A SYSTEMIC TOOL FOR A MULTI-VALUE STORMWATER MANAGEMENT SYSTEM

Kuta L, Powell T(e2Environmental)

ABSTRACT (500 WORDS MAXIMUM)

Christchurch has always been prone to flooding due to its urban waterways, flat topography and low-lying nature. Water quality in the urban waterways has been further impacted by legacy of the city's development. The Canterbury earthquakes and on-going urbanisation further increase flood vulnerability, and also Council and the local community are now putting more emphasis on the ecological and social values of the water environment; therefore, multi-value analysis and design tools that look at the system in its entirety need to be utilised moving forward.

A stormwater management approach focusing solely on improvement of stormwater conveyance is no longer best practice. An interdisciplinary method that can offer solutions to fulfill multiple functions is the more current course for stormwater management. Mathematical modelling of physical processes (e.g. wind impact, spring flow vs. stormwater flow etc.) is one of the important tools used to help designers and policy makers understand the overall behavior and interactions among some individual components within the system, and thus contributing to a better stormwater management outcome.

This paper examines how a computational modelling tool was used to provide multiple-value solutions to the stormwater challenges in a segment of the Heathcote River catchment. The design of the Sutherlands Basins stormwater system in the south west of the Heathcote River catchment was guided by the modelling results, which achieves functions such as: creating better places and connecting people with water through integrating cycleways, walkways and plantings, maintaining stream water quality and ecosystem health through reduction of fine sediments and separation of all stormwater from spring-fed stream, maintaining healthy flow regimes through reduction of urbanisation induced flood flows in the Heathcote River, and improving adaptability through consideration of fully developed scenarios. The model expands beyond the Sutherlands Basins to include the wider Sutherlands Eastman stormwater treatment facility, which is understood to be the largest stormwater treatment facility in the South Island.

This paper outlines the modelling approach selected and how the diverse functionality of the stormwater system designed was achieved through the aid of modelling tools. This paper also discusses some innovative techniques applied such as utilisation of drone in flood modelling, analysis of wind effects and offline stormwater to maintain water quality in spring fed streams.

KEYWORDS

Multi-value stormwater management system, flood modelling, drones and floods.

PRESENTER PROFILE

Ting Powell is a consulting engineer specialising in river and stormwater engineering. She has a Bachelor of Natural Resources Engineering as well as an LL.B.. Her primary focus is on numerical modelling of hydrology and hydraulics, concept and detailed design of urban stormwater infrastructure as well as river control and hydraulic structures.

Laddie Kuta is a chartered engineer with over 20years of global experience in local/regional government, academic research, and private consulting. Laddie specialises in river engineering and flood mitigation modelling and design. His diverse technical background and his affinity for the natural environment translates into practical solutions to complex environmental problems.

1 INTRODUCTION

For the last 20 – 30 years, the stormwater management philosophy in Christchurch has shifted from a sole focus on stormwater conveyance toward a multi-value approach (Christchurch City Council, 2003). Six values: ecology, landscape, recreation, heritage, culture and drainage, were identified as being associated with the water environment. Nowadays, the stormwater facility design teams are composed of specialists with diverse backgrounds, who collectively provide inputs during the iterative design process.

The design of Sutherlands Basin, which is understood to be the largest stormwater treatment facility in the South Island when combined with the Eastman wetland system, demonstrates that computational modelling is an effective and essential design tool to provide multi-value solutions to the stormwater challenge. The flood model not only allowed a design to be tested and verified through quickly adding or/and modifying elements in the model, but also proved to be the centering tool that brings all the stakeholders of the project together, creating a collective understandings of the project.

This paper will discuss the modelling approach selected and how the diverse functionality of the stormwater system designed was achieved through the aid of modelling.

2 BACKGROUND

2.1 MULTI-VALUE STORMWATER MANAGEMENT APPROACH

Christchurch has always been prone to flooding due to its urban waterways, flat topography and low-lying nature. Most of the Christchurch City is built on an area of low-lying floodplain bounded by the Waimakariri River to the north, the Port Hills to the south and the Pacific to the east. The city has 240 km of rivers and tributaries, 130 km of utility waterways (lined/unlined drains), 790 km stormwater pipe network (Parsons & Preston, 2016) and over 50 wetlands (Christchurch City Council, 2003). The Christchurch earthquake sequence has further increased flood risks in certain communities due to land subsidence, reduced storage capacity in some reaches of streams and damage to the stormwater infrastructure.

Historically, the management of surface water in Christchurch was focused solely on drainage efficiency. However, for the last 20 – 30 years, the management philosophy has slowly shifted toward a more holistic and integrated approach (Christchurch City Council, 2003). The new philosophy intends to work with nature rather than a sole focus, emphasising on incorporating knowledge from a diverse disciplines to achieve multiple societal values. A multi-value stormwater management approach was adopted and six values associated with water environment were identified as ecology, landscape, recreation, heritage, culture and drainage.

2.2 STUDY AREA

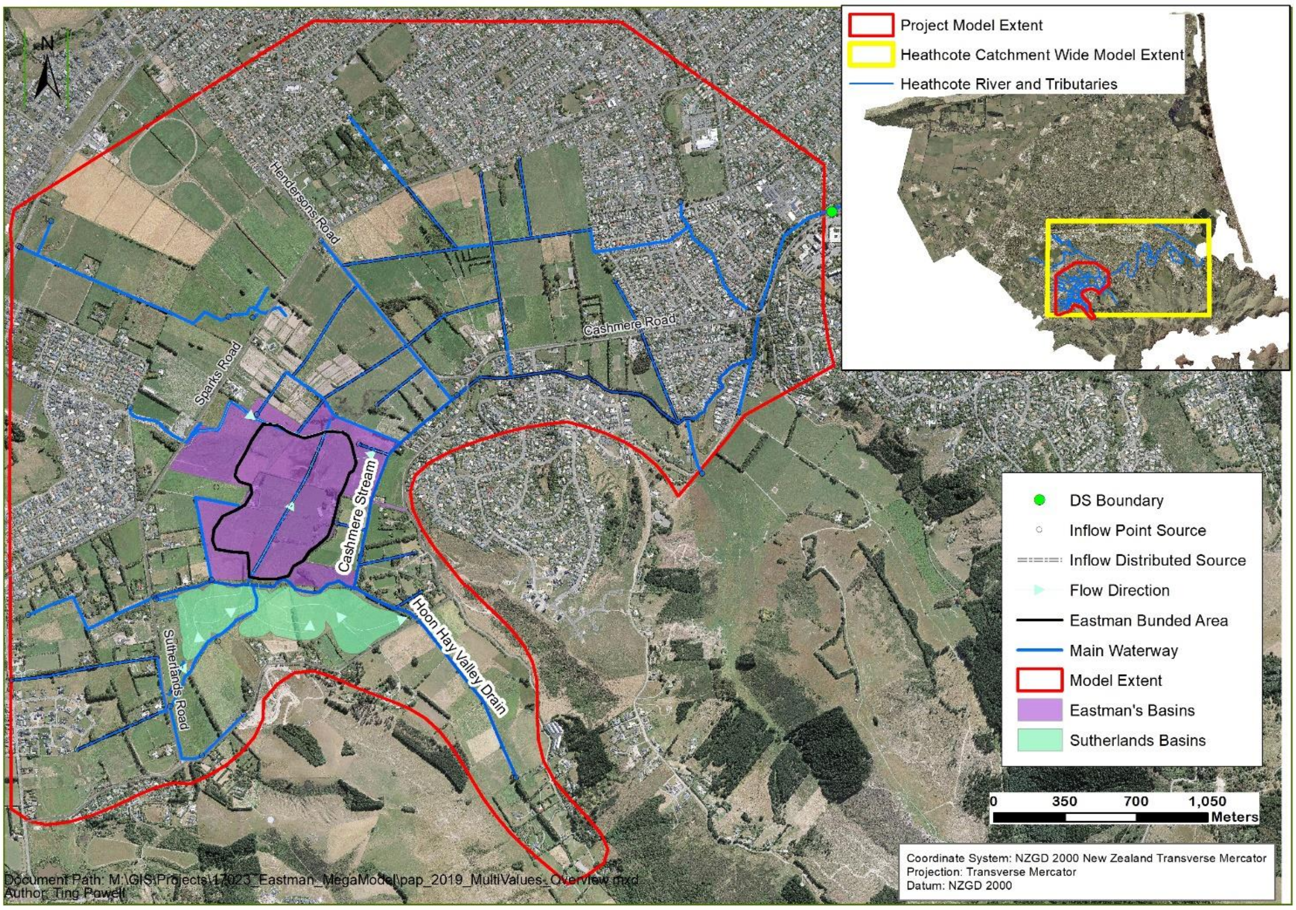
The Heathcote catchment stretches from the south-west of Christchurch to the Avon-Heathcote Estuary to the east covering an area of 103 km² (Christchurch City Council, 2016). The 25.5 km long Heathcote River originates from springs that are interconnected to the Waimakariri River system. The Heathcote River collects its runoff from the steep

Port Hills along its entire length from the right bank side and from the flat Canterbury Plain from its left bank side.

The Canterbury Plain and the Port Hills have distinct surface geology. The soil on the plain is mainly gravel, sand and silt that was deposited when Waimakariri River fanned across the land. On the other hand, the Port Hills were formed by volcanic activities and are composed of basaltic flows, ash deposits and intrusive rocks (Christchurch City Council, 2009). The readily erodible soil on the Port Hills is glacier clay known as ‘loess’, which was blown across from the Southern Alps. In the Heathcote catchment, runoff can occur rapidly from the hills once the soil moisture has been restored, contributing to the flood risk and generating yellow-brown opaque colour sediment from the highly erosive loess soil. Sediment from the Port Hills has been identified as a major contributor to reduced flood carrying capacity of the river/tributaries and decreased in-stream habitats (Christchurch City Council, 2016).

Eastman/Sutherlands/Hoon Hay stormwater facilities (Figure 1) are located within the Hendersons Basin in the upper Heathcote catchment. Hendersons Basin, bounded by Sparks Road, Hendersons Road, Cashmere Road and Sutherlands Road, is the largest natural ponding area of the catchment where remnant wetlands can be found. This area is prone to flooding because of the shallow groundwater aquifer, the confluence of streams and tributaries, and the restriction on downstream flows.

Figure 1: The location of Eastman/Sutherlands/Hoon Hay stormwater facilities and the flood model extents.



The rain-fed Hoon Hay Valley Drain flows seasonally from the Port Hills and discharges into eastern side of the Sutherlands Basins with a large amount of fine sediment. The spring-fed Cashmere stream separates the Sutherlands Basins from the partially constructed (as in February 2019) Eastman Wetlands. The 10 km Cashmere stream is the most significant tributary of the Heathcote River, and was identified as one of the areas with highest ecological value of the catchment (Christchurch City Council, 2016).

The development in the Heathcote catchment historically begun in the lower Heathcote. Now, the upper Heathcote area is expected to undergo major urban growth in the next 20 years (Christchurch City Council, 2009). Existing old development limits options to expand the floodway to the estuary for major flood events. As development continues in the upper catchment, it was identified that provision of adequate flood detention in the upper catchment to moderate peak flow into the Cashmere Stream is one of the most practical flood mitigation measures (Christchurch City Council, 2016).

2.3 PROJECT BACKGROUND

Christchurch City Council (CCC) Land Drainage Recovery Programme (LDRP) has been progressing works south-west of the city in the lower land of the Cashmere Stream Catchment. These projects serve numerous functions, and some of which will be discussed in detail in Section 5.

Initially, the design of Sutherlands Basins was independent of the study of the Eastman and Hoon Hay Valley stormwater facilities. A 1-D hydrodynamic model was developed to guide the preliminary design of the volume and general grade of the basins, which consists of a series of first flush basins, flood attenuation basins and constructed wetlands.

As the Sutherlands Basins project progressed, Council decided to take a more holistic approach, so the surrounding two stormwater systems (i.e. the Eastman Wetlands and Hoon Hay Valley Drain) were also being taken into account. The Eastman Wetlands, which was already partially constructed, is located to the north of the Sutherlands Basins across the Cashmere Stream. Both the Eastman Wetlands and Sutherlands Basins are sizable projects in terms of their footprints at over 60 ha and over 20 ha, respectively. Since these projects are adjacent to each other, it is logical they hydraulically work together under various runoff scenarios other than their individual and original design intention.

Following the original design of the Eastman Wetlands and Sutherlands Basins, Council decided to investigate the potential of not only combining these two systems for their local runoff management, but also to include the management of runoff from Hoon Hay Valley. Requirements to progress these systems include understanding the collective hydraulic potential for all of the Eastman Wetlands, Sutherlands Basins, and Hoon Hay Valley runoff. This includes understanding the potential of infrastructure required to hydraulically connect all of these systems by retrofitting the currently built and designed systems. As a result of the complexity of the interaction between the three systems, it became obvious that a 1D/2D coupled flood model would be an essential tool for the design process.

In addition, because the combined Sutherlands Basin and Eastman Wetlands cover a large area of 80 ha, impacts such as wind effects need to be understood. Only when wave setup at critical points in the basins during and following an event is estimated, an appropriate freeboard at the basins’ full capacity can be designed for. Another important constraint in terms of design flood level on the Eastman Wetlands is a substation located on the north side of Sparks Road. The critical level on the substation will determine how high flood waters, inclusive of wind effects, can safely be raised within the Eastman Wetlands. This further exemplifies the need for a complex and high resolution numerical model since the waters that create this critical flood level are sourced from local rainfall and runoff, backwatering from the Cashmere Stream, and potentially spill over from the Sutherlands Basins.

Eventually, a more sophisticated 1D/2D coupled flood model that covers the expanded study area and with an adequate resolution for study/design purpose was developed. The model could be changed, manipulated and re-simulated quickly, which provided an efficient and effective way to test and verify the designs during the iterative design process. This iterative process involved a multi-disciplinary team. The visualisation that resulted from the 2D model aided communications between engineers and other professionals such as project managers, planners, ecologists and landscape architects who were all involved in the projects. The flood model proved to be the centering tool that brings all the stakeholders of the project together, creating a collective understandings of the project.

3 MODELLING APPROACH

Several flood models have been built which covers the project area. CCC already owns a coarser flood model that includes the entire Heathcote Catchment. The existing Heathcote catchment-wide model couples 1D open channel with 2D floodplain on 10 m x 10 m classic grids. The Eastman Wetlands was presented as a bunded area in the latest version of the Heathcote model at the time, a significantly simplified representation of the facility. The use of this model is primarily for planning purposes, so the resolution is not refined enough for design purposes.

At the initial Sutherlands Basins' design stage, a 1D flood model that covers Sutherlands Basins, the open drains and the Cashmere Stream upstream of the facility was developed. It was used to confirm preliminary sizing and hydraulics of the facility. This work also involved field survey and catchment analysis. A hydrological model was developed using estimated and established catchment parameters. The hydrological model results formed the inflow boundary conditions for the 1D channels. Appropriate values for channel roughness was estimated after a site condition assessment. However, this model only considers the Sutherlands Basins system alone ignoring its interactions with the adjacent Eastman Wetlands and Hoon Hay Valley Drain systems.

In the end, a new integrated modelling approach was selected to cover the Eastman Wetlands, Sutherlands Basins and Hoon Hay Valley stormwater systems. This model couples 1D channels with 2D floodplain in flexible mesh. The model was developed using DHI MIKE Flood software. The hydrological input and 1D channels of the model were predominately based on the existing Heathcote catchment-wide model, but with greater and up-to-date details on the Eastman Wetlands and Sutherlands Basin areas. The model contains the complete length of Cashmere Stream, the likely flooded area on the lower land of the Cashmere catchment as well as Hoon Hay Valley. The model boundary was set further away from the area of interest to minimise potential artificial effects on the model within the area of interest. Further details about the model will be discussed in the following section. The reasoning for the modelling approach selected is summarised as follow:

- The Heathcote catchment-wide model, which uses 10 m x 10 m grid, was developed for planning purposes. It does not provide sufficient resolution for the purpose of designing Sutherlands Basins. Furthermore, because a design process involves numerous iterative steps it is not efficient to use a complete catchment-wide model. By developing a refined model with the same hydrological input as the catchment-wide model, the degree of alignment between the coarser and finer flood models can be compared and evaluated. Any misalignment provides a warning sign of any potential modelling issues.
- Flexible mesh enables better representation of roads and major features of topography without resorting to very small elements, which may require much longer model runtime and create stability issues.

- The initial Sutherlands Basin model only covers Sutherlands Basins, the open drains and Cashmere Stream upstream of the facility. A model that covers adjacent Eastman Wetlands and Hoon Hay Valley Drain area provides better understanding of the collective hydraulic potential for the systems. This provides designers a more holistic picture of the complex interactive stormwater systems.
- A 2D model allows basin to be modelled more realistically (i.e. proper side slopes) and provides visualisation of the flooding results.
- A coupled model allows water exchange between floodplain, basins and open channels providing more realistic results of the complex interactive systems.
- The resulting coupled model with flexible mesh would be readily integrated with the Council's city-wide model project.

4 MODEL DESCRIPTION

4.1 MODEL CONFIGURATION

The 1D component of the Eastman-Sutherlands-Hoon Hay stormwater model consists of 42 branches representing open channels, generally laterally link to the 2D surface from both the right and left banks. All the channels that have been modelled in 1D were removed in the 2D mesh to avoid doubling conveyance.

The catchment hydrology runoffs were connected into the 1D model via boundary conditions as point or distributed sources. The hydrology and baseflow data were directly copied from the existing Heathcote model without modification.

4.2 MODEL EXTENT

Figure 1 shows the Eastman-Sutherlands-Hoon Hay stormwater model extent. The extent covers the complete length of Cashmere Stream and a major part of the Cashmere catchment. The area covers the likely flooded area on the lower land of the Cashmere catchment as well as Hoon Hay Valley. The downstream open boundary condition was located at the Heathcote River (Ferniehurst) further away from the area of interest to minimise potential artificial effects on the model in the area of interest. The total 2D extent is 1,100 ha among which Eastman's Basins and Sutherlands Basins cover approximately 60 ha and 20 ha respectively.

The Cashmere Stream and the majority of its tributaries and connecting open drains were modelled in 1D. Cashmere Stream rises from springs west of Sutherlands Road and flows into Heathcote River at Cashmere Road near the Hoon Hay Road and Worsleys Road junction.

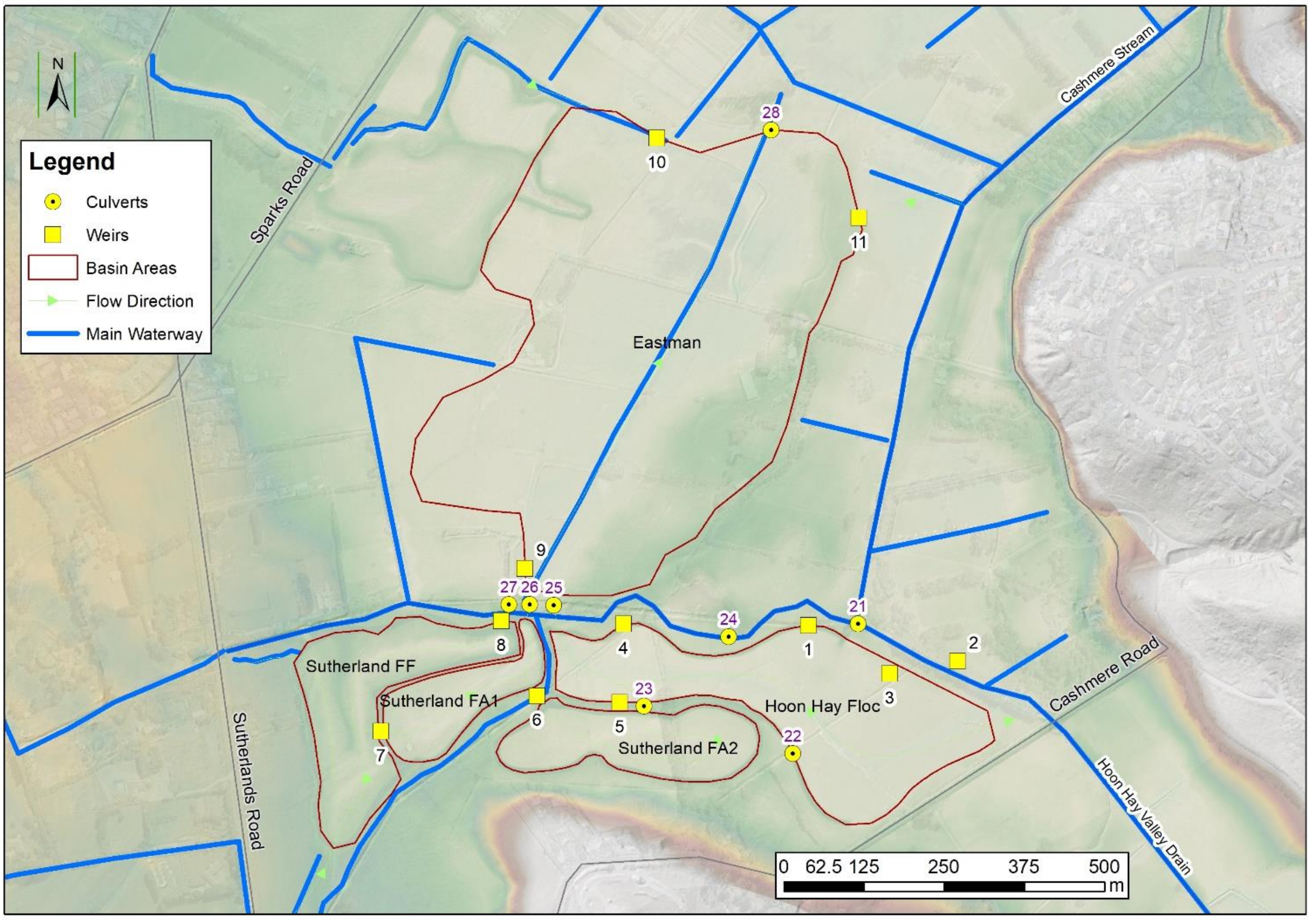
4.3 BOUNDARY CONDITIONS

The original Heathcote Catchment wide model results were used to form the boundary conditions of the new model. The water level result from the existing Heathcote model at the most downstream end of the new model was used as the new model's downstream open boundary condition, and the discharge at the upstream 1D channels were used as the inflow boundary conditions at those locations.

4.4 CONTROL STRUCTURE

The complex control structures were simulated and designed during the iterative design process. Figure 2 shows the complex control structures designed in the model.

Figure 2: The complex control structures modelled in the Eastman-Sutherlands-Hoon Hay stormwater model.



4.5 2D MODEL WITH FLEXIBLE MESH

Flexible mesh was generated to represent the major features of the topography without resorting to very small elements. The smallest mesh generated was approximately 0.7 m². All the channels that have been modelled in 1D were removed in the mesh to avoid doubling conveyance. The total number of mesh elements of the model is 90,310.

4.6 COUPLED 1D/2D MODEL

34 standard links coupled the ends of the 1D branches to the basins in the 2D model. The 1D open channels were linked laterally from both the left and right banks of the channels to allow water to exchange between the channel and the 2D surface.

4.7 SENSITIVITY TESTING

An additional two model runs on the 2% AEP storm events were conducted to assess the sensitivity of hydraulic roughness or flow. In both of the 1D and 2D models, the manning's numbers were increased by a factor of 1.15 and decreased by a factor of 0.85 from the original set-up.

4.8 WIND EFFECTS

Constant wind forcing was included in the 2D models in two model runs to investigate the local wind effect on the water level in the Eastman's bunded area. One included constant NE wind forcing at 16.7 m/s (NE 32.5 knots or 60 km/hr), and the other included constant SW wind forcing at 7.2 m/s (SW 14 knots or 26 km/hr).

4.9 APPLICATION OF DRONE

Drone footage was taken during the extreme storm event on the 22nd of July 2017. The extreme rainfall coincided with some very high storm tides for Christchurch. The footage provides an insight to the actual flood behavior of the area and the extent of flooding for this period of return event. Figure 3 & 4 show a couple of snapshots taken by the drone.

Figure 3: A snapshot of the aerial footage taken on the 23rd of July 2017 looking at the constructed Eastman Wetlands.

Figure 4: A snapshot of the aerial footage taken on the 23rd of July 2017 looking from the constructed Eastman Wetlands toward the proposed Sutherlands Basins.

5 PROJECT OUTCOMES

The ultimate design of the Sutherlands Basins stormwater facility meets the multi-values functional requirements discussed in Section 2.1. The design process of the project was iterative, with opinions from other specialists continuously being incorporated into the design. The flood model was modified and re-simulated when necessary to confirm the integrity of the system. The final design achieves functions such as:

- Improve water quality through treatment prior to entering the river and tributary system.
- Improve in-stream and riparian habitats through enhancing waterway corridors for Cashmere Stream and Quarry Road Drain.
- Reduce fine sediment entering the Cashmere Stream from Port Hills through the use of constructed wetlands to store and treat runoff from Hoon Hay valley drain.
- Maintain the ecological value of the Cashmere Stream through the use of off-lining stormwater system to prevent mixing of spring water with stormwater runoff.
- Reduce flood risk, at least, returned to pre-earthquake levels through slow release of stormwater into the Heathcote Catchment.
- Maintain healthy flow regimes through control structures to reduce urbanisation induced flood flows in the Heathcote River.
- Provide local stormwater conveyance.
- Create better places and connect people with water through integrating cycleways, walkways and plantings.
- Maintain stream water quality and ecosystem health through reduction of fine sediments and separation of all stormwater from spring-fed stream.
- Improve adaptability through consideration of climate change and full development scenarios.

6 CONCLUSIONS

A coupled 1D/2D flood model with flexible mesh was developed to design the Sutherlands Basins stormwater facility in the upper Heathcote catchment in Christchurch. The final design of the Sutherlands Basins stormwater facility achieves a number of ecological, drainage, landscape, cultural and recreational functions. The model incorporates the adjacent Eastman Wetlands system as well as Hoon Hay Valley drain system. This integrated approach provides a better understanding of how these interconnected systems interact with each other, therefore, a more holistic design outcome can be accomplished.

The Sutherlands Basins design project showcased in this paper shows that computational modelling is an efficient and effective tool to provide multiple-value solutions to a stormwater management challenge. With the aid of modelling, various scenarios from sensitivity of the system to the effects of potential future changes can be evaluated appropriately. Any design changes can be quickly tested by adding or modifying elements/boundary conditions in the model. The project also demonstrates that computational modelling is a valuable tool during an iterative design process, particularly one that involves a multidisciplinary design team. Computational modelling proves to be a centering tool that can bring all the stakeholders of the project together, creating a collective understandings of the project.

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