MANAGING POST-EARTHQUAKE STORMWATER RISK IN NEW BRIGHTON

Kate Purton (SCIRT/Beca) & Murray Kerr (SCIRT/Beca)

ABSTRACT

The Christchurch suburb of New Brighton is bounded by the Pacific Ocean to the east and the Avon River/Ōtakaro and Avon-Heathcote Estuary/Ihutai to the west. It drains towards the lower Avon River and the Estuary, both tidally influenced. During the Canterbury earthquakes, the area suffered from liquefaction, land settlement (up to 600mm) and lateral spreading. Some areas are now very low-lying relative to extreme high tides. This creates significant challenges to restoring the stormwater drainage performance.

This case study of the Bridge Street catchment in South New Brighton explores the challenges in servicing the area and managing stormwater runoff and flood risk. These challenges include draining low-lying land during high tide events, difficult ground conditions, high and tidally influenced groundwater, and heightened seismic risk, as well as maximising reuse of existing infrastructure. Solutions include reconfiguring the catchment outlets, providing a new stormwater basin to contain stormwater during high tide events and a pump station for large events, plus careful material selection and detailing to provide a more resilient system.

The design involved a multi-disciplinary team of civil, geotechnical and structural engineers working together with modellers, landscape architects and Council stormwater staff and parks planners. The works are currently under construction.

KEYWORDS

Stormwater, flood, basin, pump station, earthquake, Christchurch earthquake, Canterbury earthquake sequence

PRESENTER PROFILE

Kate Purton is a senior civil engineer at Beca, with 13 years’ experience in water, wastewater and stormwater engineering. Kate is based in Christchurch and since the Canterbury earthquakes she has been involved in a range of stormwater damage assessment and rebuild projects.

1 INTRODUCTION

The Bridge Street catchment in South New Brighton, Christchurch, suffered damage in the Canterbury earthquake sequence, including liquefaction, lateral spreading and settlement. This paper sets out the challenges faced in restoring service to the area following the earthquakes, including managing stormwater runoff and managing flood risk. It describes the issues, the options considered in addressing these issues and the final design solution adopted. It also provides information on some of the details included in the design to provide resilience.

2 PROJECT BACKGROUND

2.1 STRONGER CHRISTCHURCH INFRASTRUCTURE REBUILD TEAM (SCIRT)

The project was carried out by the Stronger Christchurch Infrastructure Rebuild Team (SCIRT). SCIRT is the alliance responsible for rebuilding the horizontal infrastructure in Christchurch following the 2010 and 2011 earthquakes. The alliance includes the Canterbury Earthquake Recovery Authority (CERA), Christchurch City Council (CCC), NZ Transport Agency (NZTA) and contractors (City Care, Downer, Fletcher, Fulton Hogan and McConnell Dowell). A number of engineering consultancies provide design resources to SCIRT, mostly through secondment of staff into the design teams.

2.2 SCIRT DESIGN PROCESS

SCIRT Design process involves:

- Project Definition – The project is scoped and briefed and assigned to a design team (engineers) and a delivery team (contractors).

- Concept Design – Information is gathered, damage is assessed, and options are considered and costed, with a recommended option identified. The delivery team is involved in an options workshop, a risk workshop and early contractor involvement (ECI) discussions.

- Detailed Design – The recommended option from concept design is advanced to a full detailed design including drawings and a specification. The delivery team is involved in early contractor involvement (ECI) discussions and a risk workshop. A target out-turn cost (TOC) estimate is agreed between the SCIRT TOC (cost estimating) team and the Independent Estimator representing the clients (CERA, CCC and NZTA).

- Construction – The delivery team carries out the construction of the works, including managing communication with the local community and affected stakeholders. The design team responds to construction queries from the delivery team.

2.3 PROJECT TEAM

The design team for the Bridge Street stormwater catchment consisted of a multi-disciplinary team of consultants and CCC staff seconded into SCIRT. These included stormwater, general civil, roading, geotechnical, and structural engineers, landscape architects, and draughtspersons. Hydraulic modelling was carried out on behalf of SCIRT by Beca. CCC's Asset Owner Representatives and Technical Advisors (CCC stormwater engineers seconded to SCIRT) provided review and approvals.

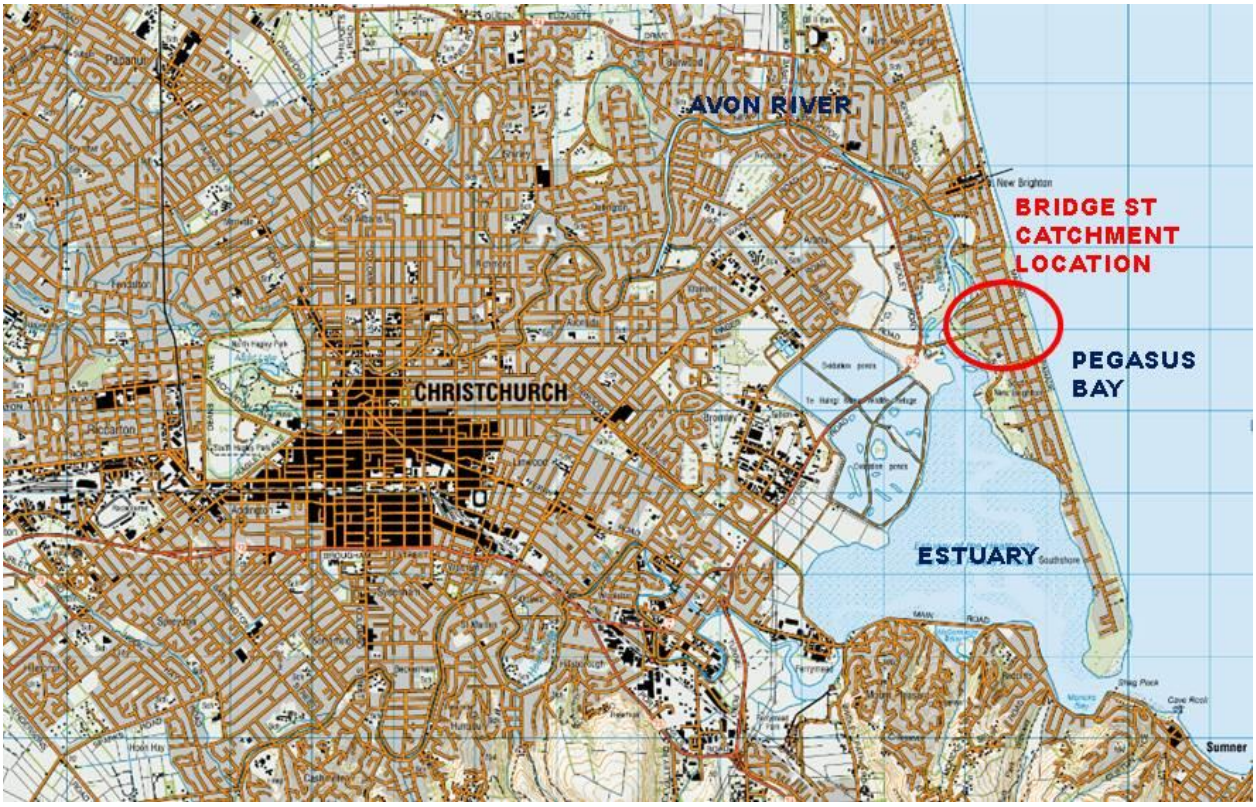
The delivery team for this project is Fulton Hogan.

3 BRIDGE STREET CATCHMENT

3.1 LOCATION

The Bridge Street catchment is located in South New Brighton, as shown in Figure 1. It is bounded by the Avon River/Ōtakaro and Avon-Heathcote Estuary/Ihutai to the west, and to the east by the coastal dune system between Marine Parade and the shoreline of Pegasus Bay.

Figure 1: Location of Bridge Street catchment, South New Brighton (Base map source: LINZ)



3.2 CATCHMENT CHARACTERISTICS

The catchment extends from Mountbatten Street in the north to just south of Bridge Street, as shown in Figure 2. The total catchment area is 70.7ha, with the majority being residential.

The catchment falls gently to the west, draining to the Avon River, which is tidally influenced in this area. The highest ground in the catchment is along the dune system at the coast. The lowest ground in the catchment is in the Bridge Reserve in the west.

The soils in the catchment are generally sands and silty sands. Groundwater is close to ground surface level and tidally influenced.

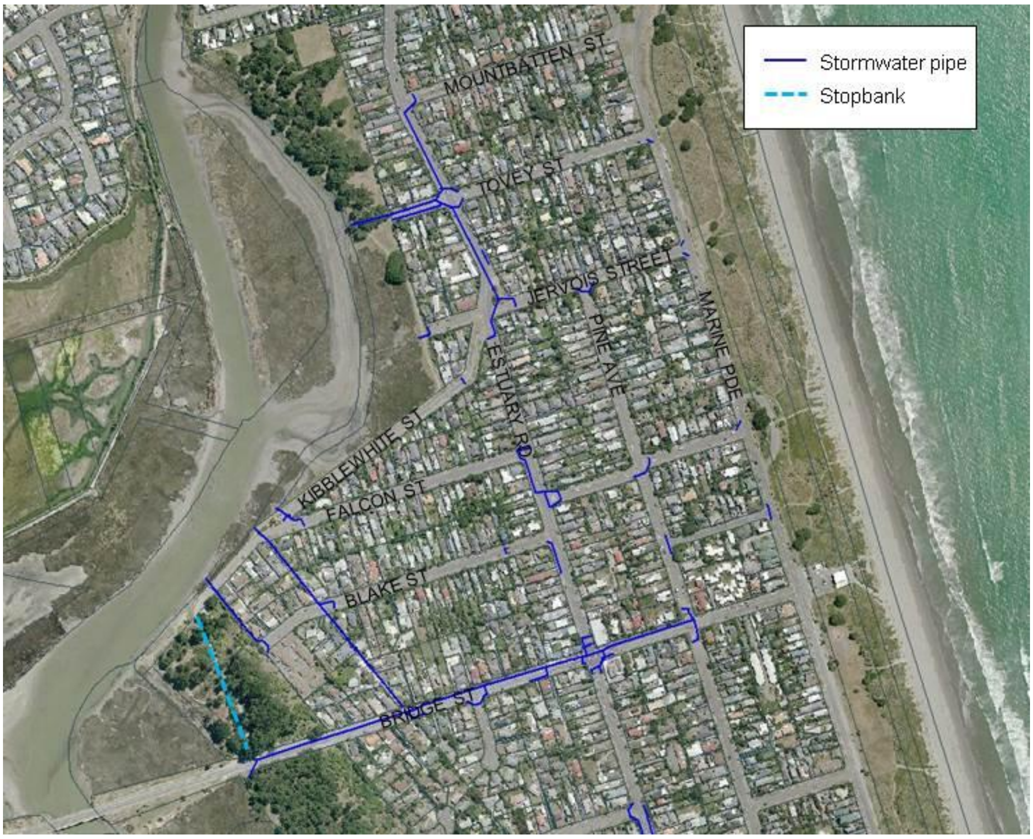
Figure 2: Bridge Street catchment

3.3 PRE-EARTHQUAKE STORMWATER SYSTEM

The pre-earthquake stormwater system for the catchment consisted of a pipe system discharging to the Avon River and Estuary, with flap gates on the outlets. There were a number of discharge locations to the Avon River between Kibblewhite Street and Tovey Street; and one discharge to the Estuary from Bridge Street. The pre-earthquake stormwater system is shown in Figure 3.

There was a stopbank from Bridge Street to Jervois Street to prevent river and tidal flooding from entering the low-lying area. In other areas, including along Kibblewhite Street, the local land levels provided river and tidal flooding protection.

Figure 3: Pre-earthquake stormwater system



Prior to the earthquakes, when rainfall events coincided with high river levels or extreme high tides, there would be some ponding in the roads while there was insufficient head available to open the flap gates. When the river level dropped, the flap gates would open and the ponded water would drain away.

The system generally operated satisfactorily, however there were occasional issues with flap gates not sealing properly causing ingress of water during extreme high tides (with no rainfall). There was also a recurring issue with silt partially blocking the Bridge Street outfall.

4 CANTERBURY EARTHQUAKES

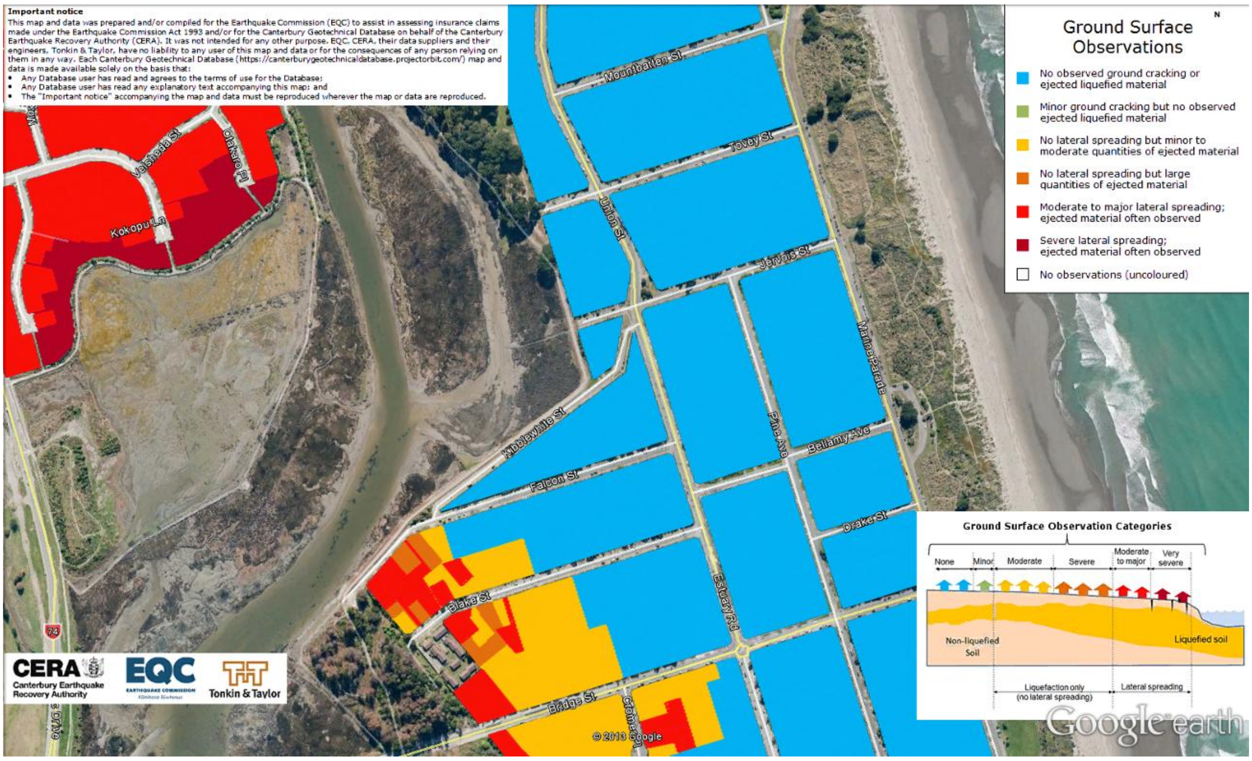
4.1 EVENTS

The catchment suffered damage in the September 2010 M7.1, February 2011 M6.3, June 2011 M6.3 and December 2011 M6.0 events. The majority of the damage occurred in February 2011 M6.3 event.

4.2 LAND DAMAGE

The Bridge Street catchment suffered from shaking and settlement, with the western part of the catchment also suffering from liquefaction, lateral spreading along the Avon River and Estuary edge, and related settlement. Observed liquefaction and lateral spreading from the February 2011 earthquake is shown in Figure 4 (from the Canterbury Geotechnical Database). It can be seen from Figure 4 that the land damage was minor in the eastern part of the catchment and moderate to severe in the western part of the catchment.

Figure 4: Liquefaction and lateral spreading, February 2011 event (Source: Canterbury Geotechnical Database)



4.3 EMERGENCY WORKS

4.3.1 STOPBANKS

Emergency stopbanks were constructed along low-lying areas of the lower Avon River, including Kibblewhite Street and Bridge Reserve.

4.3.2 TREES IN BRIDGE RESERVE

Land settlement relative to groundwater in Bridge Reserve caused the ground within the Bridge Reserve to become waterlogged, with the consequence that a large number of mature trees died. Due to the inevitability of more trees in the Reserve dying, and the risk of falling debris from dead and dying trees, the remaining trees in the Reserve were felled.

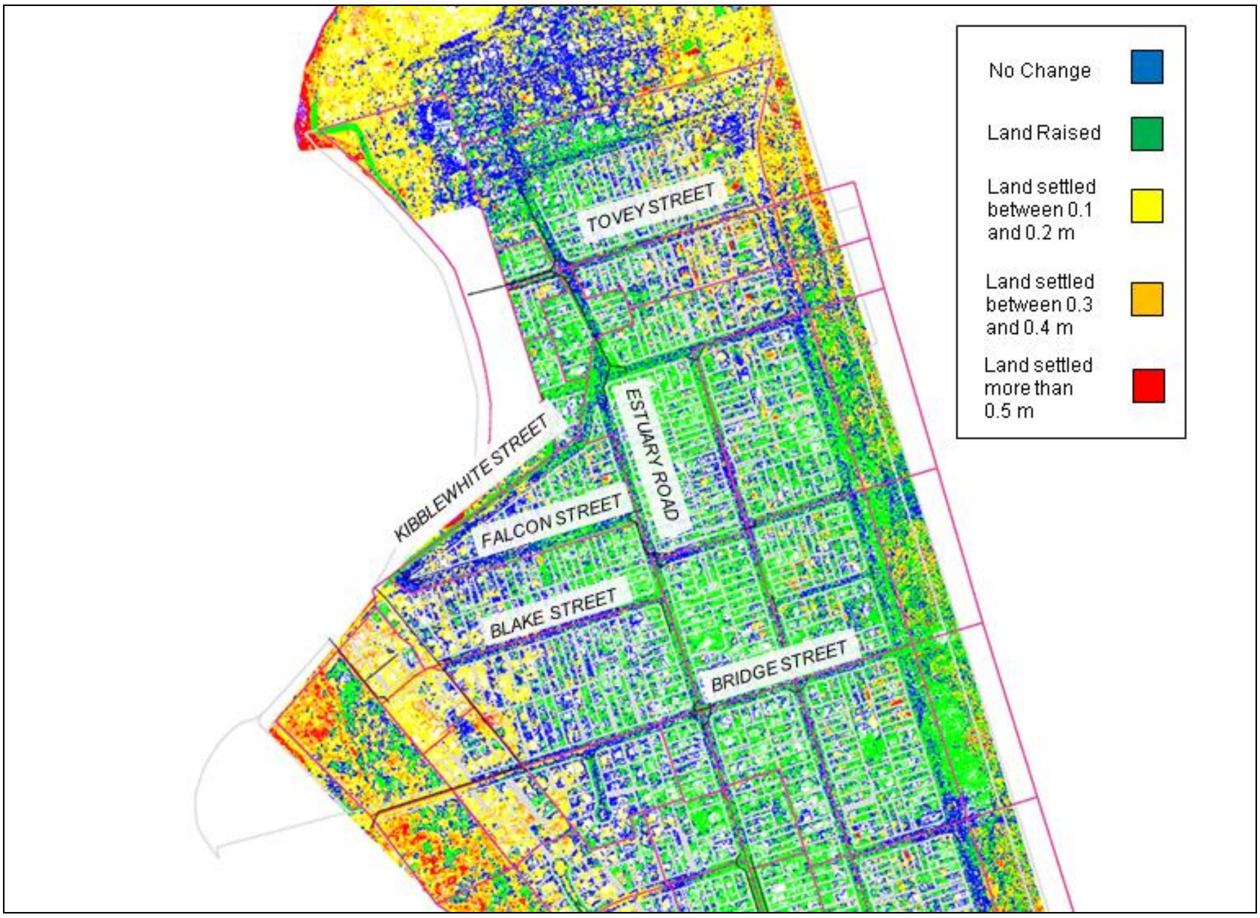
4.4 STORMWATER DAMAGE ASSESSMENT

4.4.1 LIDAR DATA

LiDAR (Light Detection And Ranging) is a technology for aerial measuring and mapping of land levels. Prior to the Canterbury earthquake sequence, CCC had existing LiDAR of Christchurch from 2003. Further LiDAR was flown following each of the major earthquakes and aftershocks (September 2010, February 2011, June 2011 and December 2011), to understand the post-earthquake ground levels. The coverage area of these post-earthquake LiDAR data sets varied.

Comparison of these sets of LiDAR data has been carried out to understand the change in levels as a result of the earthquakes. A map showing the comparison of the post-September 2010 and post-June 2011 LiDAR data for the Bridge Street catchment is shown in Figure 5. It is noted that the post-September 2010 LiDAR rather than the 2003 LiDAR is used as the "pre-earthquake" case for this comparison. This is due to accuracy issues with the 2003 LiDAR data. Although the post-September LiDAR was flown after the 4 September 2010 event, information from LINZ is that there was limited movement in Christchurch city in the September 2010 event.

Figure 5: Earthquake settlement from LiDAR, Bridge Street catchment



It can be seen from Figure 5 that between Falcon Street and Bridge Street, the western side of the catchment (adjacent to the Estuary) has settled by between 100mm and 400mm in the residential areas, and more than 500mm in some parts of Bridge Reserve.

4.4.2 CCTV OF PIPE SYSTEM

The stormwater pipe system was cleaned and recorded using CCTV (Closed Circuit Television). CCTV footage was analysed and graded in accordance with the NZ Pipe Inspection Manual to determine pipes requiring repair or replacement.

4.4.3 LEVEL SURVEY

Topographical survey of the stormwater pipe system, roads and Bridge Reserve was carried out. This survey information, in conjunction with LiDAR data for the remainder of the catchment, was used to understand post-earthquake levels and inform design.

LiDAR data was also assessed to compare levels on private properties with the adjacent road level. This information, as well as a catchment walk-over, was used to identify houses which were low relative to the road and may have an issue with secondary flow paths. Further survey was then undertaken of ground and floor levels at these low-lying properties.

Tidal levels at Bridge Street and key levels for the post-earthquake Bridge Street catchment are included in Table 1 and Table 2 below. The levels included in Table 1 are from Goring, 2011, as published in CCC's Waterways, Wetlands and Drainage Guide (CCC, 2011). They do not include an allowance for climate change.

Table 1: Peak tide levels at Bridge Street for various return periods

Return Period	Median tide	2 year	5 year	10 year	50 year	100 year	200 year
Level (RL m)	10.10	10.69	10.78	10.82	10.91	10.94	10.96

The mean level of sea (MLOS) at Bridge Street is RL9.36m.

Table 2: Key post-earthquake levels in Bridge Street catchment

Description	**Location**	**Level (RL m)**
Highest ground level in catchment	Dunes east of Marine Parade	17.0
Lowest ground level in catchment	Kibblewhite/Falcon Street intersection	10.10
Lowest known floor level	Kibblewhite Street, near western end	10.68
Bridge Reserve levels	Bridge Reserve	10.0 to 10.6
Temporary stopbank level	Kibblewhite Street and Bridge Reserve	11.3

4.4.4 EARTHQUAKE DAMAGE TO STORMWATER SYSTEM

From the damage assessment described above, it was apparent that the Canterbury earthquake sequence caused a range of damage to the primary and secondary stormwater systems in the catchment.

The primary system consists of kerb and channel and the stormwater pipe system. Stormwater from private properties generally discharges to the kerb and channel via kerb outlets. Damage to the primary system included changes in kerb grades and low points, pipe cracks and breaks, pulled pipe joints (in areas of lateral spread), and changes in pipe system levels due to floatation (in liquefied soil) or settlement. It also included loss of hydraulic grade due to settlement (as tidal levels in the Avon River and Estuary have stayed the same). Some properties have also settled relative to road, and may no longer drain to the kerb.

The secondary system is generally overland flow along the road to low-lying areas. Secondary flow from private properties is generally overland to the road. Damage to the secondary system includes changes to secondary flow paths along roads due to non-uniform settlement (e.g. local dips in the road) and hydraulic grade lost due to settlement of land relative to tidal levels. Also, the loss of hydraulic grade in primary (piped) system will divert additional flow into the secondary flow system. Secondary flow paths from some private properties to the road will also be affected by differential settlement, and secondary flow from the road may now enter properties in some locations.

In addition to the surface water issues described above, settlement of the catchment has reduced the depth to groundwater.

The stormwater system no longer meets CCC's level of service, that is:

- Primary system (kerb and channel and pipe system) shall convey a 5 year storm
- In a 50 year storm, ponding may occur on roads and private properties, but shall be below habitable floor levels (i.e. not flood houses).

4.5 RESIDENTIAL RED ZONE

In June 2011 (after the June 2011 event), land zonings for greater Christchurch were released, mapping all flat residential land into three zones – red, orange, and green. A red zoning meant that the land had been assessed as uneconomic to repair, while a green zoning indicated that the land was considered generally suitable for residential construction and rebuilding. An orange zoning meant that further information or analysis was required before a decision could be made to zone the land red or green.

While most properties in the Bridge Street catchment were zoned green in June 2011, a number of properties at the western end of the catchment were zoned orange. These properties were eventually zoned green in November 2011.

5 ISSUES

The rebuild of the Bridge Street catchment needs to provide stormwater drainage of the low-lying catchment, including during extreme high tide or large storm events. The design level of service is that the primary system copes with a 5 year storm, with no houses flooding in a 50 year storm.

In addition to the hydraulic requirements described above, the design needs to be resilient to future seismic events and sea level rise. It should not affect the risk of future land damage to adjacent provide properties.

The design also needs to be operable and maintainable, and fit within the surrounding environment, including the Bridge Reserve. If possible the design should address the six values as set out in CCC's Waterways, Wetlands and Drainage Guide (CCC, 2011), that is ecology, landscape, recreation, heritage, culture, and drainage.

6 OPTIONS

Three main options were identified to address earthquake damage and return levels of service to CCC's standards:

- Replace/repair existing pipe system – The pipework could be repaired and replaced as required by assessment of the CCTV and level survey information. Pipework could be increased in size where required to increase capacity to off-set the loss of available hydraulic gradient due to settlement of the catchment. However, the catchment would not be able to drain in flood and extreme high tide events, when the Avon River and Estuary level are higher than the water level in the catchment. A basin or pump station would be required.

- Detention basin – A basin could be constructed in Bridge Reserve with a gravity outfall through the stopbank to the Avon River, and a flap gate on the outlet. If the basin invert level was set at approximately mid-tide, this would allow the catchment to drain to the basin during extreme high tide events, and the basin to drain to the River under gravity once the tide level dropped and flap gate opened.

- Pump station – A pump station could be constructed in Bridge Reserve discharging to the Avon River. This would allow discharge during high tides or when capacity of gravity system was exceeded.

Preliminary design work was carried out for each of these options. This included:

- An assessment of the levels in the catchment and tidal levels in the river and Estuary, to determine the limitations of a gravity system.

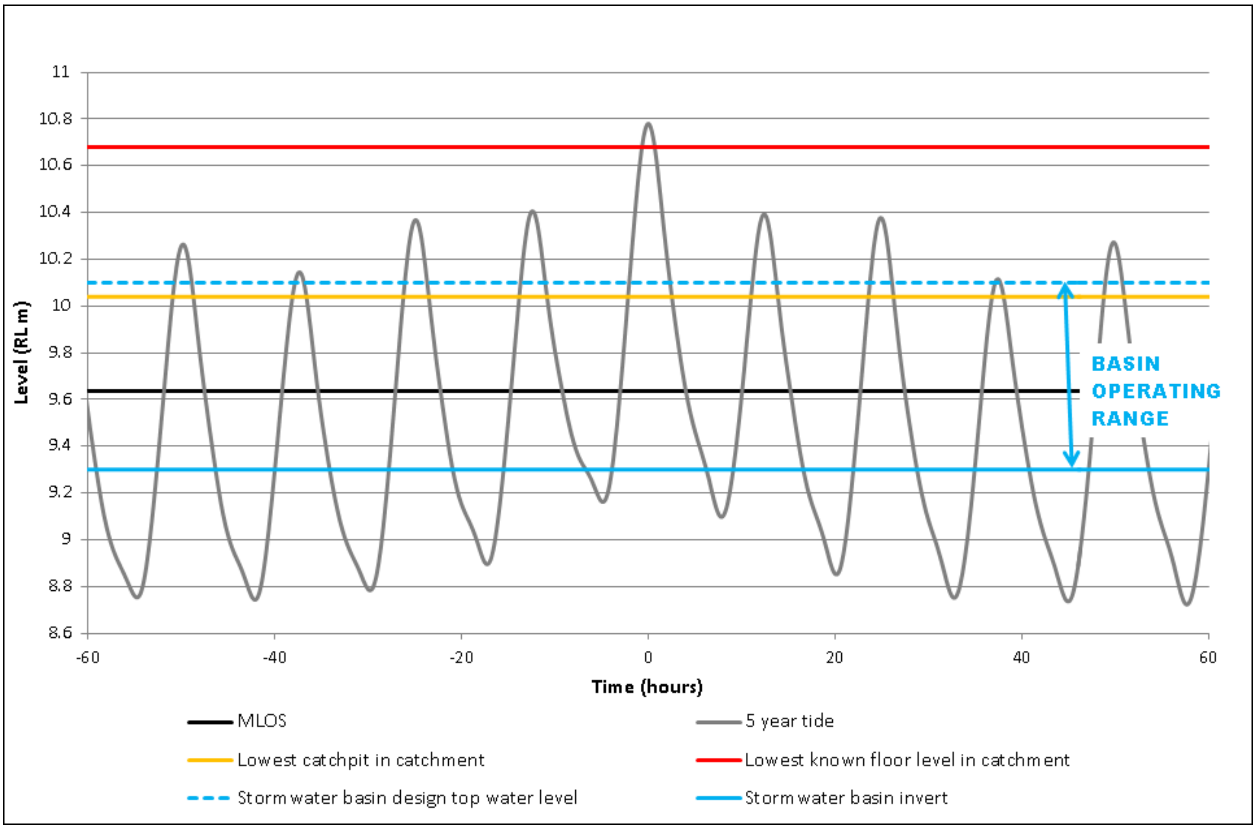
- Spreadsheet based design checks of the pipe capacities (using the Rational Method and backwater calculations) and an assessment of the volume of runoff which would need to be stored or pumped in a 5 year 6 hour or 50 year 6 hour event. (Six hours being the approximate time of the high part of the tide cycle when the flap gates could be shut and the system unable to drain via gravity.)

- Geotechnical analysis to determine the basin setback required from the residential property boundary and toe of the stopbank, to not increase the risk of local land instability (lateral spreading) to private properties.

- Civil assessment of the achievable storage volume, using survey information and an assumed basin invert level.

The critical levels for this system are shown in Figure 6. The tidal levels in Figure 6 reflect a storm surge creating a 5 year tide level at time 0 hours.

Figure 6: Critical levels for the Bridge Street catchment



The advantages and disadvantages of the basin and pump station options were assessed and are summarised in Table 3 below.

Table 3: Advantages and disadvantages of basin and pump station options

Option	**Advantages**	**Disadvantages**
Basin	Could provide storage for approximately a 5 year 6 hour storm. Could provide aesthetic, landscape and ecological value. Lower capital cost than pump station. Lower operation and maintenance costs than pump station. Gravity system, not reliant on power supply.	Depth limited by high groundwater. Insufficient space available to store runoff from a 50 year 6 hour storm. Could increase local instability of (lateral spread risk to) adjacent properties. Risk of damage/infill of basin in future seismic events. Gravity outfall will become less effective with sea level rise.

Pump Station	Could be sized to match required design capacity for a 50 year 6 hour storm. Smaller footprint than basin, occupying less reserve area. Could be designed to account for sea level rise.	Risk of pump failure or power outage. Risk of damage to structure in future seismic events. Higher capital costs than basin. Higher operational costs than basin.

It was decided that the best way forward was a combination of the options described above, that is, repairing and replacing pipework (upgrading sizes where necessary), leading to a stormwater basin in Bridge Reserve with a gravity outfall to the Avon River, and a pump station for more extreme events. The design of this system is described in section 7.

7 DESIGN

7.1 DESIGN APPROACH

The design level of service was:

- Primary system (kerb and channel and pipe system) shall be designed to convey a 5 year storm
- Secondary system shall be designed so that in a 50 year storm, ponding may occur on roads and private properties, but shall be below habitable floor levels (i.e. not flood houses).

It is noted that the design changes in the pipe system and roads were limited as much as possible to areas where the level of damage required the roads rebuilt and/or the pipework replaced.

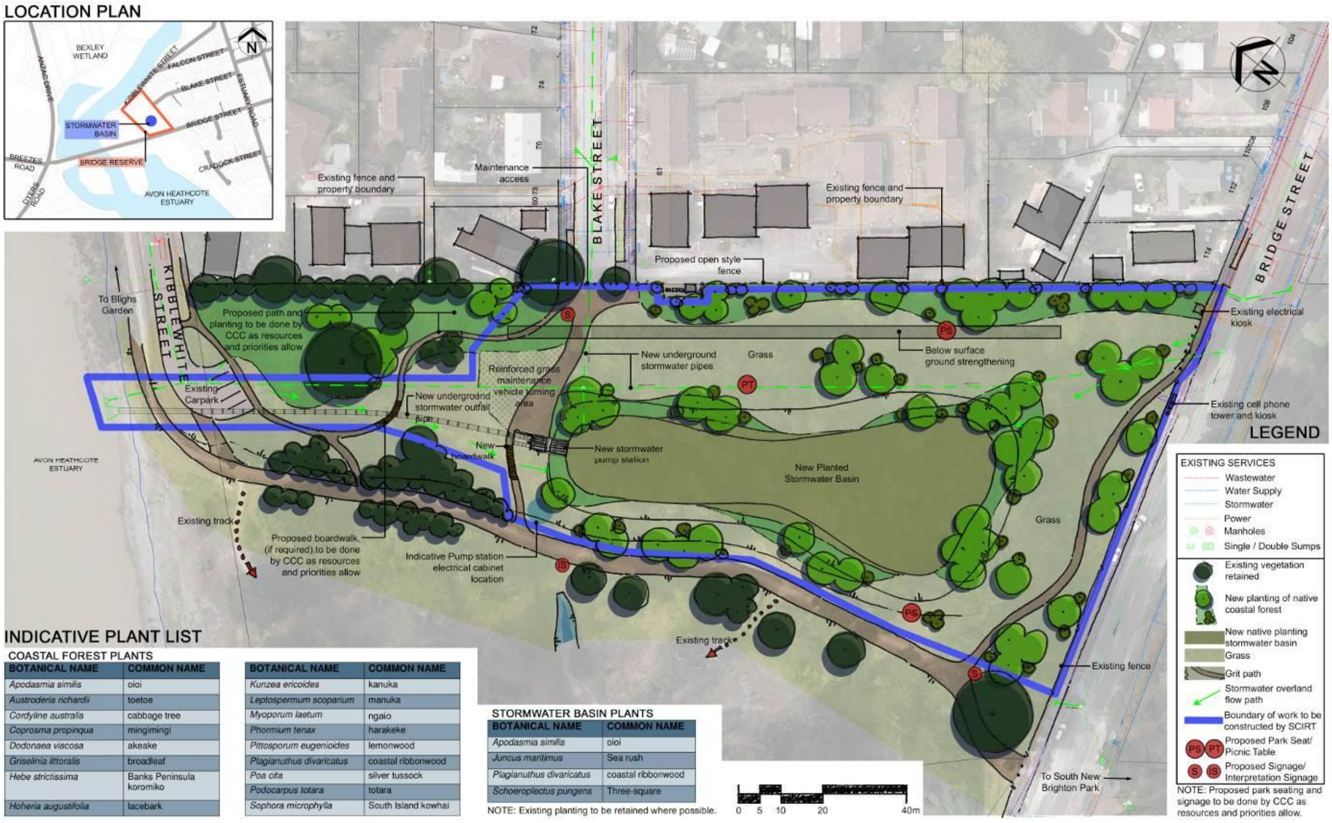
The following design cases were used:

- 5 year storm with a 1 year tide, for the primary system
- 50 year storm with a 5 year tide, for the secondary system

In accordance with SCIRT's design guidelines, the rainfall intensities used for the design included an allowance for climate change, while the tide levels used were current tide levels with no sea level rise. For a given event, sea level rise will increase the period of time that the flap gates are shut and the catchment is unable to drain by gravity, and therefore the amount of storage required or length of time that the pump needs to run. Sea level rise can be countered in future by relatively minor alterations to pump capacities and stopbank heights.

The final design is shown schematically in Figure 7 and described in more detail in the following sections.

Figure 7: Final basin and pump station design layout



7.2 HYDRAULIC MODELLING

Due to the complexity of the catchment, 1-dimensional (1D) and 2-dimensional (2D) hydraulic modelling was carried out using MIKE FLOOD, with a two-way coupled MIKE URBAN and MIKE 21 model.

Hydraulic modelling in 1D and 2D allowed the pipe system, overland flow paths, catchment ponding, basin and pump station to be modelled, for a range of storms and tide scenarios.

The 1D pipe network was informed by the SCIRT GIS, level survey and CCTV. It was later updated to include and test the detailed design of the upgraded pipework. This was achieved efficiently by exporting the pipework design data from the SCIRT civil design software (12d Design) and importing it into the hydraulic model.

The 2D surface was a 2m x 2m grid digital elevation model (DEM) from an amalgamation of most accurate available level data. This included survey data in the roads, low properties and Bridge Reserve, and LiDAR levels for the remainder of the catchment. The 2D surface was also updated later in the design process to include the final road design, designed secondary flow paths through the reserve to the basin, and the basin design. Again this was achieved by exporting the design surface from 12d Design and importing it into the model.

The 1D model was used to test a range of storm durations, tide cases, and storm and tide coincidence to establish the critical durations for peak flow and flooding, and best and worst case tide timing for the design cases (refer section 7.1). This allowed for a range of scenarios to be tested in a relatively short timeframe. The critical duration for the peak flow in the 5 year storm was a 2 hour event, while the critical duration for ponding in the 50 year storm was the 6 hour event. The critical cases were then run in the 2D model. This approach was also taken in testing options for the reticulation and pump station sizing, and pump start and stop levels. This approach improved modelling efficiency by using the 1D model to optimize the design before testing it in the 2D model, limiting the number if time consuming 2D model runs required.

The final design confirmed using the hydraulic model was:

- 2,100m³ basin, with a RL9.30m invert level and RL10.1m design top water level and a new outfall to the Avon River.
- 1,000 L/s pump station, discharging to the Avon River.
- New reticulation in Bridge Street, Blake Street and Kibblewhite Street (refer section 7.4)

The peak catchment water level predicted by the model in 50 year 6 hour storm with a 5 year tide (worst case tide shift), with the 1,000 L/s pump (with final operating levels) was RL10.35m. This gives over 300mm freeboard to the lowest floor level of RL10.68m.

The model was also run without the pump, with reticulation and pipework in place, to understand the effects of power or pump failure and inform a minimum level for the pump station electrical cabinet. The peak water level in the Reserve, predicted by the model for a 50 year storm with a 5 year tide (worst case tide shift) without the pump was 10.74m.

7.3 STOPBANKS

It is understood that the temporary stopbanks will remain in place in the medium term, and will be replaced by CCC at some stage in the future. Design of replacement stopbanks was therefore not included in the project. Instead, the temporary stopbanks were included in the 2D surface in the hydraulic modelling, and where pipes will be laid through the stopbanks, the stopbanks will be reinstated to an equivalent standard.

7.4 RETICULATION

The final reticulation design includes:

- A number of localised pipe repairs and replacements throughout the catchment.
- New stormwater pipework in Kibblewhite Street (600mm diameter) and Blake Street (450mm diameter) discharging to the new basin in Bridge Reserve.
- A new 600mm diameter stormwater pipe from the existing 600mm diameter stormwater main in Bridge Street, discharging to the new basin in Bridge Reserve. The existing outfall from Bridge Street to the Estuary will be abandoned, resolving a maintenance issue with siltation of this outfall.
- A new 1200mm diameter gravity outfall from the Kibblewhite Street reticulation and the new basin to the Avon River, replacing the existing outfalls in the area. This reduces the number of outfalls from Kibblewhite Street to the Avon River, to reduce the maintenance requirements and the number of flap gates that can potentially leak.

The pipes were sized initially in spreadsheet-based calculations (using the Rational Method and backwater calculations) for a 5 year storm with mid-tide. These pipe sizes were then tested in the model for a range of 5 year and 50 year storm scenarios.

The pipe materials selected were generally reinforced concrete rubber ring jointed (RCRR) pipe and reinforced concrete manholes, with profiled wall polyethylene (PE) pipes for areas prone to lateral spreading (e.g. the gravity outfall through the stopbank). In large diameters, rubber ring jointed concrete pipes are much less expensive than polyethylene pipes. The earthquake performance of rubber ring jointed pipes was generally acceptable, except in areas of severe liquefaction or lateral spread. Concrete pipes are also relatively straightforward to repair.

Where the outfall pipe penetrates the stopbank, puddle flanges with bentonite waterstops will prevent water from tracking through the backfill and affecting the integrity of the stopbank.

Inline rubber check valves (e.g. Tideflex Checkmate) were included on all new outfalls. A number of these valves have been installed by CCC and SCIRT on outfalls in Christchurch since the earthquakes. Experience to date is that they are less prone to theft or vandalism than traditional metal flap gates, and are more reliable in terms of limiting leakage.

7.5 OVERLAND FLOW PATHS & ROAD DESIGN

The roading and overland flow path design was carried out in conjunction with the stormwater design, using the civil design package 12d Design, to grade kerbs, place catchpits at low points, and where possible direct secondary flow to the Bridge Reserve and stormwater basin.

The ability to modify secondary flow paths is limited by the existing road levels. Raising the levels of the roads is generally not an option as it affects property drainage to the kerb. Lowering the levels of roads is complex due to the need to tie into existing levels at property boundaries without over-steep berms, driveways and footpaths, and the relocation of shallow services such as water submains (rider mains) and telecommunication cables.

Secondary flow paths were able to be achieved from Bridge Street and Kibblewhite Street to the basin in Bridge Reserve. A secondary flow path could not be achieved along Blake Street to the basin, due to the existing road levels and an area of high land at the Reserve end of the street. Additional sump capacity was therefore installed at the low point in Blake Street.

7.6 BASIN

7.6.1 BASIN FORM

The basin was designed to maximise the storage provided within the available area, and therefore minimise the pump station capacity required, without affecting the stability of the neighbouring properties or stopbank (refer section 7.6.2).

The final basin design was for a 2,100m^3 basin, with an invert level of RL9.30m, a crest level of RL10.30m and a design top water level of RL10.10m. It has a 1200mm OD PE (1050mm diameter internal diameter) gravity outfall through the stopbank to the Avon River at Kibblewhite Street.

The basin is generally in cut, except for areas where the ground is locally low and there is a minor embankment. The basin is curved in shape to naturalise its appearance and will be planted in species which are tolerant to wet and dry conditions and saline water. For public safety the basin has moderate side slopes (4H:1V) and a grill on the outlet structure.

7.6.2 GEOTECHNICAL DESIGN

Geotechnical analysis was carried out to determine the effect of a new stormwater basin on the local stability of the adjacent private properties and the stopbank. Based on this analysis it was recommended the basin was set-back 30m from the property boundary and 5m from the toe of the stopbank. It was also recommended that ground improvement in the form of deep soil mixing was installed within the 30m buffer between properties and the basin.

7.6.3 GROUNDWATER

A series of seven shallow piezometers were installed by PDP in 1999 for CCC to monitor salinity of the water and groundwater levels within Bridge Reserve. The monitoring identified that groundwater salinity increased towards the Estuary, suggesting that estuarine water infiltrates the groundwater at the site. Groundwater levels in these piezometers were monitored by PDP between 2001 and 2002. This data shows that the groundwater level ranged from RL9.5m to RL10.1m, with seasonal variation. There was no historic information on tidal variation of groundwater levels.

Three new piezometers were installed and monitored during detailed design to gather additional groundwater information. This monitoring showed groundwater levels within the same range (in terms of absolute levels) as the previous monitoring, and also showed approximately a 200mm tidal variation. A groundwater level of RL10.1m was adopted for design purposes, which is approximately the lowest ground level in the Reserve.

With a basin invert of RL9.30m, the groundwater level will regularly be above the basin invert level. This suggests that groundwater will flow into the basin. Although the basin would be able to drain out via the gravity pipework on each low tide cycle, groundwater inflow would cause water to pond in the basin, and depending on the volume could cause nuisance (standing water providing habitat for mosquito breeding) or a loss of available storm storage. To better understand the likely scale of this groundwater inflow, permeability testing was carried out at the site and the basin and groundwater interaction was modelled using Geostudio SEEP/W 2007. This modelling indicated that groundwater inflow into the basin would be in the order of 1 to 10 L/s.

A small sump pump (16 L/s capacity) is included in the pump station design, which will assist with draining any groundwater inflow.

7.6.4 LANDSCAPE DESIGN

The landscape design includes basin planting and walkways to retain use of the reserve. The plants included in the design are mainly native species, tolerant of wet ground conditions and occasional dry periods. The plantings are grouped to give the basin a less rectangular and more natural appearance.

The landscaping design formed a key part of the consultation with stakeholders regarding the use of the Reserve, and was modified through this consultation process to address issues raised.

7.7 PUMP STATION DESIGN

7.7.1 PUMP & RISING MAIN ARRANGEMENT

The pump station design capacity is 1000 L/s, which is delivered using two axial flow pumps operating on a duty-assist basis. The pumps are operated at fixed speed with control based on pond water level as measured by a pressure transducer.

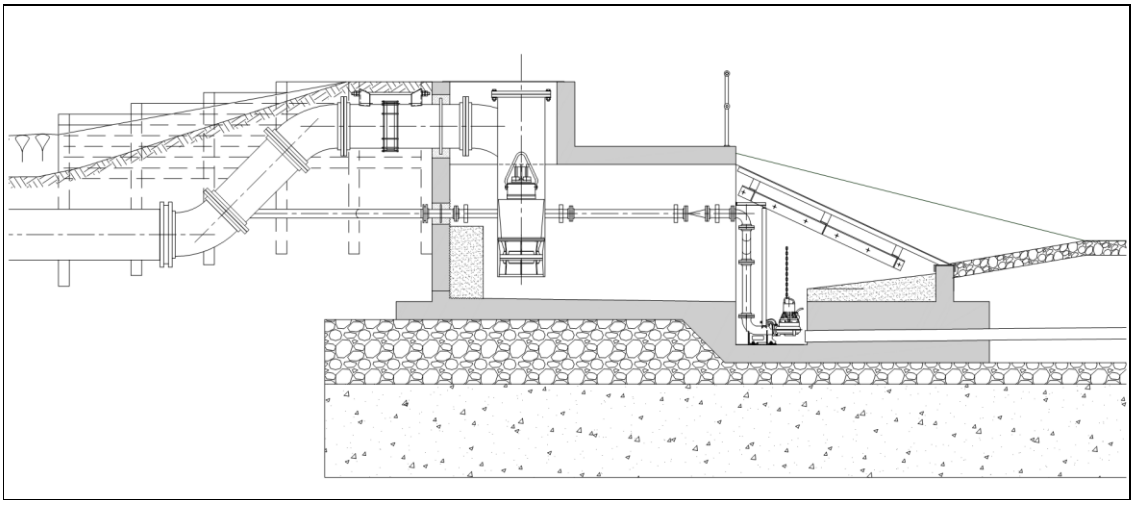
The pumps have been selected to deliver 1,000 L/s with a current 5 year high tide (RL10.78m). During higher tides (i.e. more extreme events or a 5 year tide with sea level rise) the head required will increase and therefore the pump flow will decrease slightly. However, the pumps have been selected so that, if required in the future due to sea level rise, the impellors can be replaced to provide higher discharge head capacity.

Each pump discharges into a dedicated 710mm OD (600mm internal diameter) polyethylene pressure main which allows the pumps to operate at a constant 500 L/s. The use of twin pressure mains was estimated to be cost neutral compared to a single discharge pipe, with savings being made in the manifold pipework and easier management of pipe buoyancy.

A sump pump is provided in the wetwell structure to clear remnant water from the pump station. This sump pump will also help control groundwater levels in the basin.

A cross section of the pump station is shown in Figure 8. It can be seen from Figure 8 that the top of the pump station is above the surrounding ground level, and the invert is below the basin invert level.

Figure 8: Pump station cross-section



7.7.2 STANDBY POWER SUPPLY

A standby generator is not included in the pump station design, however there is provision to connect a mobile generator. The location of the pump station within a reserve adjacent to private properties means that a generator would be an issue in terms of visual impact, emissions and noise. The basin storage provides a buffer, allowing time for a temporary generator to be brought to site. As noted in section 7.2, the effects of power failure have been modelled. The model indicates that for a 50 year 6 hour storm with a 5 year tide (worst case tide shift) with no pumping throughout would result in a peak water level in the Reserve of RL10.74m.

7.7.3 GEOTECHNICAL DESIGN

It is expected that the land will settle further should another liquefaction inducing earthquake occur. The foundations of the pump station have been designed to settle with the surrounding land rather than be fixed at the original elevation. Moving with the surrounding land will allow continued gravity flow into the pump station inlet if seismic settlement should occur. The foundations and structure are designed to minimise differential settlement, however if it should occur, re-levelling can be accomplished using grout injection techniques.

To allow construction of the structure in the high groundwater, the foundation design uses an unreinforced concrete pad that will be poured using a tremmie tube into a sheet-piled excavation. Compacted engineered fill will then surround the structure to minimise liquefaction of the material immediately surround the structure.

The pipe connections are vulnerable to damage from movement of the structure in a future seismic event. To minimize capital cost, the connections have been designed with thrust restrained flexible couplings (gibaults) which are intended to act as a preferential failure point (or 'fuse') should movement occur. Repair of these shallow connections will be relatively fast and simple.

7.7.4 STRUCTURAL DESIGN

The structure will be a cast insitu reinforced concrete with dimensions of approximately 3.5 m by 7m in plan and 3.6 m deep. The pump station is built into the embankment of the storage basin and the surrounding ground has been built up around it to mitigate the visual effects and provide ease of access for maintenance.

To minimise the risk of differential settlement, the pump station structure has been designed to be as symmetrical as possible and with an even distribution of mass. To compensate for the weight of the pumps at one end of the structure and an open inlet at the other, additional concrete has been included in the floor at the inlet end.

Electrical equipment is housed in a separate light-weight timber framed building. The decision to enclose this equipment in a small timber building (approximately 2m by 3m), rather than in a simpler large electrical cabinet, was made to minimise the visual impact of the structure in the reserve. To protect the electrical equipment from flood damage during a temporary power outage, the base of the equipment is located above the modelled 50 year flood level with the pump station not operating, of RL10.74m.

7.8 RESERVE APPROVALS

As Bridge Reserve is a recreation reserve an approval under the Reserves Act was required to construct the reticulation, basin and pump station within the Reserve. This involved community and iwi consultation, the opportunity for public submissions, and a Community Board hearing, followed by formal approval by the Council of the Community Board's recommendation.

8 CONSTRUCTION

Construction of the reticulation, including the new 1200mm diameter outfall, and the basin, began in January 2014 and is underway at time of writing. This will be followed by construction of the pump station. Construction of the reticulation, basin and pump station is programmed to be complete in mid-2015.

9 STORM EVENTS

Since the catchment was damaged in the Canterbury earthquake sequence, there have been a number of minor storms and one significant storm on 4 and 5 March 2014. At time of writing the return period of this event has not been assessed by the authors.

This storm resulted in significant ponding in Kibblewhite Street and Falcon Street, as well ponding in Blake Street and Tovey Street. The ponding in Kibblewhite Street is shown in Photograph 1. This observed ponding was generally consistent with the ponding predicted by the hydraulic modelling (without the reticulation work, basin and pump station in place).

Photograph 1: Flooding in Kibblewhite Street, 5 March 2014

10 CONCLUSIONS

The Bridge Street catchment suffered damage in the Canterbury earthquake sequence. This damage included settlement, liquefaction, and lateral spreading, with only minor damage in the eastern coastal part of the catchment, and more severe damage in the western part of the catchment adjacent to the Avon River and Estuary. The settlement in the eastern part of the catchment meant that some areas are no longer able to drain to the River or Estuary during flood events or extreme high tides.

The designed solution returns the Bridge Street catchment to the design level of service, so that the primary system will convey a 5 year storm and houses will not flood in a 50 year storm. It includes new pipework and secondary flow paths leading to a basin (with a gravity outfall) and a pump station (with twin rising mains), both discharging through the stopbank to the Avon River. The existing stopbank will be kept in the interim and replaced by CCC in the long term, at its current level or higher.

The design of the new stormwater system has been optimized and tested using a 1D and 2D MIKE FLOOD hydraulic model of the catchment. The detailed design of the system has been carried out by a multi-disciplinary team and includes a number of features to provide resilience.

The work is currently under construction and is due for completion in mid-2015.

ACKNOWLEDGEMENTS

Steve Hart and Paula Lock, SCIRT.

Paul Dickson, Peter Wehrmann and Chris Greenshields, SCIRT/CCC.

Owen Southen, Ken Couling and Mike Gillooly, CCC.

Amber Murphy, Lucy Conrad and Marcus Gibson, SCIRT/Beca.

Elliot Tuck, Graham Levy and Mike Law, Beca.

REFERENCES

Brown and Weeber (1992), Geology of the Christchurch Urban Area, Institute of Geological and Nuclear Sciences.

Canterbury Earthquake Recovery Authority (CERA) website http://cera.govt.nz/

Canterbury Geotechnical Database
https://canterburygeotechnicaldatabase.projectorbit.com

Christchurch City Council (2003), Waterways, Wetlands and Drainage Guide, Part A: Visions

Christchurch City Council (2011), Waterways, Wetlands and Drainage Guide, Part B: Design.