Drive catchments.

Figure 9. Existing Stormwater Catchments Draining to the Bexley Project Area

The areas of each catchment are shown below in Table 3.

Table 3. Existing Stormwater Catchment Areas and First Flush Volumes for the Bexley project area

Catchment	Area (ha)	First flush volume (m^3)
Estuary Drain - Total	131.8	N/A
Estuary Drain – Residential and roads	82.2	8,324
Anzac Drive	2.2	502
Pages Road	0.6	136

5.2.1 STOPBANK

The stopbank in the Bexley area will be formed from engineered fill as per Figure 11 and will have the same finished crest level of 12.26 mRL as the Wainoni site (refer Section 5.1.1). The proposed stopbank in the Bexley site is positioned as far away from the river as possible, while still allowing sufficient room for treatment of the Anzac Drive catchment along the eastern side of Anzac Drive. Similar to the Wainoni site, this provides the best performing stopbank in seismic events and will also provide a higher level of flood protection during and after earthquakes. The stopbank is proposed to tie into the Pages Road Bridge at the northern end and existing ground at the southern end.

The proposed stopbank has the same cross section as the Wainoni site, as shown in Figure 11.

5.2.2 ESTUARY DRAIN CATCHMENT

The location and depth of the treatment system is dictated by the levels of the upstream gravity stormwater network and levels along Estuary Drain, which conveys the majority of this catchments flow. As noted above, both on-site and off-site treatment options were evaluated, but it was determined early in the design process that a treatment wetland within the Bexley project site would occupy a large portion of valuable space designated for ecological restoration and naturalisation of the river margin (as discussed in Section 4), rendering it an unfavourable option.

It was also determined that a treatment wetland in the Bexley site would be particularly susceptible to lateral spread during seismic events due to the ground conditions and proximity to the river. With time, high, saline groundwater would also likely impair wetland performance and plant survival. Similar to the design proposed for the Wainoni site, pumping into the wetland would be required to keep excavation depths to a minimum. It was also determined that the presence of the Bexley landfill in the lower section of the catchment creates a risk that landfill contaminants will be present in the runoff from the Estuary Drain catchment and that these are not suited to be effectively treated by a wetland. Consequently, a subsequent investigation was initiated to examine options for treating runoff from both the Bexley Landfill and Estuary Drain. This investigation is ongoing and is excluded from further discussion in this paper.

5.2.3 ANZAC DRIVE AND PAGES ROAD

The Anzac Drive and Pages Road catchments require treatment options that address the small and linear nature of these road catchments. Swales were identified as a suitable starting point as they provide a means of combining the conveyance of runoff flows and treatment using vegetation to reduce contaminants. Vegetated swales were preferred over grass swales due to their greater effective treatment capabilities. Grass swales are also not desirable in areas with high groundwater levels, as they may result in waterlogged grass that cannot be maintained.

The design of the vegetated swales was carried out in accordance with Auckland Council's GD01 (as per recommendations in the WWDG), which ensures an average hydraulic residence time of greater than 9 minutes and a velocity of less than 0.8 m/s for a water quality event, and velocity less than 1.5 m/s for a 10-year ARI event.

A. Anzac Drive

A typical cross section for the Anzac Drive swale is illustrated in Figure 15 below. The swale is proposed to be located along the eastern side of Anzac Drive, sloping north towards the intersection with Pages Road. Due to the high groundwater and risk of lateral spreading in the area, the swale depth has been minimised as much as possible without increasing the base width past 2.5 m. Widths greater than 2.5 m can lead to the formation of preferential flow channels within the swale base, limiting the ability of the flow to spread evenly across the base and subsequently limiting treatment efficiency.

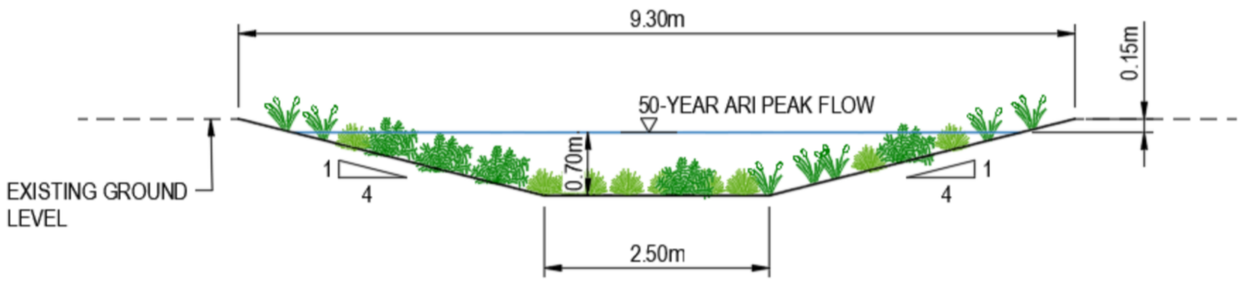

Figure 10. Anzac Drive Typical Vegetated Swale Cross Section

B. Pages Road

A typical swale cross section for the Pages Road swale is shown in Figure 16. The swale is proposed to be located along the southern side of Pages Road, sloping west towards the intersection with Anzac Drive, to meet the discharge of the Anzac Drive swale. This prevents the requirement for two separate pump stations (one at the end of each swale).

The existing stormwater infrastructure on the northern side of Pages Road will remain, including the existing DN375 earthenware culverts (dependent on their condition), to convey runoff from the north side of Pages Road into the proposed swale.

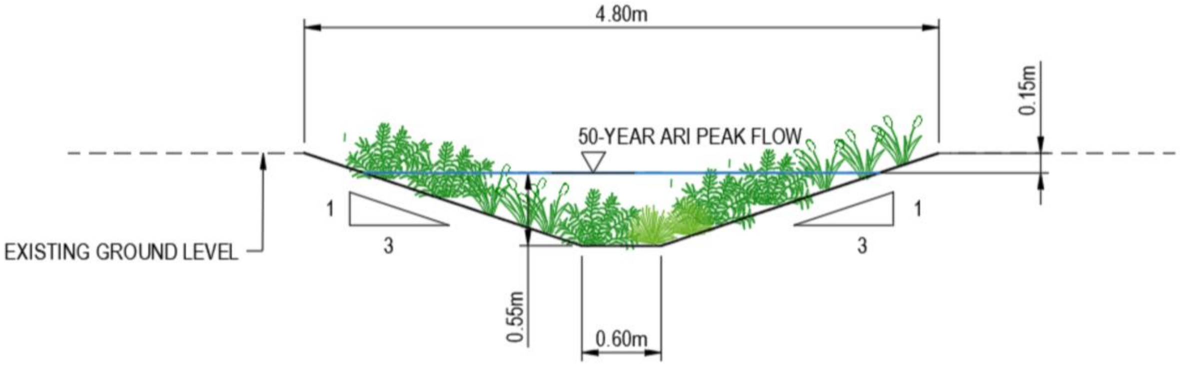

Figure 11. Pages Road Typical Vegetated Swale Cross Section

The use of swales is the preferred option for the conveyance and treatment of these local catchments, as the catchment areas do not warrant the construction of a large treatment facility that would reduce the available space for the Bexley tidal wetland.

Typical cross sections were developed to consider the impacts of the proposed swales on the adjacent infrastructure (Anzac Drive and Pages Road), and the impacts on the proposed permanent stopbank alignment (i.e. required offset from road boundaries), and subsequent impacts on land stability and groundwater (Figure 12 and Figure 13).

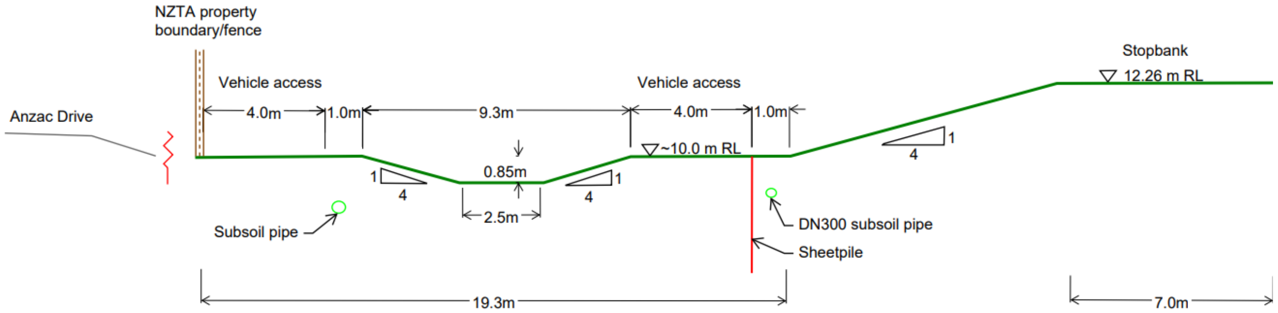

Figure 12. Typical Cross Section Anzac Drive

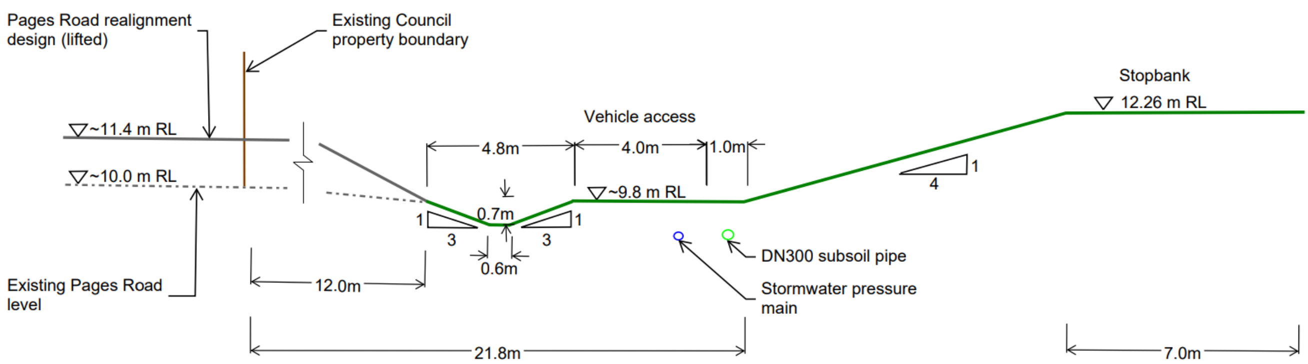

Figure 13. Typical Cross Section Pages Road

Despite making the treatment swales as shallow as practicable, it is likely that the Anzac Drive swale will still intercept groundwater, drawing in saline water from the east and landfill leachate from the Bexley Closed Landfill from the west. Similarly, the Pages Road swale is likely to intercept saline groundwater from the south. This saline ingress has the potential to limit the ability for freshwater flora to be maintained in the swale, particularly in light of potential sea level rise in the future. As such, treatment efficiencies may be limited.

To mitigate this risk, sheet piles and subsoil drains have been incorporated into the design. A sheet pile wall has been included at the base of the adjacent stopbank to cut-off saline groundwater paths from the tidal wetland that will be present on the opposite side of the stopbank. Additionally, subsoils have been included on either side of the swale. The eastern subsoil will help intercept what saline groundwater does flow towards the free face of the swale, as well as any drainage from the stopbank. While the western subsoil will intercept leachate flow from under Anzac Drive.

To treat potential landfill leachate, consideration is being given to pumping the western subsoil drain to the Christchurch Wastewater Treatment Plant via the existing wastewater system. The eastern subsoil drain, on the other hand, is proposed to be connected to the stormwater pump station and pumped to the Ōtākaro / Avon River.

As sea levels rise and associated groundwater levels increase, the subsoils and cut-off protection will become increasingly important in providing protection against potential increases in saline groundwater and landfill leachate generation in the vicinity of the stop banks.

5.3 CURRENT STATUS AND NEXT STEPS

The concept designs for both sites have been delivered to Council, however, there are unresolved items that will need to be addressed in future design stages. The most critical of these are:

- The type of stormwater treatment facility for treating runoff from the catchments draining to the Wainoni site. Council has identified a preference for land-based treatment, however, the significant spatial constraints of the site may warrant the use of a proprietary device
- The type and location of the stormwater treatment facility for treating runoff from the Estuary Drain catchment. The runoff is contaminated due to the presence of the Bexley Landfill, so cannot be treated conventionally.

The solutions to these issues will require ongoing coordination between multiple disciplines and project stakeholders who will need to consider and balance the challenges associated with each site. There may be changes to the proposed design solution as the design develops and with engagement with other stakeholders.

6 CONCLUSIONS

The ŌARC project provides a unique opportunity to transform a significantly damaged part of Christchurch into an area that provides ecological, environmental and community benefits.

The Wainoni and Bexley sites of the ŌARC present several design challenges. These include:

- Spatial constraints associated with the river, Anzac Drive / SH74 and private property

- Low lying ground that is susceptible to liquefaction and lateral spreading in seismic events
- High, saline groundwater
- Tidally influenced river and groundwater levels that will be affected by climate change
- Low lying existing stormwater networks in relation to river levels
- Contaminated land

The concept design has been developed by a multi-disciplinary team, including Council staff, working together to understand the constraints and issues for each discipline and arrive at compromises and design solutions. The proposed concept design for each site addresses these challenges while maintaining consistency with the ŌARC Regeneration Plan and Council's six values approach for surface water management. The design is subject to ongoing development informed by Council discussions with mana whenua and other stakeholders.

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