# DREDGING TO RESTORE RESILIENCE TO A CRITICAL CHRISTCHURCH WATERWAY

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## ABSTRACT

Natural waterways and drainage networks are important features within the urban landscape. They provide a critical link by managing stormwater runoff and offering opportunities for enhancing community amenities. Restoring, protecting and managing surface water has become a critical focus for Christchurch as result of the Canterbury Earthquake Sequence (CES, 2010 – 2011), particularly in combatting increasing sedimentation rates within various watercourses.

The Christchurch City Council (CCC), through the Land Drainage Recovery Programme (LDRP), has initiated a series of investigations and ensuing projects into floodplain management in Christchurch, including in the Ōpāwaho / Heathcote River. The river has a long history of flooding, which has increased both in severity and frequency since the CES. Dredging was known to have little impact in larger events, and with a projected forecast of up to 1 m sea level rise. However, it was found to be effective at reducing the severity of smaller flood events, and with sea level rise of less than 0.25 m. Therefore, the lower Heathcote River Dredging project was developed to provide immediate relief to frequently flooded properties adjacent the Heathcote River. Many of these properties had flooded under- or above-floor multiple times since the CES.

The scope of the project was to fast-track design of the dredging profile and associated bank and landscape works for the lower Heathcote River. As well as flood relief, it was also important to minimise the environmental impact from the works and to enhance the riparian margins where possible. The work area is defined as the reach of river from the Woolston Tidal Barrage to the Beckford Road Bridge and is approximately 3.4 km long.

This paper will discuss the nature of the project and how the project team (CCC and Stantec) has developed a process to facilitate the dredging works, incorporating bank stability pre- and post-dredging and seismic performance analyses. Impacts from the dredging works on urban waterways and local communities will be discussed, including protection of existing drainage values, recreational enhancement, and improvements in ecological and landscape features where possible. These enhancements will contribute to a healthier waterway system and improved hydraulic capacity along this reach of the river. The paper will also discuss consideration and methodologies for restoring resilience to the community, as this has become a key element for people of Christchurch since the CES.

Working near waterbodies escalates risks associated with undertaking the dredging works and maintenance thereafter. This paper will describe; how the design mitigates construction risks; some of the site-specific constraints and challenges encountered during the design and construction phase; and highlight the benefits of bank treatment options adopted.

**KEYWORDS**

**Restoring urban waterways, Flood management, Resilience, Riverbank stability, Sea-level rise, Improved hydraulic capacity, Keeping people safe**

**PRESENTER PROFILE**

Bryan has over 25 years' experience in structural and civil engineering. He specialises in the feasibility, design and construction of waterways and general civil projects. Bryan has also been involved in the design, assessment and construction of over 100 bridge and culvert structures for both national and territorial authorities in New Zealand.

# 1 INTRODUCTION

The CCC, through the LDRP, has initiated a series of investigations and ensuing projects into floodplain management in Christchurch, including in the Ōpāwaho / Heathcote River. The river has a long history of flooding, and the severity and frequency of flooding have both increased as a result of the CES.

*Photograph 1: River Sedimentation in the Heathcote River (low tide)*

In response to this elevated risk, the CCC LDRP has commissioned modelling and subsequently construction of additional flood attenuation and storage in the upper catchment of the Heathcote River. The Dredging Feasibility Report was prepared to investigate the feasibility of dredging of Heathcote River, as one of several flood management options (JACOBS, 2017). Based on this report, CCC engaged Stantec to undertake the detailed design of the river banks and slopes stability associated with the dredging profile proposed. Thus, dredging of the Heathcote River (approximately 3.4 km), between Beckford Road Bridge (upstream end) and the Woolston Tidal Barrage (downstream end), as part of the development of flood risk management was prepared. Figure 1 depicts its extent.

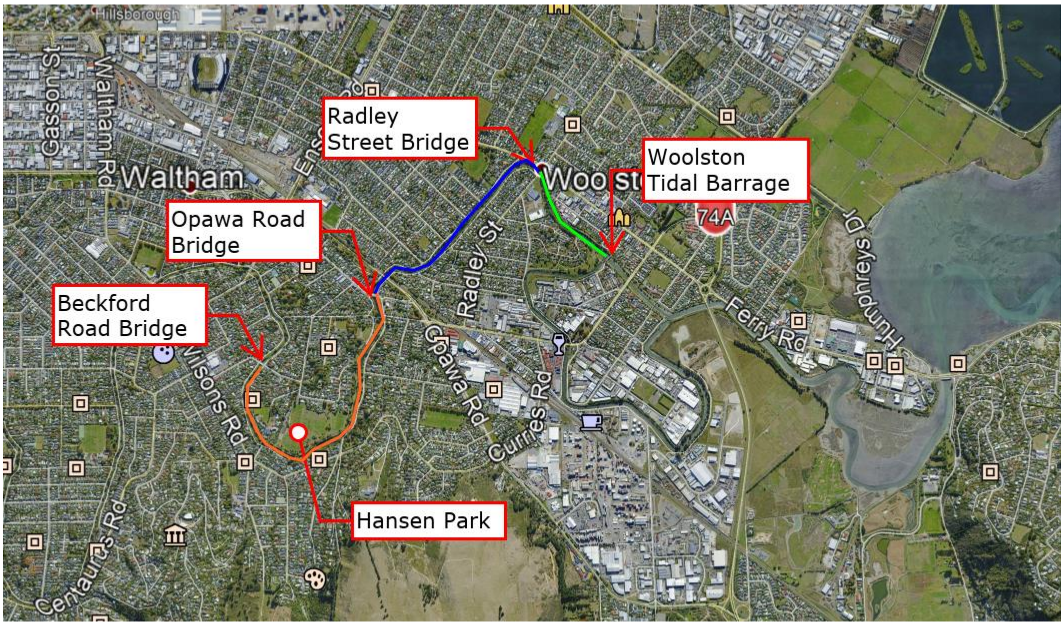



*Figure 1: Aerial image showing the plan of the Heathcote Dredging*

To facilitate the program, and allow a favorable construction window with respect to the īnanga spawning season (1 March to 30 May) in the Heathcote River as recommended by the Dredging Feasibility Report, the program has been separated into three stages (downstream to upstream):

- Stage 1 – Woolston Tidal Barrage to Radley Street Bridge (green line)
- Stage 2 – Radley Street Bridge to Opawa Road Bridge (blue line)
- Stage 3 – Opawa Road Bridge to Beckford Road Bridge (orange line)

This paper focuses largely on the Heathcote Dredging Stage 1 and 2, as the design of Stage 3 is still progressing.

# 2 RESTORING THE WATERWAY

## 2.1 INTRODUCTION

Natural river waterways generally provide less efficient drainage capacity than artificial waterways, despite their similar waterway flow areas. This is because non-uniform factors of natural waterways influence drainage capacity significantly, including narrow channels, meandering channels and presence of other constrictions to water flow. However, natural waterways can provide a wider range of values while maintaining drainage capacity. The Heathcote Dredging Project was progressed to maintain ecological, cultural, recreational, landscape and heritage values as well as to maximise drainage capacity of the Heathcote River with the proposed dredging profiles. This section sets out the history of dredging and principles used to establish a dredging philosophy, while Section 3 sets out the various dredging profiles adopted.

## 2.2 HISTORY OF DREDGING IN THE HEATHCOTE RIVER

Dredging had previously been undertaken up until approximately 1989, and managed by the Christchurch Drainage Board (CDB). Based on records, regular dredging was undertaken between the late 1920’s and 1989. Specifically, the reach between Radley Street and Opawa Road has been dredged frequently (Stage 2), referred to as Reach 3 in Figure 2 below (Hicks, 1993). Figure 2 depicts historical records of the Heathcote Dredging, including longitudinal lengths and volume of dredging.

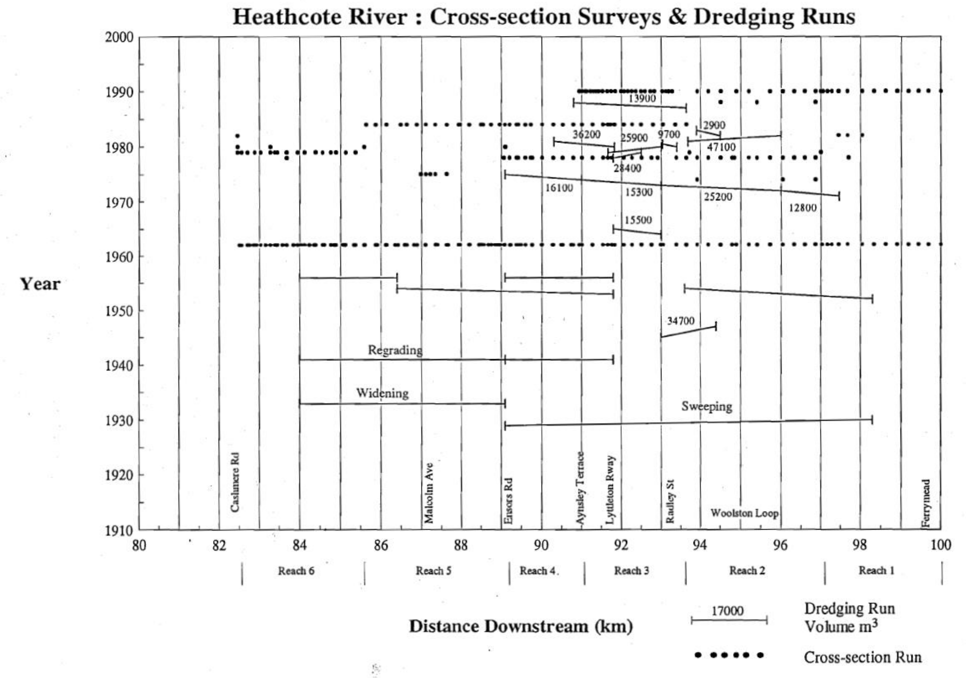



*Figure 2: Historical records of the Heathcote Dredging (Hicks, 1993)*

No systematic dredging in the Heathcote River has been undertaken since 1989 because:

- Dredging may have caused local bank erosion and further sedimentation from over-deepened channels
- Sand bearing springs were exposed near Hansen Park, leading to bank collapse
- Increased consideration of other river values including environmental and ecological

## 2.3 BASELINE HYDRAULIC MODEL

Hydraulic modelling with the existing channel profiles has indicated that inadequate flow capacity to convey water/flood flow to the Woolston Cut has caused flooding upstream of Radley Street. Dredging was therefore proposed to increase the rate of water conveyance, and ultimately lower flood water levels and reduce frequency of inundation of the affected properties.

Based upon analyses of existing channel profiles, as shown on the latest full river cross-section survey in 2011, there was no significant change in cross-sectional area (flow area) further upstream of Hansen Park. Thus, no significant hydraulic benefit from channel widening and deepening was expected upstream of this location. However, between Hansen Park and Woolston Cut significant raising of the river bed was observed, leading to loss in cross-sectional areas through sedimentation and possibly liquefaction ejecta from CES. It was considered that this reach could benefit from dredging.

Modelling of the baseline dredged profile showed a maximum water level reduction of 300 mm around the upstream end of Hansen Park (JACOBS, 2017). The baseline dredging model also included the hydraulic benefits gained from the planned upstream storage basins as the foundation of all options. The model predicted an approximate volume of 60,000 $m^3$ of material (sediment) would need to be removed to achieve the proposed channel profile from Hansen Park to Woolston Cut a stretch of approximately 3.4 km. The difference between the modelled 2011 river profile water levels and baseline dredged profile can be seen on Figure 3, noting that the green line represents the un-dredged 2011 river bed levels.

For those properties currently at risk of above-floor flooding in the 1-in-10 year average recurrence interval (ARI) event, the JACOBS baseline model predicted that the risk of above floor flooding would reduce to below-floor flooding for:

- 70 % properties upstream of Radley Street, and
- all properties would be protected from over-floor flooding at Ensors Road (upstream of Hansen Park).

In 1-in-50 year ARI event, this rate was reduced to 40 % upstream of Radley Street. Reductions in street flooding (both extent and duration) were also considered in the dredging assessment.

The baseline model also considered sea-level rise of + 0.25 m and + 1.0 m, from its current level and combined with 1-in-10year ARI flood event model. The results indicated that the protected property rates above would reduce to 65 % and 10 %, respectively.

The overall conclusion was that for the reach between Hansen Park and Woolston Cut dredging could be effective at reducing the severity of smaller flood events, and with sea level rise of less than 0.25 m.

## 2.4 PRINCIPLES FOR DEVELOPING THE DREDGING PROFILE

### 2.4.1 HYDRAULIC MODELLING

The hydraulic model for the Heathcote River has been developed using Mike 11 (1D) and Mike 21 (2D) software and undertaken by DHI Group. Following Stage 1 of the assessment, Stantec and CCC agreed that a faster design path could be achieved with a simpler hydraulic model for Stage 2 and beyond. Stantec developed a simplified spreadsheet backwater model to determine the rough order hydraulic improvements due to various proposed bank treatments, so that different bank profiles could be trialed and the implications on upstream water levels quickly understood. After several simple model iterations, the results were then verified using the more complex Mike 11 software.

An example of hydraulic comparison of the two model types is shown in Figure 3, and indicates that water level reductions are a close match with the Mike 11 model showing improved reduction in water level over the simplified backwater model.

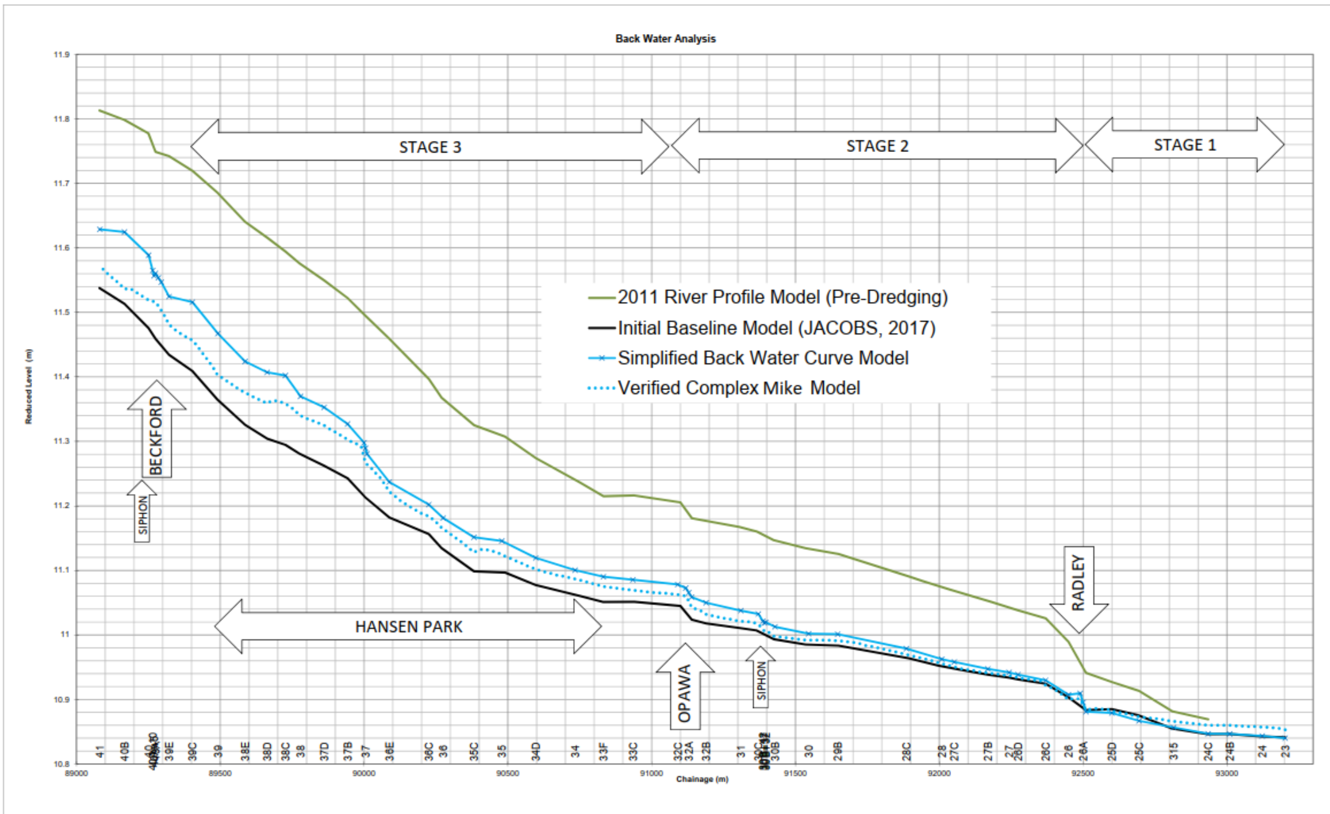



*Figure 3: Comparison between Simplified Backwater Model and Verified Mike 11 Model*

From early simplified option modelling, some extreme variation in flow area between adjacent model cross sections was identified – i.e. sections with significantly less flow area placing a restriction on flow capacity. Stantec proposed that significant hydraulic improvements could come from aggressive improvement of channel size in parts of the river that are relatively narrow, or shallow, compared to the adjacent upstream and downstream channel. This approach has allowed us to target specific parts of the river to assess the cost vs the benefits of widening and dredging associated with removal of these flow constrictions.

### 2.4.2 BANK STABILITY

Several cross-sections with the initially proposed dredging profile, assuming 2 Horizontal (H) : 1 Vertical (V) (i.e. from the 2017 Dredging Feasibility Report), were considered and provided to Stantec to assess stability of the post-dredging banks. These cross-sections were used for a preliminary bank stability analysis to provide conceptual treatment options. The modelled dredging slope of 2H:1V is considered by judgement to have marginal stability.

Following a review of the existing banks, a typical modified channel section was adopted using a flatter 3H:1V dredging slope from toe of bank. This approach was targeted at minimising the risk of instability to existing banks above, while providing a maximum increase in channel size for flood flows. In addition, the modified dredging profile was also adjusted locally to minimise dredging in front of sensitive sections of the bank (i.e. at existing structures) by reducing the dredge slope and providing some clearance (termed a buffer) from toe of bank.

Figure 4 shows the development of sediment accumulation since 1990 at one location (Clarendon Terrace/ Stage 2). The profile appears consistent with what is inferred to be an accumulation of sediment on the river bank moving the bank toe further towards the river centerline, and a significant thickness of sediment at the current bank (i.e. the vertical distance between the grey and blue lines). The sediment accumulated on the river was found to be soft/loose from site inspection and was determined not to contribute significantly to stability of the natural river bank. The 3H:1V nominal dredging slope is therefore often wholly within river sediments.

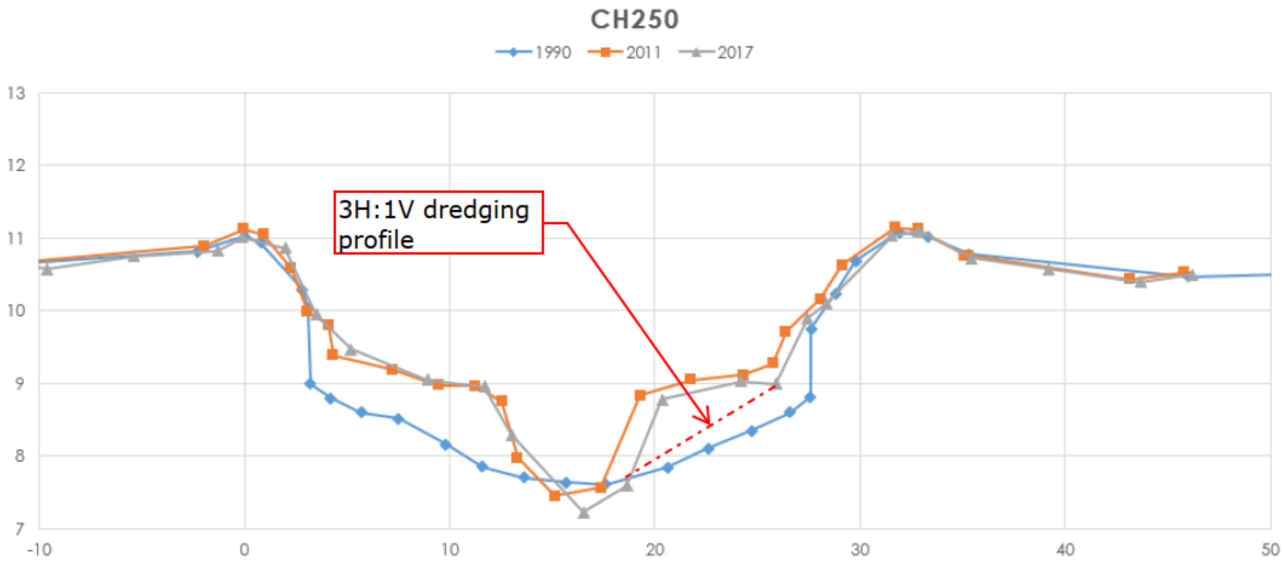



*Figure 4: Sedimentation since 1990 in the Heathcote River (Clarendon Terrace)*

For parts of the channel that are overly constrained by bank width, a full height bank cut (at 3H:1V) and or some form of vertical retaining structure may be justified. However, this would require an assessment, in combination with geotechnical/construction issues, to determine the resulting impact on adjacent CCC assets (road, potable water, waste water, etc.). In the majority of cases an acceptable dredging profile could be achieved without the need for vertical retaining structures.

Some areas within the proposed dredging reach are densely vegetated with native and exotic plants along the bank (particularly the Stage 1 area). The established vegetation limits access for dredging and transportation equipment / plant due to narrowness between the vegetated area and the cadastral boundaries. Early engagement with community groups and potential contractors identified an opportunity to combine the access needs of the dredging project with an eradication exercise of a large portion of the problematic white poplar trees. Tree removals were able to be progressed while considering the interests of river access along with landscape amenity and ecological enhancement.

*Photograph 2: Access limited by established dense vegetation (Stage 1)*

The design philosophy selected was to generally maintain the existing bank stability in a long-term static condition rather than targeting a specific factor of safety. A slope of 3H:1V was therefore used for all bank stability analyses, and applying this slope was found to achieve relatively similar Factor of Safety (F.o.S) to the existing bank stability.

### 2.4.3 SEISMIC PERFORMANCE OF BANKS

To assess lateral spreading, a Newmark sliding block approach was adopted, setting a control point at the nearest private property boundary. From our assessment there is the potential for increased lateral spreading due to the dredging works, but only in situations where significant liquefaction would have occurred and displacements in the order of hundreds of millimeters are predicted (with or without dredging). If lateral spreading displacements in an earthquake are assessed to be small (tens of millimeters) with the current river profile, then they are also predicted to remain small after dredging. Where pre-dredge lateral displacements are assessed to be large (hundreds of millimeters) then post-dredge increases in the order of 20% are possible, however, this would be of a magnitude that is damaging to residential property with or without dredging.

None of the analyses performed represent the lateral displacement towards the river exactly. In reality, the earthquake acceleration and soil strength are varying on a continuous basis and even extremely sophisticated time history model can only approximate the displacement that would vary with every unique earthquake event. However, simplified analyses can give an understanding of the trends pre and post-dredging.

It is therefore concluded that in earthquake events that do not trigger significant liquefaction, there will be little difference in lateral displacements pre- and post-dredging at nearby properties. While in earthquake events that do initiate significant liquefaction and produce displacements in the order of several hundred millimeters, displacement increases in the order of 20% are possible, however, the displacements would be large and potentially damaging to nearby residential houses regardless of the dredging.

#### 2.4.4 LANDSCAPE DESIGN

The Heathcote River within the project area is a site of ecological significance in the District Plan. The proposed dredging works and the development of the landscape elements represent an opportunity to preserve and enhance the landscape values within the project area. Proposed ecological improvements include riparian planting along the banks to encourage īnanga spawning, and the provision of a protection area over part of the reach to maintain the existing ecological habitat.

#### 2.4.5 EXISITNG STRUCTURES

Most waterway bridges are very similar in flow area to the adjacent open water way within the Stages 1 and 2. Any piers within the waterway typically pose a minor restriction to water flow as they reduce the net flow area, but his effect is minor relative to total water level rise. Most piers and abutments are founded on driven piles approximately 9.0 m to 11.0 m in length. The proposed dredging profile is therefore considered to be acceptable based on the significant pile embedment depth below dredge level.

The foundation of the retaining wall associated with Woolston Tidal Barrage is protected from undermining by reno-mattresses, typically laid in 6H:1V slope and 3.0 m length as per the as-built drawing set. The area in this vicinity was up-lifted by the CES. These structures may therefore become more exposed than allowed for in their designs. Thus, it was recommended that locating the existing erosion protection structures (reno-mattresses) should take place prior to commencing the proposed dredging works to minimise the risk of undermining.

The Heathcote / Ōpāwaho River provided access for small ships into Christchurch City. There are still some traces of the historical wharves along the project extents. The existing wharf and bollards are to be protected during the operation of dredging.

There are several stormwater features (i.e. pipes and outfalls), conveying surface water to the Heathcote River. Most of them are not affected by the dredging works. Some that are affected by the proposed dredging works will be reinstated as per the CCC's Construction Standard Specification (CSS). Moreover, pre- and post-survey works, including conducting CCTV inspection, will be required to minimise risks of damaging services during the construction and post-construction.

# 3 DREDGING PROFILE

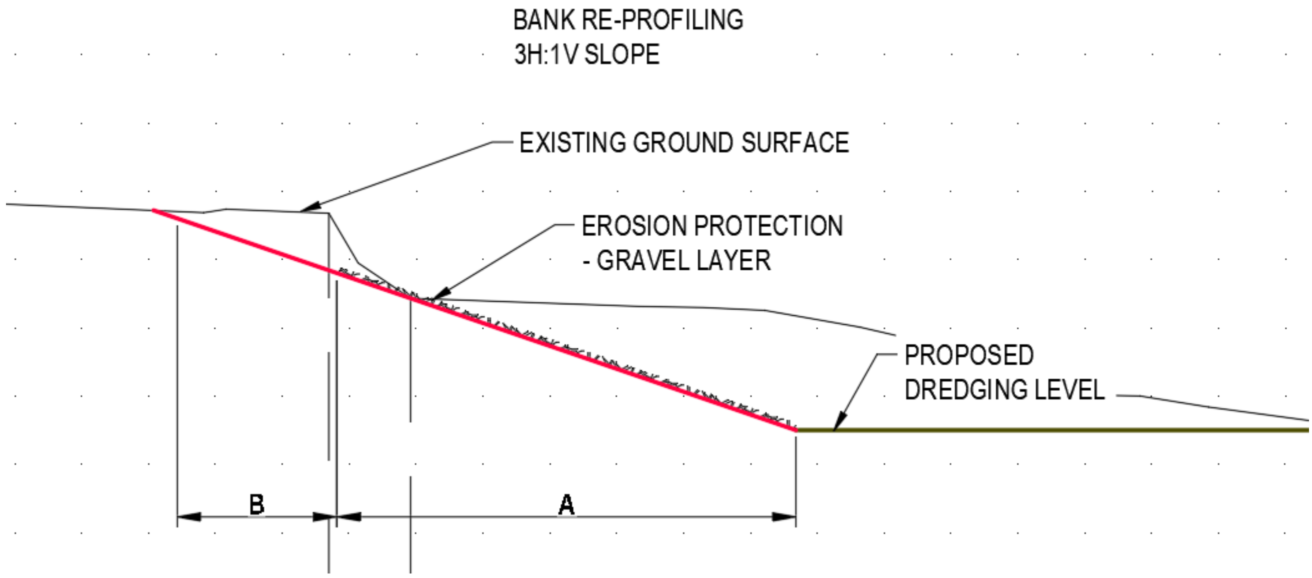
## 3.1 INTRODUCTION

There are four typical bank treatments that were applied to the Stage 1 and Stage 2 reaches, taking into account the principles stated in Section 2. Retaining structures were also considered to maximise drainage capacity by allowing greater channel widening and deepening during the optioneering stage. However, this was typically not favorable due to geometry constraints, constructability and low cost-effectiveness for the gains achieved.

#### 3.1.1 TYPE 1 - BANK RE-PROFILING (STAGE 1 ONLY)

The option constitutes approximately 24 % of Stage 1, 325 m out of 1360 m (both banks).

This option is typically applied to the Stage 1 area, where the established vegetation limits easy access for dredging and transportation equipment / plant due to the narrowness between the vegetated area and the cadastral boundaries. In order to obtain adequate access for the construction equipment, some sections along the reach required tree removals to allow the dredging and bank treatments works to occur. Where the existing trees are removed and space above the river banks allows this, the banks have been re-profiled to an average slope of 3H:1V, formed as a constant slope from the dredging level projected to top of banks. Forming a constant slope will result in exposing fresh soil to erosion, therefore the need for erosion protection was considered. The primary cause of instability of the existing bank by observation was wind driven wave erosion within the tidal zone (approximately R.L 9.1 m to R.L 10.2 m).




A: 3H:1V dredging profile with gravel protection layer
B: Raparian planting zone R.L 9.6 m to R.L 10.6 m

*Figure 5: Typical Section of Bank Re-profiling Option*

In order to address this erosion potential, a protection layer composed of gravel is applied on the dredged slopes in stretches where the proposed works will expose fresh soil within the tidal range as shown in Figure 5. The gravel layer is tamped into the dredged slope (loose silt sediment) until the surface of gravel layer ceases to exhibit observable movement. Vegetation, that would otherwise provide erosion protection, will not grow below RL 9.6 m based on operational experience and this has, therefore, been adopted as the upper most vertical extent of the erosion protection. The expected behaviours of the erosion protection material is for erosion of the fine fraction to occur leaving behind a 'beach' of larger (> 10 mm) material that is erosion resistant as illustrated in Photograph 3. However, placing a single-sized gravel (i.e. railway ballast) layer was suggested by the contactor due to constructability and availability, and this option was ultimately adopted.

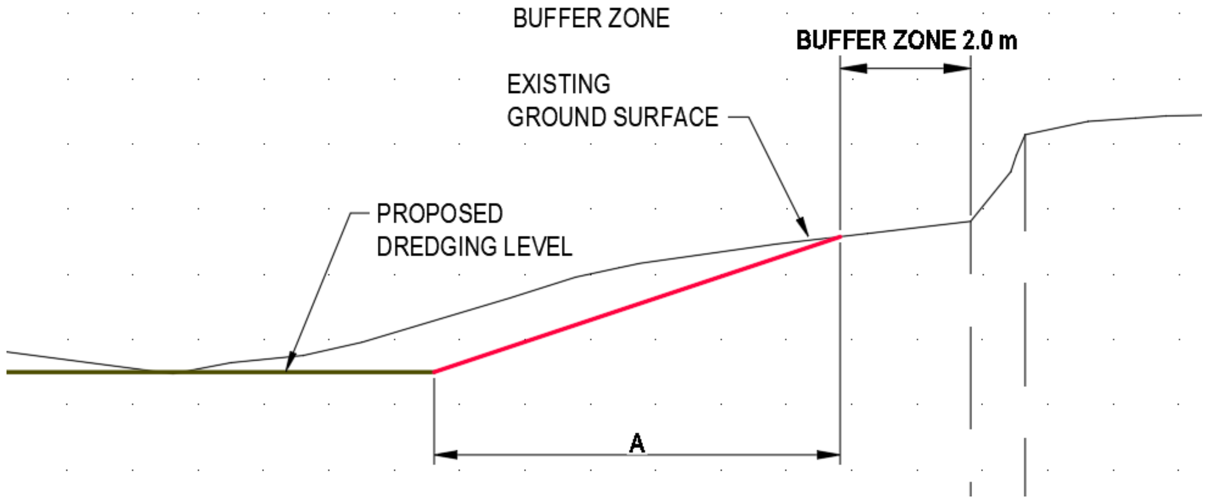
*Photograph 3: Beach formed in sandy gravel protection layer (example – not from Heathcote River*

Installing raparian plants above the erosion protection layer will provide ecological habitat, and may potentially encourage īnanga spawning. Removing existing trees and re-profiling with milder slope will result in an wide open space on the bank and this is hoped to attract community members to the water edge, encouraging recreational and cultural activities in the Heathcote River.

*Photograph 4: Open space on river bank with riparian plants (Connal Reserve)*

### 3.1.2 TYPE 2 - BUFFER

This option provides a clearance, or 'buffer', to the existing banks and structures and was applied over both Stages 1 and 2. The option constitues approximately 49 % and 16 % of Stage 1 and Stage 2, respectively. The rationale behind providing a buffer zone is to maintain bank stability by preserving some of its existing toe support and also providing a zone that can be monitored for erosion by river flows and wind driven waves.




A: 3H:1V dredging profile

*Figure 6: Typical Section of Buffer Zone Option*

Provision of a buffer area to the dredged slopes and banks is considered to be the most feasible option where the existing vegetation/trees are desired to be retained. This is because:

- No access is required from the banks to conduct the dredging operations, barge operation is required,
- Not removing existing vegetation/trees, especially the root system, contributes to aid bank stability,
- The difference in hydraulic benefits between full bank re-profiling option and full buffer zone option in Stage 1 was minimal, and
- The provision of buffer areas will have reduced impacts from the proposed dredging works on the natural habitats along the river.

We have adopted a buffer area to bridge abutments that are founded on shallow non-piled foundations (i.e. footbridges) reducing the risk of undermining from the proposed dredging works as shown in Figure 7. This poses a minor restriction to water flow but is considered to be negligible over such a short distance.

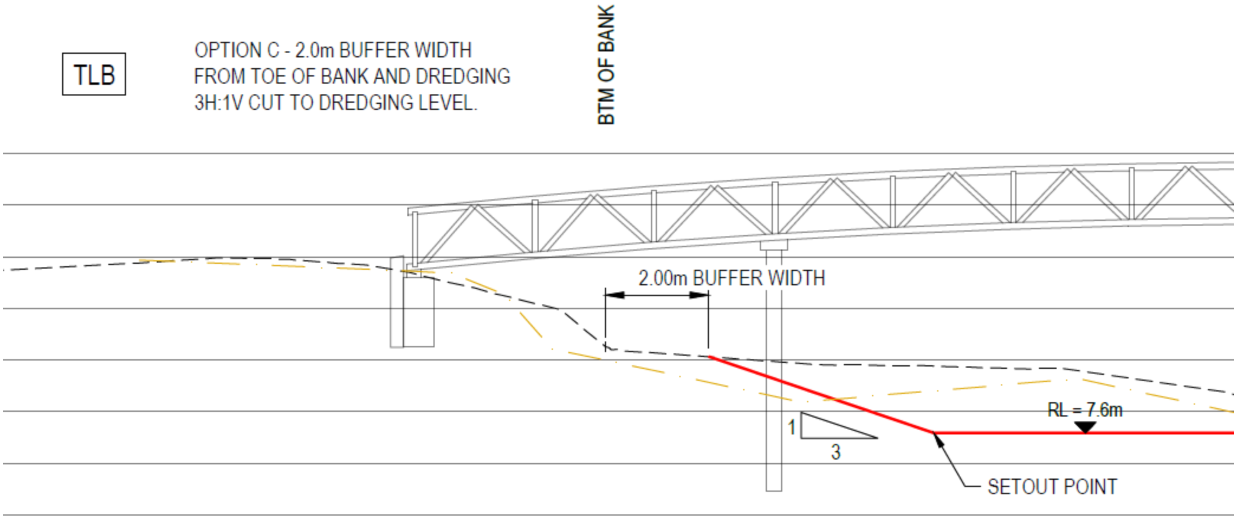



*Figure 7: Typical Section of Buffer Zone Option to Existing Structures*

### 3.1.3 TYPE 3 - DREDGING ONLY

Our observation has been that the principal cause of bank instability in Stages 1 and 2 has been wind driven wave erosion in the tidal zone, exposing fresh soil and causing erosion. Where no reshaping of the river banks is preferred (with that decision being driven largely by the quality and density of existing vegetation) this option has been adopted and involves only dredging below water level.

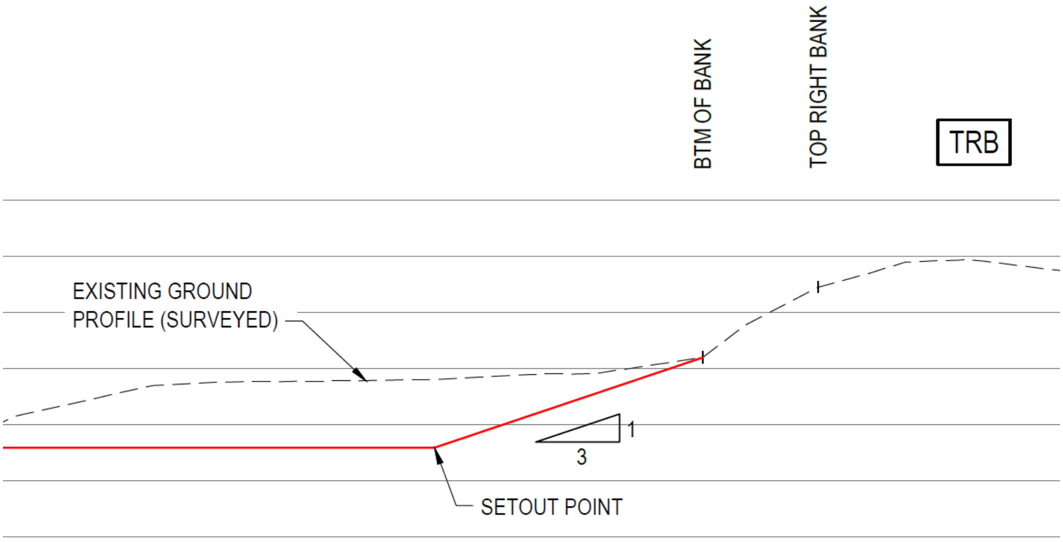



Figure 8: Typical Section of Dredging Only Option

Most bridge abutments and wingwalls within Stage 1 and 2 are founded on deep driven piles. To maximise drainage capacity, dredging to toe of abutments has been applied as shown in Figure 9. There is a residual risk of the abutments undermining, potentially leading to dropouts forming in the road approaches, however, the risk of this occurring is very low, and any resulting damage can be easily rectified as required. Based on discussion with CCC, it was determined that the benefit outweighed the risk associated with this treatment.

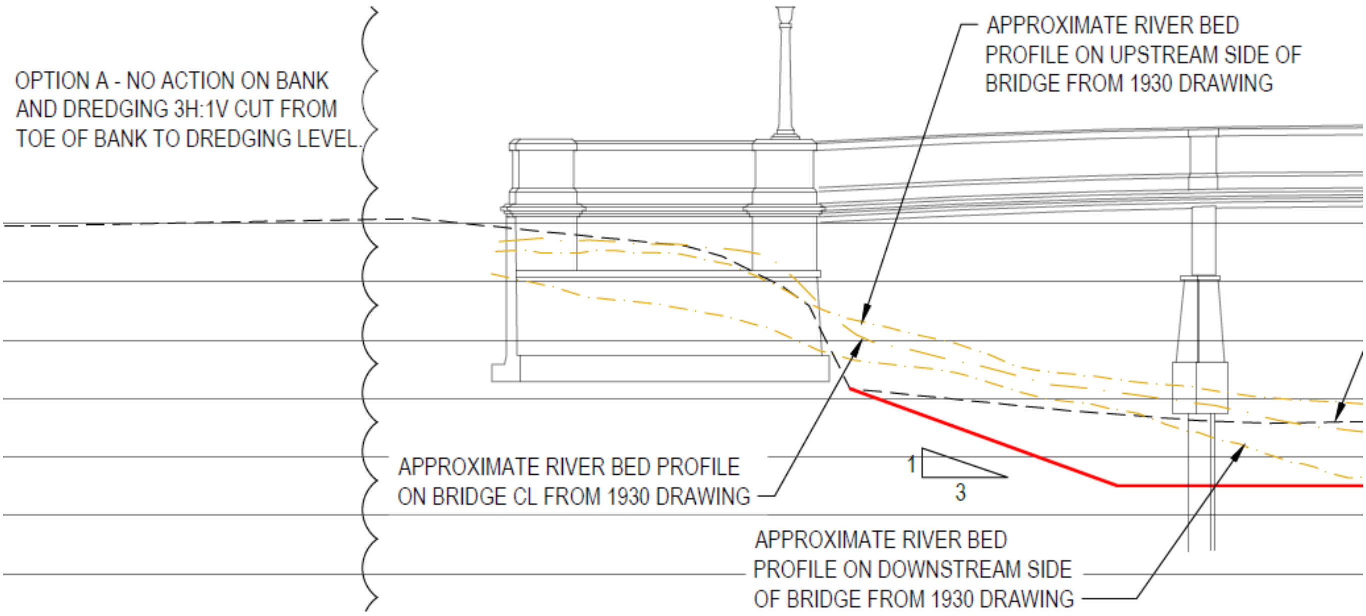



*Figure 9: Cross-Section of Radley Street Bridge*

This option constitutes approximately 17 % and 76 % of the Stage 1 and Stage 2, respectively.

### 3.1.4 TYPE 4 - NO ACTION (STAGE 2 ONLY)

Due to fast flowing water with greater energy on outside of bends, the river generally forms a deeper channel and an asymmetrical river cross section. This often results in the current river bed level being lower than the proposed dredging level. Thus, this section type has been adopted along sections that do not require dredging/bank works to increase flow area. The option constitutes 9 % of Stage 2, 250 m out of 2780 m, and is not used in Stage 1.

# 4 PROJECT LOGISTICS

Site works have been primarily driven by access and river characteristics. For the Stage 1 reach, the early identification of tree removals meant good working areas could be established at the upper and lower limits of the dredging reach and dredging by barge with dedicated load-out areas was possible.

*Photograph 4: Dredging by barge operation (Stage 1)*

For the Stage 2 reach, access is readily available from adjacent public roads so a moving option of excavation by long reach and/or amphibious excavator was ultimately adopted by the contractor.

*Photograph 5: Dredging by long reach and amphibious excavators (Stage 2)*

Site works methodology and programme have had to be managed around ecological constraints and natural system conditions, with sediment control and tidal flows presenting significant challenges. Ongoing monitoring and engagement with key stakeholders has been prioritised to manage impacts of the works and ensure long term improvements will more than offset short term impacts.

Sediment removal and disposal has been informed by extensive sediment quality testing carried out prior to contractor procurement and experience from previous dredging project on the Heathcote River post CES. Sediment quality has also been monitored throughout the dredging in accordance with consent conditions and to date all material has met recreational soil guidelines. Due to elevated stormwater contaminants monitoring of the sediment will be continued throughout and the contractors are required to maintain vigilance in identifying unforeseen contamination such as uncontrolled fill sites on the banks, elevated contamination from stormwater discharges or illegal dumping direct into the river.

# 5 RISKS AND SAFETY IN DESIGN

## 5.1 RISKS

Construction and operation key risks of the proposed dredging works and associated possible mitigation measures that could be included in the design were identified.

Key risks were:

- Cutting sediment and leaving a segment behind may result in instability of the post-dredging bank. Sediment contributes very little to bank stability as understood to be loose silt from site inspection, thus, considered acceptable.

- The proposed dredging works may disturb the existing ecological habitat. Bank works is proposed along relatively small proportion of the reach (24 % of Stage 1 only). Based on ecological survey, the Stage 1 is outside of the īnanga spawning area, therefore, insignificant impact is expected.

- Seismic liquefaction may result in post-dredging bank instability and ground movement. Analyses indicated that the level of liquefaction induced damage /displacement on the post-dredging bank remains similar (+20%) to the pre-dredging bank.

- Further upstream dredging works (Stage 3 reach) may accelerate sedimentation of the dredged sections. Monitoring of the dredged sections is required, particularly over īnanga spawning season (1 March to 30 May) to estimate how much the river bed reforms over 3 months.

## 5.2 SAFETY IN DESIGN

Working near waterbodies escalates risks associated with undertaking the proposed dredging works and maintenance thereafter. During design, and from the safety in design workshop with contractors, potential safety risks were raised and addressed.

The design intent has been to optimise the dredging work (design profile) to minimise the footprint of physical works, including those activities associated with bank stability works. Simplified design was developed, where possible, to minimise surcharge loading and/or allow for the available reach of construction plant. Using construction methodologies which minimise the extent of the excavation from existing bank was also beneficial. Minimising the extent of excavation around the existing structures (i.e. providing 2.0 m width buffer to the structures unless structures have driven piled foundations) was also adopted for shallow footing. As part of the pre-construction activities, the design also considered the location of services and initiated setting up a service management plan to protect and to reinstate them if affected by the proposed dredging works.

# 6 CONCLUSIONS

Dredging of the Heathcote River has the potential to reduce flood risk to some of the most at-risk river side properties. The maximum hydraulic benefit that can be achieved by dredging must be balanced against a number of other constraints, including:

- Stability of the banks (both static and seismic)
- Maintenance of riverbank habitats
- Maintaining or enhancing access to the river for recreational purposes
- Maintaining or enhancing riverbank vegetation
- Logistics constraints to excavate and remove sediment
- Resource consent and other regulatory requirements

On this project these constraints were best balanced by adopting a variety of different cut profiles and typically undertaking minimal works above water level. The resulting dredging profile can therefore be constructed much quicker than one using heavily engineered riverbank structures, while preserving more of the current desirable riverbank characteristics.

**ACKNOWLEDGEMENTS**

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