RIVER MAINTENANCE ACTIVITIES TO ADDRESS EARTHQUAKE DAMAGE ON THE STYX RIVER

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ABSTRACT

The 2011 Canterbury earthquakes have had significant impacts on the Styx River and Kaputone Creek in Christchurch, including land damage, the heaving and subsidence of stream bed and banks, and the increase of flood depth. The impacts have been surveyed and assessed against the Christchurch City Council's (CCC) six-values of water environment: ecology, landscape, recreation, heritage, culture, and drainage.

Using the results of a complaints data analysis, Operational Water Levels (OWL) have been calculated and proposed for the 5-year ARI as well as the base flow level. The 5-Year level is based on an analysis of complaints data and land damage.

To meet these proposed OWL targets, a range of maintenance activities have been investigated including the activities that are currently being used as well as potential new options. During this investigation phase, nonviable alternatives were removed to produce the following shortlist of options:

- Weed Harvesting
- Minor bank modifications
- Dredging
- Shading with riparian planting to limit aquatic weed growth

The project has carried out an assessment of the above options against several key criteria: effectiveness at water level reduction, environmental impact, and cost. The purpose of the project was to present the options to Council, not to indicate preferred options. After identifying the preferred option or options, Council could then perform hydraulic modelling to confirm effectiveness and to refine the maintenance trigger levels.

This study was able to quantitatively and qualitatively assess the earthquake impacts and then present a suite of potential maintenance options to mitigate those impacts. This required not just flood modelling, but also analysing complaints data, use of LIDAR, rating curve analysis, and the investigation of riparian shading to control aquatic weed growth.

KEYWORDS

Styx River, earthquake damage, river assessment, land drainage, river maintenance, weed harvesting, dredging, riparian shading

PRESENTER PROFILE

Robert Le is an intermediate water engineer with GHD Limited in Auckland. Robert has carried out system assessments and planning projects for natural and man-made water systems. He has over seven years' experience in Three Waters planning and design in New Zealand and California, USA.

1 INTRODUCTION

1.1 PURPOSE OF THE STUDY

The 2011 Canterbury earthquakes have had an effect on Christchurch City Council's (Council or CCC) maintenance of the Styx River. Council wish to better understand the impacts that the earthquakes have had and what balance of maintenance activities (with consequences) it could utilise in the future on the river. Council's Operational Water Levels Project seeks to investigate these issues and assess the maintenance options available to reduce frequent minor flooding. Council engaged GHD Limited (GHD) to carry out a Styx River Maintenance Options Study as part of the wider Styx River Operational Water Levels Project. The study investigated and documented the following:

- Customer complaints analysis
- Post-earthquake river assessment
- Assessment of operational water levels and maintenance trigger levels
- Collation of historical and current maintenance activities
- Future maintenance options assessment

The key purpose of the study was to provide a suite of maintenance options or tools that Council could use to achieve target operational water levels (OWLs). The study did not indicate preferred options or make recommendations on a future maintenance regime. Instead, the study summarised the options available, their efficacy at reducing water levels, and other relevant information to aid in Council decision-making. Council plans to use the provided information to decide which options are best suited for particular circumstances.

The options report was limited to maintenance activities only and excluded capital works and other activities that do not relate to water level reduction.

1.2 RIVER DESCRIPTION

The Styx River is located in the north of Christchurch and bisects Redwood and Belfast. The Styx River is spring-fed and begins to the east of Harewood. The river is approximately 12.5 kilometres in length, and discharges into the Brooklands Lagoon near the mouth of the Waimakariri River.

The Styx River catchment is predominantly rural and is typically drained through engineered open channel networks (timber-lined drains) which discharge either directly to the Styx River or to one of its tributaries.

The study also included Kaputone Creek from its confluence with the Styx River to Factory Road. A photograph of the Styx River is shown on Figure 1. The river project extents are shown on Figure 2.

Figure 1: The Styx River within the lower reach

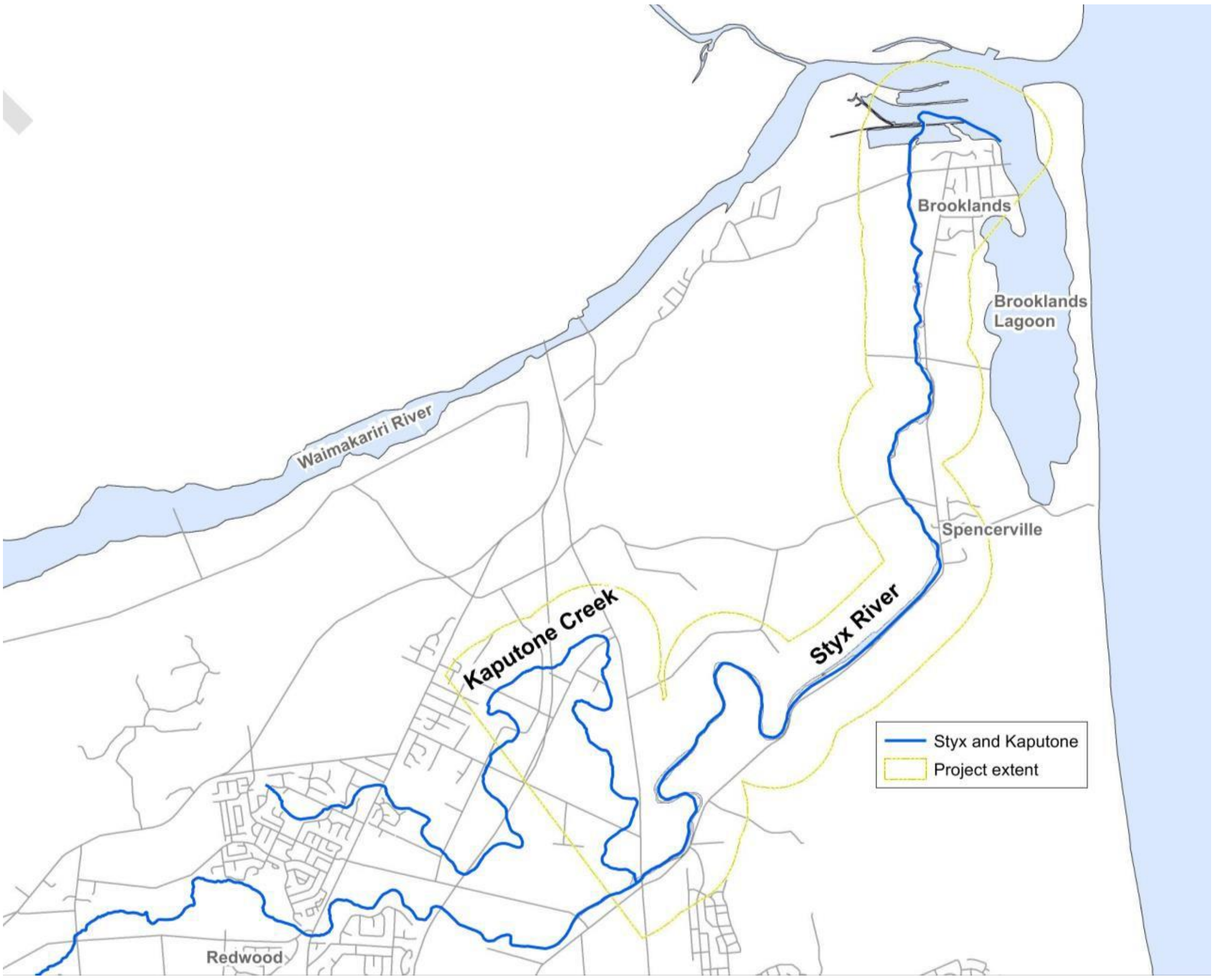

Figure 2: Location Map and Project Extents

2 POST-EARTHQUAKE RIVER ASSESSMENT

2.1 METHODOLOGY

First, the post-earthquake river assessment methodology included an analysis of complaints data to identify areas where residents have been affected by the post-earthquake river condition and also to identify areas that may require increased maintenance. Second, the assessment documented major changes in the landscape (land damage, water level and flood depth analysis). Afterwards, post-earthquake impacts to the Council 'six-values of the water environment' were assessed. The six values (ecology, landscape, recreation, heritage, culture, and drainage) were considered in the study because Council's waterways philosophy is based on the interdisciplinary management of these six values. Finally, the flood depth analysis results were used to inform the establishment of new operational water levels.

2.2 COMPLAINTS DATA ANALYSIS

Complaints data was analysed to determine the areas where earthquake impacts to the river were affecting residents. This analysis was also used to refine the calculations of the proposed operational water levels. The complaints data was extracted from the Council Customer Service Request (CSR) database.

Figure 3 shows the recorded CSR complaint locations in relation to the 5-year ARI flood extents within the lower reach of the Styx River.

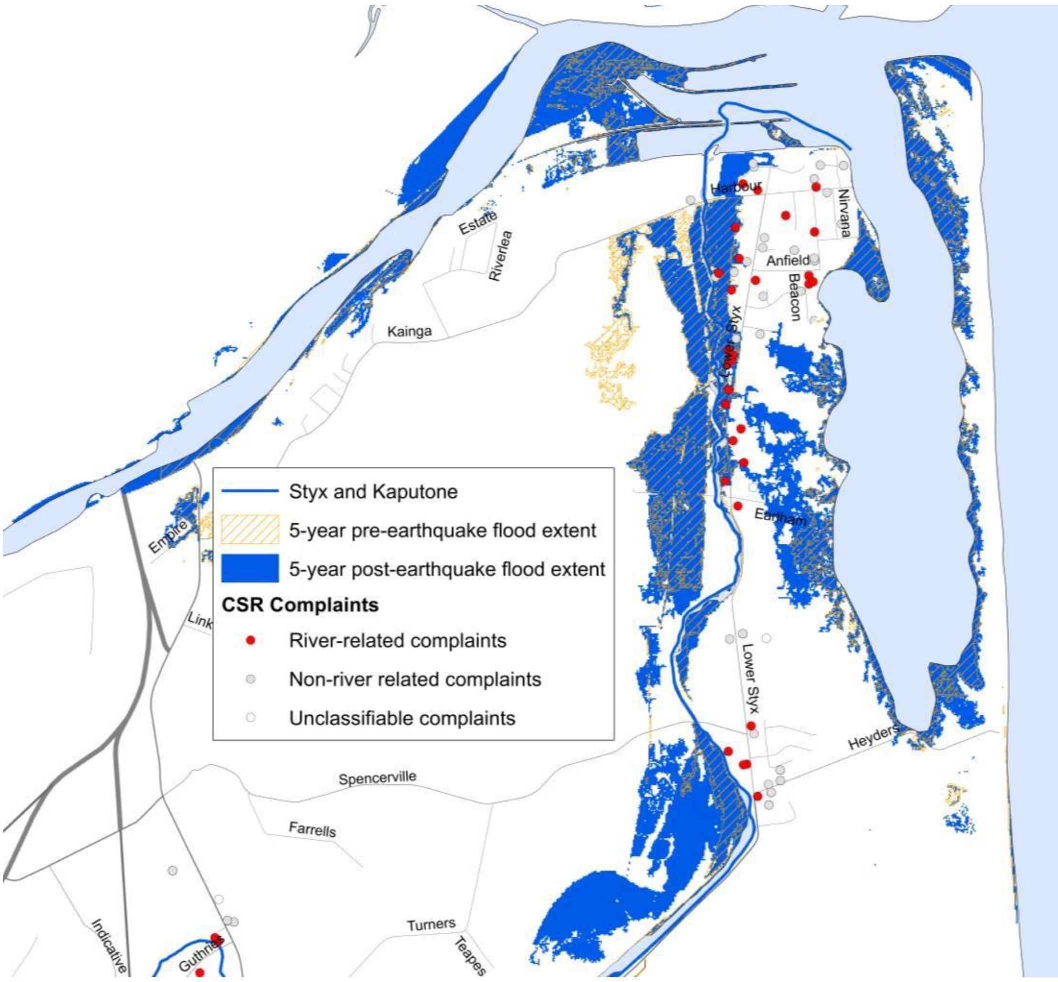

Figure 3: Map of CSR Data Overlain with Pre and Post-Earthquake 5-year ARI Flood Extents

The red dots on the Figure are river-related complaints. The light green cross-hatching defines the pre-earthquake 5-year Average Return Interval (ARI) flood extent, and the dark blue hatching defines the post-earthquake 5-year flood extent.

The location and concentration of the shown complaints were later used to inform the magnitude of change for the proposed OWLs. This is described in a later section.

2.3 LAND DAMAGE ANALYSIS

A Digital Elevation Model (DEM) was used to compare the pre-earthquake LIDAR (2003) and the most recent LIDAR dataset (hybrid 2011-2012). The outcome was limited to the accuracy of the LIDAR data. The comparison showed that the Styx and Kaputone floodplain subsided during the earthquakes. At river-related complaint locations the land subsided up to 500 mm.

A long-section of the Styx River was generated to compare pre and post-earthquake levels for the river bed as well as the left and right banks. This long-section is shown in Figure 4.

The average left and right bank changes were noted for the Styx River and Kaputone Creek. A summary of these averages are shown in the following Table 1. The maximum average is defined as the largest of the averaged values.

Table 1: Summary of Streambank Damage

	Right Bank Average Change	Left bank Average Change
Styx River	-42 mm	-87 mm
Kaputone Creek	-17 mm	-29 mm
Overall Average	-43 mm	
Maximum Average	-87 mm	

The overall average streambank level change for both the Styx River and the Kaputone Creek is -43 mm and the maximum average is -87 mm. The elevation changes were averaged for each bankside (left and right) of the Styx River and Kaputone Creek.

The land damage, along with the water level changes, would later be used to compute the changes to flood depth.

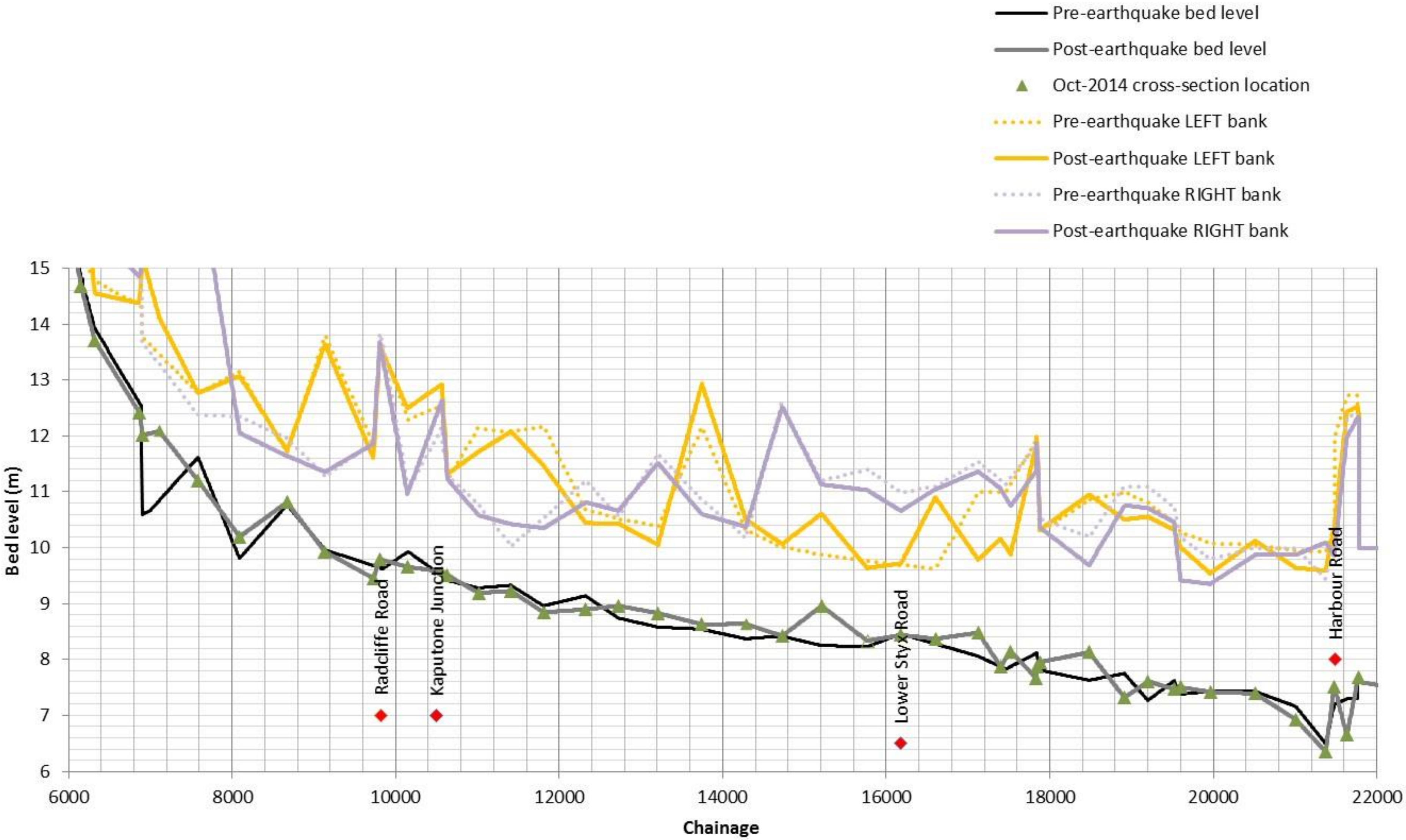

Figure 4: Styx River Pre- and Post-Earthquake Long-section

2.4 RIVER CONDITION ASSESSMENT

A site condition assessment of the Styx River and Kaputone Creek was undertaken on 16 and 17 March, 2015 with the objective to identify areas where land damage may be visible. The Styx River long-section, shown previously on Figure 4, shows sections of river bank that may have subsided or heaved. The site assessment targeted these suspected areas.

The map shown on Figure 5 is colour-coded to indicate the positive/negative change in river bank elevations, pre- and post-earthquake. Photographs from the river site walk are shown and georeferenced onto the figure. Blue indicates a post-earthquake drop in elevation greater than 100 mm, and red indicates a rise in elevation greater than 100 mm. White equates to less than 100 mm change in elevation. The colour-coding is shown for the left and right banks and the river bed.

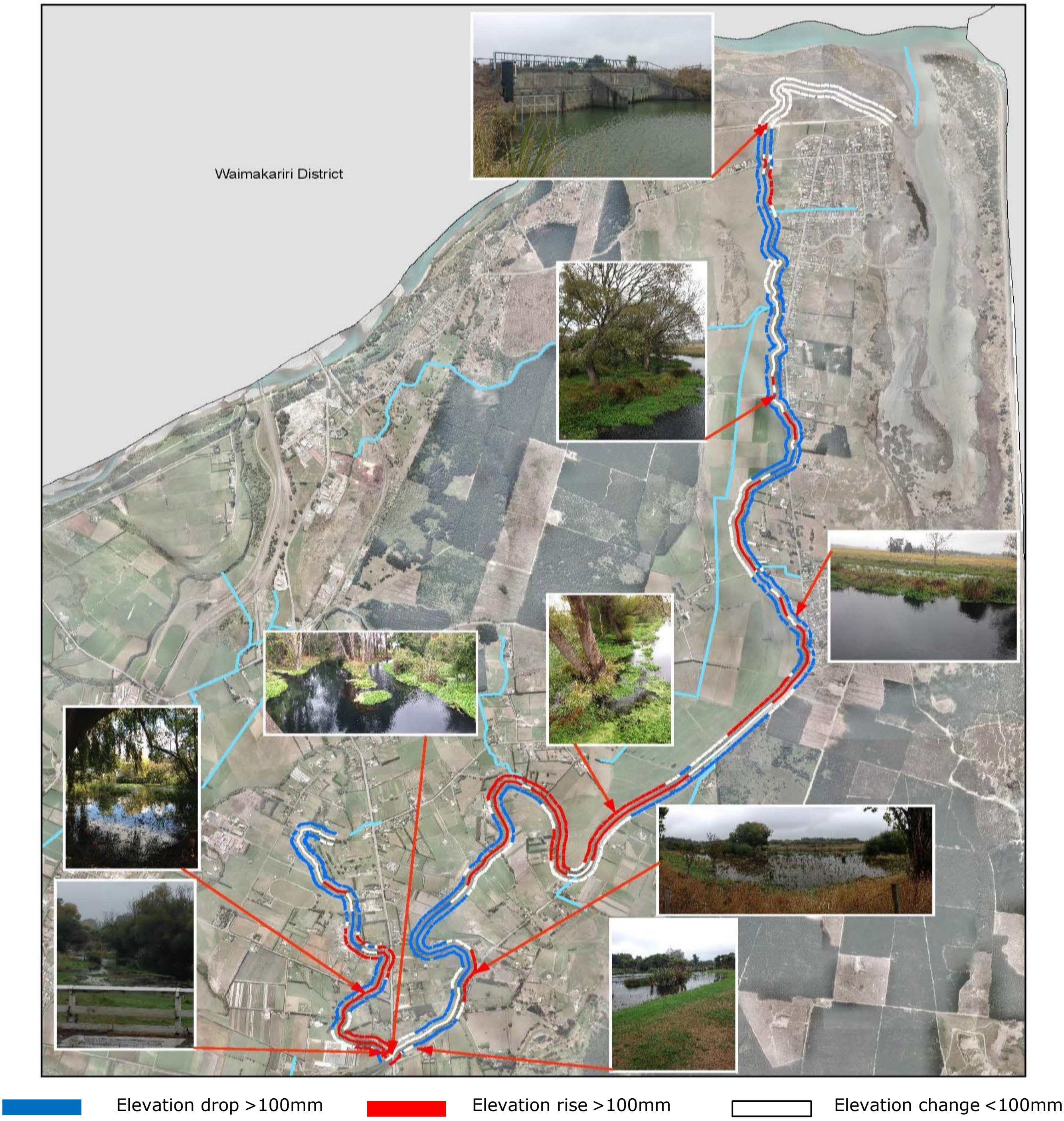

Figure 5: Post-Earthquake River Condition Assessment Map

The map indicates that some sections of river bank experienced an increase in elevation while site observations clearly showed signs of inundation and subsidence. An explanation to these inconsistencies is the way the river banks are defined in the cross-section survey. The banks are defined as, and measured at, the point where the steep river bank slope changes gradient to a milder slope. Even if a river bank 'point' rises in elevation, the land immediately next to this point still could have subsided and caused ponding of water. A riverbank elevation decrease nearby could allow river water to flow into these subsided areas.

It should be noted that bed heave would decrease the cross-sectional flow area and could also be contributing to the flooding of adjacent land.

2.4.1 SIX-VALUES ASSESSMENT

As outlined in the 2003 *Waterways, Wetlands and Drainage Guide* published by Council, the six values are: Ecology, landscape, recreation, heritage, culture, and drainage. Table 2 is a summary of the six-values assessment of earthquake impacts to the Styx River and Kaputone Creek. Each criterion is assigned a qualitative rating from negligible to significant. This qualitative assessment was based on the site investigation as well as the complaints and land damage analyses.

Table 2: Post-Earthquake Impact Six-Values Assessment

Six Values Criteria					
Ecology	**Landscape**	**Recreation**	**Heritage**	**Culture**	**Drainage**
Medium	**Significant**	**Medium**	**Negligible**	**Minor**	**Significant**

Notable Impacts

Streambed subsidence and bed heaving has likely disturbed river ecology with adverse impacts. The physical habitats of river flora and fauna have changed. However, an ecological assessment of the river was not undertaken.

The subsidence and heaving of streambanks has increased inundation of the riparian landscape during dry weather flow. Power poles and trees have tilted off centre. The aesthetic landscape on private property has been damaged due to the water inundation of the land.

As discussed in previous sections, the earthquake has increased the effect of the river baseflow and 5-year ARI flood on land in the Styx River Catchment. Although the majority of properties are rural or agricultural, the increased flooding has resulted in public and private land being inundated more frequently causing concern to local residents.

2.5 WATER LEVEL AND FLOOD DEPTH ANALYSIS

An overall assessment of flooding throughout the catchment is described in this section.

The project also included a desktop study to investigate historical water level trends, causes of seasonal fluctuations, and sedimentation effects with the objective to identify causes of water level changes. Although trends were observed, it was difficult to quantify the impact of such causes on the river water levels.

The difference in predicted water levels, ground levels and water depths for the 5-year flood event was calculated for post- and pre-earthquake, at the complaint locations identified on Figure 3. A summary of the flood depth analysis is provided in the following table.

Table 3: Flood Depth Analysis Summary

Land subsidence at complaint location (LIDAR comparison)	[-460 mm, +13 mm], average -260 mm
Change in predicted flood level (Pre and Post-Earthquake Level Comparison)	[-250 mm, -75 mm], average -160 mm
Resulting impact on flood depth	[+260 mm, -28 mm], average +100 mm

Although the predicted post-earthquake flood levels are lower than the pre-earthquake levels, the difference is less than the land subsidence. This resulted in a maximum increased flood depth of 260 mm and an average of 100 mm for the 5-year Average Return Interval (ARI) rainfall event. A diagram of this change is illustrated on the following figure.

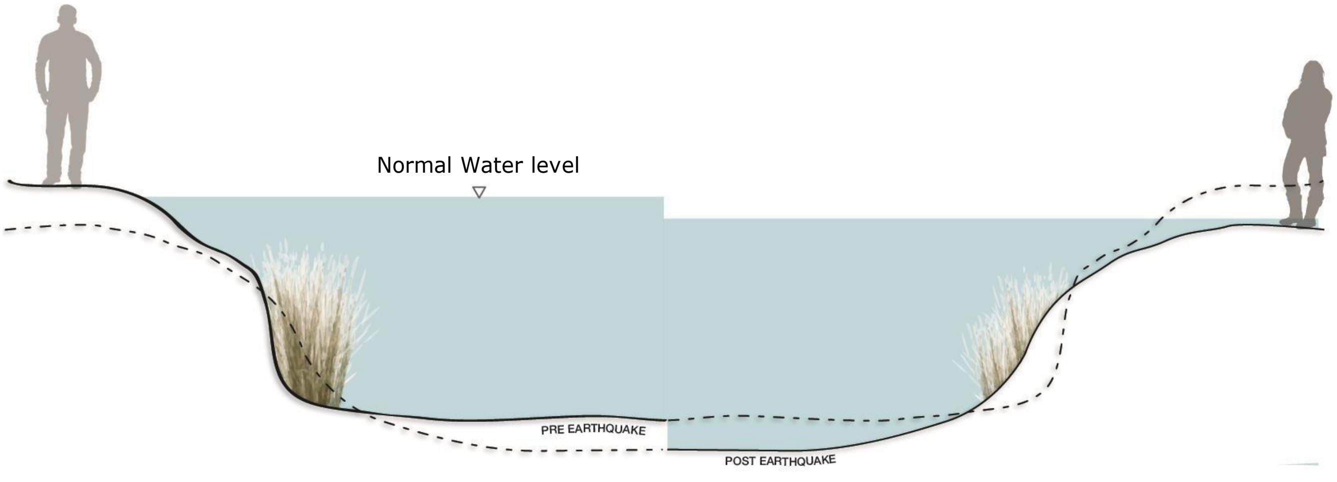

Figure 6: Diagram of Pre and Post-Earthquake Land and Water Levels

The increase in relative flood level increases the extent of flooding. The predicted post-earthquake 5-year ARI flood inundation area is approximately 54% greater than the predicted pre-earthquake inundation area.

The results of the flood depth analysis were used to inform the proposed target OWLs.

3 OPERATIONAL WATER LEVELS

Using the results of a complaints data analysis, operational water levels (OWLs) have been calculated and proposed for the 5-year ARI as well as the base flow level, and these OWLs are shown in Table 4 and Table 5, respectively.

Table 4: 5-Year ARI Operational Water Levels Summary

5-year ARI	Lower Styx Road	Radcliffe Road
Pre-earthquake level 5-year ARI	10.60 m	11.73 m
Post-earthquake level 5-year ARI	10.49 m	11.50 m
5-year ARI level to mitigate average EQ impact (100 mm)	10.39 m	11.40 m
5-year ARI level to mitigate maximum EQ impact (260 mm)	10.23 m	11.24 m
Note: High recurrence flood levels have reduced post-EQ, hence mitigation measures compensate for land damage only.		

The 5-Year level is based on an analysis of complaints data and land damage. The proposed OWLs are located at two existing gauge locations: Lower Styx Road and Radcliffe Road.

Table 5: Base Flow Operational Water Levels Summary

Base Flow Designation	Lower Styx Road	Radcliffe Road
Pre-earthquake level Baseflow	10.20 m	11.21 m
Post-earthquake level Baseflow	10.20 m	11.21 m
Base flow level to mitigate overall average reduction in bank height (43 mm)	10.16 m	11.20 m
Base flow level to mitigate the highest average reduction in bank height along a single bank (87 mm)	10.11 m	11.15 m
Base flow level to mitigate maximum EQ impact (260 mm)	9.94 m	11.02 m

After the new OWLs were developed, a review of historical maintenance activities was undertaken to inform the formulation of future maintenance options to reduce water levels.

4 HISTORICAL MAINTENANCE

Historical and current maintenance activities were reviewed to provide the historical context of the Styx River and Kaputone Creek in terms of maintenance. The maintenance activities identified herein will form the basis for the establishment and assessment of future maintenance options.

The programmed and reactive maintenance of the river system includes the following activities:

- Aquatic weed harvesting
- Riparian vegetation and weed control
- Dredging and invert regrading
- Bank repairs and stabilisation
- Rubbish removal

Areas of intense maintenance, where identified, are discussed as well as how river maintenance has changed after the 2011 earthquakes.

From the 1950s until the 1990s the Styx River was operated under a system of continuous dredging, with the river dredged at 10 yearly intervals using drag lines. The early dredging scheme consisted of one or two dredges working full-time for years at a time. Dredged material was generally trucked to landfill sites or left on the river banks (Hicks & Duncan, 1993). The previous dredging operations occurred in 1993 and then 2013. The 2013 operation was only a short pilot section to test its effectiveness.

The water levels maintained are believed to have been similar to current levels although not much data exists from this time. Comparison of these maintenance practices with the current practices is complex as much of the parameters have changed over time.

According to Council, there has also been significant clearance of trees along the banks over the years and a shift to more riparian plantings. In the 1990s, river maintenance moved to a programme of weed harvesting which has been refined in operation over the years to the current maintenance programme. A weed harvesting machine is shown in the following Figure.

Figure 7: Weed Harvesting Machine

According to Council operations staff, the current harvest trigger levels were considered to work well prior to the Canterbury Earthquakes. Following the Earthquakes these levels have continued to be used but land around the Styx River has moved and the way that these areas interact with the river has changed. Flooding issues have increased in a number of areas and Council operations staff have suggested that new trigger water levels are required.

The weed harvesting specifications, as shown on Figure 8, leave approximately 300 mm on the riverbed and 500 mm adjacent to the riverbanks. The objective is to minimise impact on river ecology as well as erosion of the bed and banks.

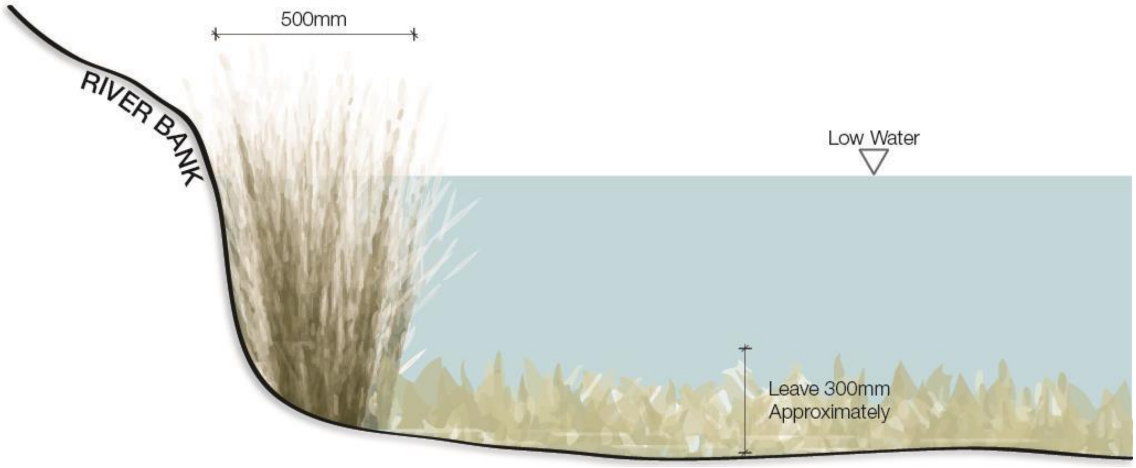

Figure 8: Aquatic Weed Harvesting Parameters

In actuality, weed harvesting is usually carried out between two and five times a year depending on weed growth, according to Council operations staff. Timing of the weed growth varies from year to year and the decision to start harvesting is based on the river water level. There are 3 level gauges in the Styx River used to monitor the water level, the middle of these is checked daily and used to trigger harvesting.

5 FUTURE MAINTENANCE OPTIONS

To meet the proposed OWL targets, a range of maintenance activities were investigated including the main historical maintenance activities as well as other options identified as potentially effective. Only activities that contribute to the reduction of water levels are included in this section. During this investigation phase, nonviable alternatives were removed to produce the following shortlist of options:

- Aquatic weed harvesting
- Dredging
- Minor bank modifications
- Shading with riparian planting

5.1 AQUATIC WEED HARVESTING

Aquatic weed harvesting is the cutting, collecting, storing and disposing of aquatic weeds using a mechanical weed harvester or by hand. Weed harvesting is used to reduce or maintain the height of the weeds. Each cut generally takes 6-7 weeks to complete.

Current Council specifications require that mechanical weed harvesting shall not take place within 500 mm of the banks. A portion of the riverine habitat is therefore retained and protected to mitigate bank erosion and entire loss of the weed system. Some fish and wildlife may be removed with the removal of or disturbance to their habitat during weed harvesting. Therefore sufficient weeds remain to allow the river ecology to reach natural equilibrium. Weed harvesting provides clear fish passage and waterway; free from obstructions for recreational purposes such as kayaking.

The increase in water level due to the effects of weed growth has been investigated using rating curve analysis. Weed growth effects on the water level have been calculated to be between 9 mm and 40 mm/week. This calculation is supported by information from Council that weed growth effects on water level have been observed at up to 50 mm per week. The average increase in water level from the analysis is 19 mm per week.

To meet the new operational water levels, new maintenance trigger levels were proposed. A trigger level is a river water surface level at which maintenance activities are to commence in order to keep the river at or below the operational water level. The proposed trigger levels for weed harvesting are presented in Table 6.

Table 6: Proposed Aquatic Weed Harvesting Trigger Levels

Scenario	Radcliffe Road	Lower Styx Road
Base flow level to mitigate overall average reduction in bank height (43 mm)	11.16 m	9.98 m
Base flow level to mitigate the highest average reduction in bank height along a single bank (87 mm)	11.11 m	9.97 m
Base flow level to mitigate maximum EQ impact (260 mm)	10.98 m	9.83 m

It was determined that to meet the proposed OWLs, aquatic weed harvesting would need to reoccur every 6 – 16 weeks (4 to 9 cuts per annum), depending on the target OWL. Assuming the lower end of 4 cuts per annum and 7 weeks of harvesting per cut, this would mean weed harvesting would be occurring approximately 28 weeks per annum. An increase in harvesting frequency would most likely require Council to purchase an additional harvesting machine as well as increase operational expenditure for the additional harvesting events.

Weed harvesting costs approximately $30,000 per cut and the cost of a new weed harvester (if required to achieve an increased harvesting frequency) is in the order of $250,000.

5.2 DREDGING

A 1993 National Institute of Water and Atmospheric Research (NIWA) report by Hicks and Duncan found that dredging in the Styx River actually increased sedimentation rates. It noted that the comparison of multiple dredging and deposition rates in several locations indicated very little net change in mean bed levels. Dredging in the Styx River accordingly initiates rapid re-deposition to obtain equilibrium (Hicks & Duncan, 1993). The study did not find significant correlation of dredging effects on the average daily water levels from an initial assessment. Therefore, any reductions in water levels were only short term.

In 2013 dredging was carried out between Spencerville Road and Styx River Place. Approximately 2,850 cubic metres of material was removed from this section. Water levels were not found to be significantly altered, with the observed reduction in the order of 10 mm according to Council operations staff. This result supports the claim that dredging is not significantly effective at reducing water levels in the Styx River.

In the 2014 Dredging Feasibility Report produced by Council for the Heathcote River, it was noted that dredging was ceased in the Heathcote River sometime in 1989 as it was considered to be contributing to bank erosion and instability. In addition, it was considered to have minor effectiveness (Christchurch City Council, 2014).

It was determined that for dredging to be effective in lowering water levels for an extended period of time it would be necessary to dredge a large portion of the river. As recommended in the 1993 NIWA report, the dredging should also be done according to an engineered profile and cross-section. Although localised dredging operations have a smaller footprint, they still have environmental and bank stability impacts. This includes upstream stability impacts as a result of dredge hole migration and the increase in flow velocity.

Dredging on the Styx River could have very significant impacts to river ecology and environment. Entire macrophyte communities are either significantly disturbed or removed with the sediments. These macrophtye communities provide habitat for fish and macro-invertebrates. Dredging also fragments and divides riverine communities located upstream and downstream of the dredged section.

Based on interpretation of deposition data for the Styx River published by the 1993 NIWA report, dredging would be required every 10-15-years. Clearly, this means that the environmental impact of dredging would be a recurring event. Consenting for the dredging may also be challenging due to its environmental impact. Given the length of time since dredging of the entire reach last occurred Council are likely to have difficulty justifying dredging given their current river management policies and objectives. According to the Styx River Stormwater Management Plan, the Styx River is a Class 1 river with high aquatic ecological values where river ecology should be maintained or enhanced. Dredging is likely to conflict with this objective.

Dredging the entire lower reach was estimated to be in the order of $40 million.

5.3 SHADING BY RIPARIAN PLANTING

Planting riparian trees shades the river and could potentially reduce weed growth. Greg Burrell of Instream Consulting Limited completed a brief study investigating the feasibility of using this option for the Styx River and also assessing its effectiveness at reducing weed growth rates.

The Study noted that:

- Shade levels of 50-70% are likely be required to markedly reduce macrophyte cover and allow for less frequent weed cutting.
- Achieving 50-70% shade across the whole river width may prove difficult to achieve even with mature trees as river widths reach around 5-10 m.

Although riparian plant shading can be a very effective method to control macophyte growth, the effectiveness is difficult to predict and quantify. For this reason, Burrell recommends trials or pilot-projects to be undertaken to assess the method's effectiveness on the Styx River.

5.4 MINOR BANK MODIFICATIONS

Minor bank modifications could include streambank repairs, which are undertaken to maintain and restore the functionality of the river.

The repair and/or modification of river banks could increase hydraulic capacity and reduce local water levels. Slumping or collapsed banks that are repaired could restore the hydraulic capacity of the local section of the river. Minor bank modifications could involve increasing the cross-sectional area of a short section to increase capacity and lower water levels.

Localised channel widening and deepening was assessed for a short section within the Styx River lower reach. Based on an assumed removal of approximately 5,000 m^3 of material along a 300 m reach, the reduction in baseflow is in the order of 50 – 100 mm.

The estimated order of magnitude cost is $500,000. With the volume of material being moved and the magnitude of cost, it could be difficult to categorise this work as minor or maintenance.

5.5 OPTIONS ASSESSMENT

The project carried out an assessment of the above options against three key criteria:

- Effectiveness at water level reduction
- Environmental impact
- Cost of implementation

The following table outlines the key attributes of each assessed option.

Table 7: Summary of Qualitative Options Assessment

Option	Effectiveness – water level reduction	Environmental Impact	Cost
Weed harvesting	Moderately effective. Increased harvesting could improve effectiveness	Moderate impact	Increasing frequency would be relatively minor cost
Dredging - localised	Only short term and local benefit	Significant impact to local environment	Significant
Dredging – entire reach	Effective but would need to be performed every 10-15 years	Significant impact to entire river	Significant. Approximately $40 million
Shading with riparian planting	Effective but trials needed to improve understanding	Positive impact if planted with native species	Cost depends on extent of planting
Minor bank modifications	Localised effects	Moderate to significant impact to local environment	Relatively moderate cost

6 CONCLUSIONS

The 2011 Canterbury earthquakes have had significant impacts on the Styx River and Kaputone Creek, including land damage, the heaving and subsidence of stream bed and banks, the increase of flood depth for the 5-year ARI. The impacts have been assessed against the Council six-values of water environment.

Using the results of the complaints data analysis, operational water levels have been calculated and proposed for the 5-year ARI as well as the base flow level. The 5-Year level is based on complaints data and land damage. The base flow level is based on bank damage.

To meet these proposed operational water level targets, a range of maintenance activities were investigated including the activities that are currently being used as well as those that have been used in the past.

The following shortlist of options was investigated:

- Weed Harvesting
- Minor bank modifications

- Dredging
- Shading with riparian planting

It was estimated that the cost to dredge the riverbed to pre-earthquake levels would be in the order of $40 million for a dredge volume of approximately 250,000 cubic metres.

Minor bank modifications could become an expensive option if large quantities of earthwork are required. Furthermore, the effectiveness may not justify the costs.

Shading with riparian planting is an option whose effectiveness is not yet well understood. Therefore, pilot-projects would need to be undertaken on the Styx River before a large scale operation could be developed. This option is not expected to be as effective as the other three in terms of water level reduction. The shading reduces aquatic weed growth, but does not completely stop it. However, this option could be used in conjunction with others to form a multifaceted water level reduction strategy.

Weed harvesting appeared to be the most favourable in terms of cost, effectiveness at reducing water levels, environmental sustainability, and consenting requirements. However, the high level of harvesting frequency, its impacts and costs would need to be carefully considered.

Before this study was completed, there was a need by Council to better understand the earthquake impacts to the Styx River as well as what maintenance options were available to mitigate those impacts. In the current water industry there has historically been more focus on capital works for flood mitigation. This study was able to quantitatively and qualitatively assess the earthquake impacts and then present a suite of potential maintenance options to mitigate those impacts. This required not just flood modelling, but also analysing complaints data, use of LIDAR, rating curve analysis for weed harvesting, and the investigation of riparian shading to limit aquatic weed growth.

Future research could involve investigating the effectiveness of riparian shading to slow aquatic weed growth or the effectiveness of aquatic weed harvesting on water level reduction. Another subject of interest could be the quantification of how river sedimentation affects water levels.

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