OPTIMISATION OF EARTHWORKS, RUNOFF ATTENUATION AND BREAKOUT FLOOD CONVEYANCE USING INFOWORKS AND MX MODELLING

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ABSTRACT

Ravenswood is a proposed 135 ha residential and commercial development north of Christchurch. This development is located in the flood path of a breakout from the Ashley River, requiring careful management of flood risk.

Space restrictions within the developed area, plus the breakout floods mean that it was not possible to fully mitigate local runoff peaks within the development. Instead, a system was designed whereby a realigned stream/flood path through the development was used to provide the additional local-flood attenuation that the conventional treatment wetlands/attenuation areas could not achieve. This proposed system was balanced against managing stream ecology, passage of breakout floods, and maintaining the existing flow balance of diverging flood paths downstream. This also needed to be achieved in the context of achieving a cut-to-fill earthworks balance across the site, while creating an attractive environment, fitting of its location as the focal area of the development.

This approach required both earthworks and terrain design modelling with MX and hydraulic modelling with InfoWorks CS, to optimise the future land form and stream design. The resulting system includes a series of weirs and culverts within the stream system which will cause water to pond behind them to provide attenuation, yet allows larger flood flows to pass safely.

KEYWORDS

InfoWorks CS, modelling, attenuation, flood, runoff

PRESENTER PROFILES

Angela Pratt - Angela is an environmental engineer with experience in designing stormwater systems for a variety of residential, commercial, industrial and roading projects. Angela was the lead design engineer for the conceptual design and consenting of the Ravenswood Development.

Andrew Cowley - Andrew is an environmental engineer with interests in hydraulic engineering and environmental management. Andrew undertook the hydraulic modelling of the proposed stream concept and stormwater management system for the Ravenswood Development.

1 INTRODUCTION

Ravenswood Developments Ltd (RDL) proposes to develop a 135 ha block of Greenfield (rural) land on the northern side of Woodend adjacent to State Highway 1 (SH1), in North Canterbury. The development will consist primarily of residential sections with associated commercial and high density residential areas. As part of the development, RDL also propose to realign the Taranaki Stream, which currently runs through the site in a highly modified channel, such that in future it flows along a more natural alignment. This realignment will also serve to position the stream in the centre of the development so that it can be used for amenity and recreational purposes.

Both the stormwater system and the stream realignment concept design required a number of design requirements to be considered. Some of these were legislative and some were client driven. The critical drivers for the concept design were provision for attenuation of site-generated stormwater, conveyance of flood flows from a breakout of the Ashley River to the north and achieving a cut-to-fill balance on the development earthworks. This mix of objectives required that both an InfoWorks hydraulic model and an MX earthworks model be developed, to demonstrate that each objective could be met.

Figure 1 shows the location of the site relative to the surrounding townships of Woodend, Pegasus and Rangiora as well as the Ashley River to the north.

Figure 1: Ravenswood Location

Note that the design developed to date is conceptual only for the purposes of supporting a plan change and resource consent applications. Further detailed design will be required to enable construction to occur.

2 PROJECT CONTEXT

2.1 EXISTING FLOW PATTERNS

Taranaki Stream is the main waterway that passes through the Ravenswood site. However, there are also a number of artificial streams and farm drainage channels present. The stream itself has been relocated at some time in the past, however the previous flow paths (including one through Woodend) still exist and still carry water during high flows. At SH1 on the eastern side of the site, the stream previously flowed down the Waihora Stream, but this stream is now normally dry and only flows during peak flows and Ashley River breakout events.

Figure 2 shows a plan of the RDL land with the proposed Taranaki Stream realignment as well as the existing drainage network, the old flow path through north-west Woodend and the Waihora overflow path.

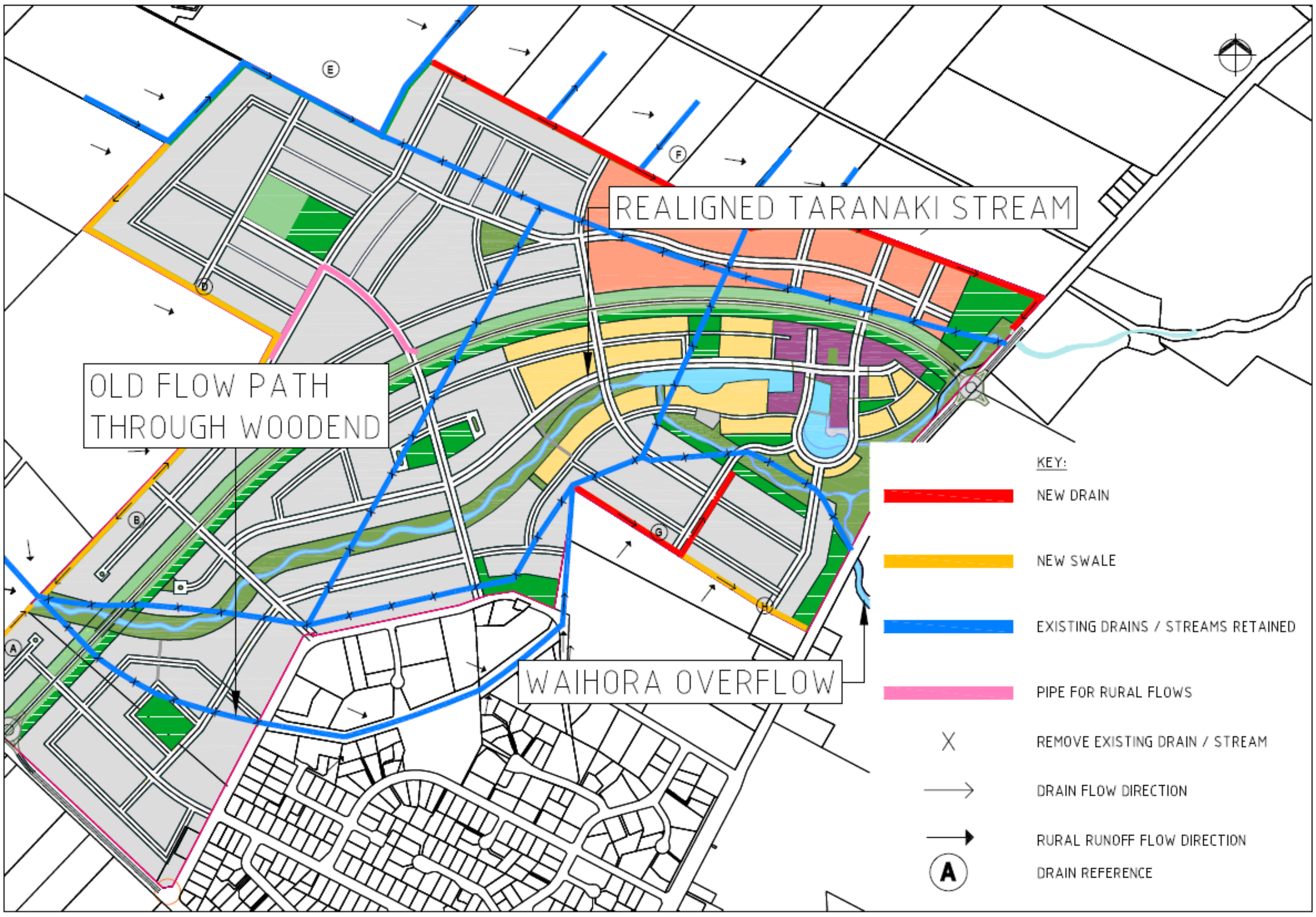

Figure 2: Existing Drainage Network and Proposed Stream Alignment.

2.2 FLOOD RISK

The proposed Ravenswood development is located in the path of a flood resulting from a potential breakout of the Ashley River near Rangiora, to the north-west of the development. This means that for the development to proceed, this flood risk must be managed. To quantify the risk to the development, flood flows from modelling carried out by Environment Canterbury (ECan) using Mike Flood, have been used. Using ground level data from a LiDAR survey for the area, combined with historical information on previous Ashley River breakout locations and flows, ECan has predicted that, in a 1% Annual Exceedance Probability (AEP) breakout event (the critical event for Ravenswood), 21 m^3/s of flow will enter the Taranaki Stream system and will pass through the Ravenswood site. This flow passes over SH1 (as is the current situation in high flows) and discharges into both the Taranaki Stream (in the north east end of Ravenswood) and the Waihora Creek dry flood channel (in the south east end of Ravenswood). ECan's modelling also provided the split of flows between the two discharge points. A flow of 1 m^3/s also currently discharges through existing Woodend to the south. The development of Ravenswood and in particular the realignment of Taranaki Stream will redirect this discharge away from Woodend and hence reduce the existing flood risk to Woodend.

Figure 3 shows the expected depth of flow through the Ravenswood area during a 1% AEP Ashley breach event.

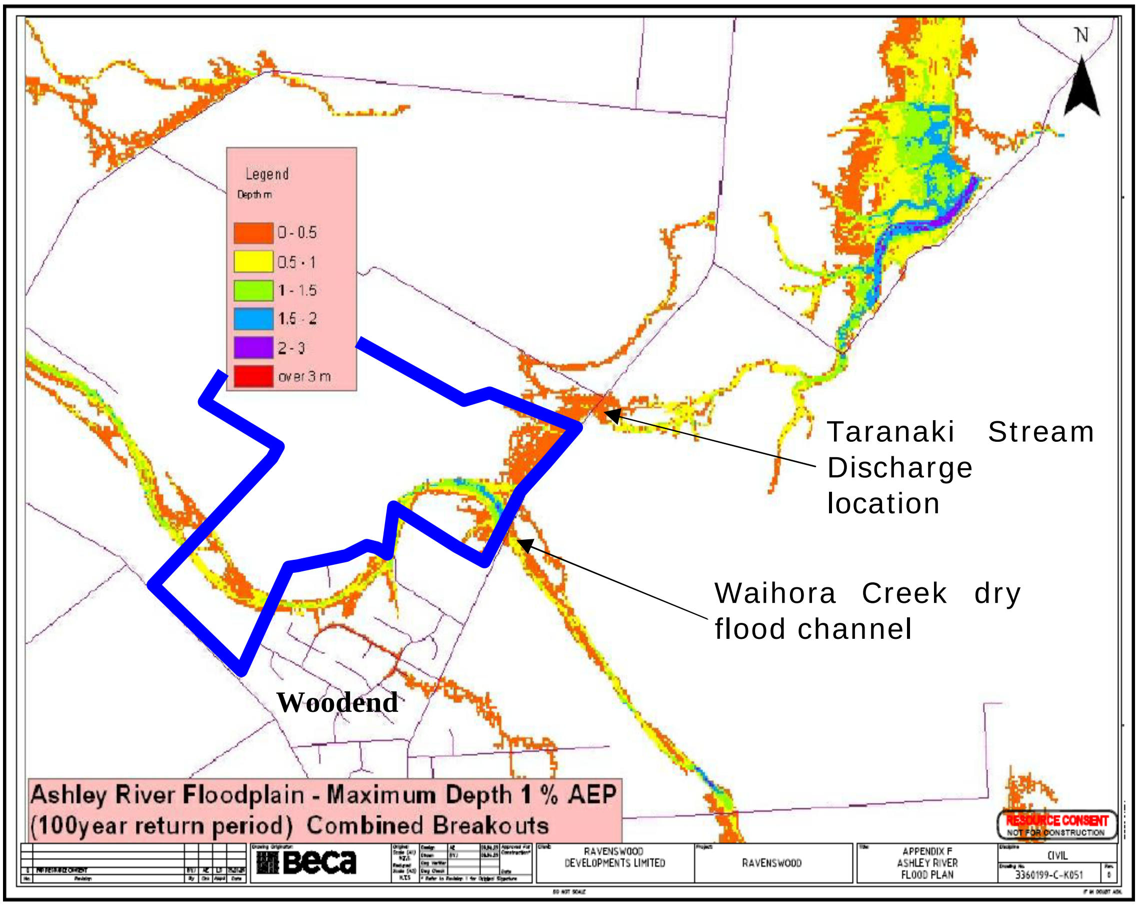

Figure 3: 1% AEP Ashley Breach Flood Depths Source:ECan 2008

2.3 DESIGN REQUIREMENTS - LEGISLATIVE/CLIENT

In developing the stormwater system and stream realignment concepts for the Ravenswood Development, there were legislative and client-driven requirements that needed to be met, for the development to be feasible from environmental, as well as from public safety and financial perspectives. These requirements included the following:

- To convey an Ashley River breakout flow through the development while minimizing the risk of inundation of property. This requirement is set by ECan and the Waimakariri District Plan, as well as the Building Code.

- To attenuate the “100%” (1-year recurrence interval), 20% and 2% AEP stormwater flows from the site to predevelopment levels. This is a Waimakariri District Council Engineering Code of practice requirement. Attenuation of smaller events is required to minimize downstream channel erosion resulting from increases in peak flows. Mitigation of larger events is required in order to prevent downstream flooding.

- Cut-to-fill earthworks balance. To control costs and reduce traffic impacts associated with importing material for fill from offsite, RDL required that a cut-to-fill balance be achieved.

- To maintain the existing flow split between Taranaki Stream and the Waihora overflow during local flood and Ashley breach events. This was an ECan requirement to avoid additional flooding that may occur if all flow was to pass through the Taranaki Stream system.

- To keep all developed areas above the SH1 level to minimize the risk of flooding should the existing SH1 culverts block. This is a Public Safety/Building Code Requirement.

- To maintain fish passage. As there are numerous species of fresh-water fish present in the Taranaki Stream, provision of fish passage is good practice. ECan and Fish and Game would normally also want to see that fish passage is provided for.

- To treat stormwater generated by the site. In order to mitigate the effects of stormwater on water quality in the receiving environment, treatment is needed and is also a requirement of ECan. ARC, 2003 has been chosen as the design standard for this project.

- To provide a highly appealing Town Centre area and stream reserve that can be used for recreational and amenity purposes. This was a RDL requirement.

Note also that in developing the concepts for the stormwater system and stream realignment, mitigation of the increase in stormwater volume discharged from the site, also needs to occur. It is proposed to provide this mitigation by installing a pumping station where the Taranaki Stream discharges into the Ashley River, near Waikuku Beach. This concept is however not dealt with further in this paper.

3 PROPOSED STORMWATER SYSTEM

3.1 PROPOSED TREATMENT AND ATTENUATION SYSTEM

Stormwater generated by the development will be collected and conveyed in a conventional pipe network which will discharge to wetlands for treatment. These wetlands will be spread around the site and will discharge to the stream at the nearest location to each wetland. A ponding area alongside each wetland will also be used for partial attenuation of peak flows up 20% AEP without surcharging of pipes (additional attenuation is provided when surcharging occurs). Due to space constraints resulting from the client's need to achieve sufficient yield of lots for the commercial viability of the development and the difficulty in many instances of directing all secondary flow to the basins, full attenuation via this method was not achievable. The remainder of the required attenuation was instead carried out within the stream corridor that passes through the town centre area of the development. Here, a series of weirs with culverts underneath will provide fish passage at normal dry weather flows and attenuation ponding areas during storm events, while still conveying the Ashley River breakout flood flows. This layout is shown in Figure 4 below.

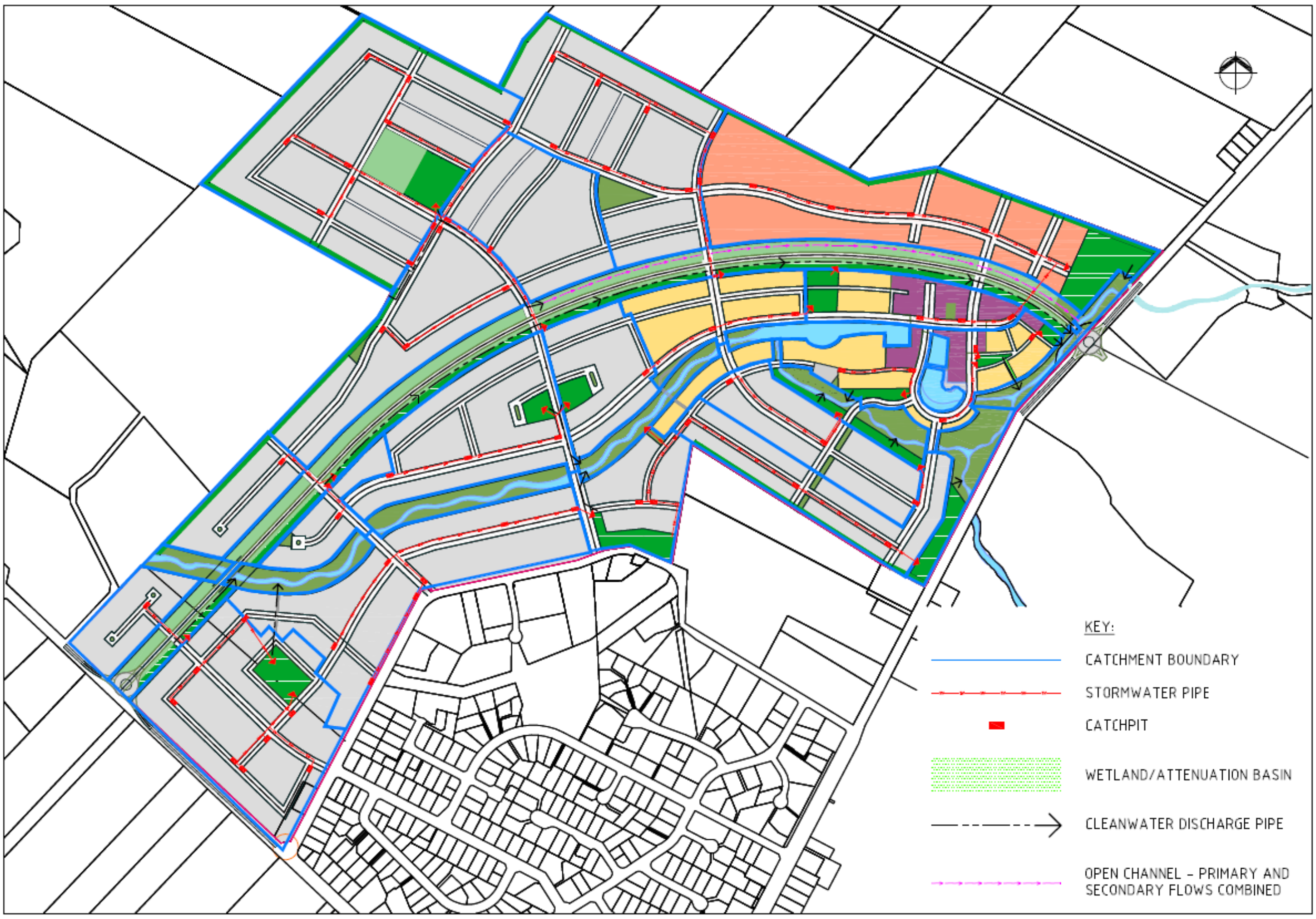

Figure 4: Proposed Stormwater Treatment System

3.2 PROPOSED FLOOD RISK MITIGATION

It is proposed to convey the Ashley River breakout flows through the development by providing sufficient flow capacity in the realigned Taranaki Stream system and generally by setting the level of adjacent developable land, above the highest occuring stream level during flood flows. The series of weirs and culverts within the Town Centre, which provide attenuation of site flows (discussed further later), have the dual purpose of maintaining the existing split of flows between the Taranaki Stream and the Waihora Stream which currently occurs during local flood and Ashley breach events.

4 MODELLING

4.1 INFOWORKS MODELLING

In order to demonstrate that the numerous client and legislative (environmental and natural hazard mitigation) requirements of the proposed stream alignment and that a stormwater management system could be met, it was necessary to build a hydrological and hydraulic model of the proposed development. There were two main objectives placed on the Ravenswood development, for which the hydraulic model was able to assist:

1. Attenuation of “100 %”(1 year), 20% and 2% AEP storm runoff to pre-development levels.
2. Conveyance of Ashley River flood breakout flows, and appropriate split at SH1.

Furthermore, the model was used to conceptually design an environment that could provide appropriate stream depths and velocities to support the fish and other aquatic flora and fauna that are present in normal dry weather flows. This aspect of the concept design was a challenge in the context of also providing attenuation and flood conveyance.

InfoWorks CS was used to build a hydraulic model of the site, as it provides the majority of tools required to simulate the hydrological changes brought about by the development, as well as the dynamics of the proposed hydraulic system. InfoWorks allowed the combination of a standard reticulated stormwater pipe network, wetlands, the adjacent attenuation ponds and an open channel stream system with weirs and culverts in a single integrated model.

The requirement to achieve a cut-to-fill balance led to a continually evolving MX terrain model (see later for further description of this model). Inputs in the form of ground levels and stream cross-section levels from the MX model were tested using the InfoWorks model to evaluate each terrain design iteration, in terms of the suitability of its corresponding stormwater management system and stream alignment performance.

A contour plan exported from MX was used as one of a number of backgrounds in InfoWorks. This assisted greatly when changing ground and stream levels as well as checking consistency between MX and InfoWorks. Any proposed changes to levels resulting from InfoWorks modelling were then exported as a CAD file containing node locations for wetlands, stream points and pipe junctions, with their corresponding ground and invert levels provided in an excel table also exported directly from Infoworks. Some manual input of levels in MX for the stream cross-section structure was however inevitable.

The InfoWorks model comprised of subcatchments covering the entire 135 ha development, with runoff collected at one or two main points in each subcatchment. At this concept design stage, only the main lateral stormwater pipe network between the collection points and the discharge points to the treatment wetlands and attenuation ponds was modelled. The wetlands and attenuation ponds were both represented by ponds in the model. Runoff is subsequently discharged to the Taranaki Stream by outlet pipes.

4.1.1 MODEL INPUTS

The main inputs to the hydraulic model were ground levels from the MX model for the post-development stage and from the LiDAR survey and river cross-section survey for the pre development stage. Rainfall intensities used to produce runoff were sourced using NIWA's High Intensity Rainfall Design Systems (HIRDS), with allowance for climate change (values increased by 15% in accordance with ECan's requirements at the time). Stream flow gaugings were carried out in conjunction with the concept design to determine the normal dry weather flow rates that could be expected. An inflow hydrograph for the Ashley River breakout scenario was developed with ECan based on outputs from their modelling.

4.1.2 MODEL OUTPUTS

The hydraulic model provided estimates of the following:

- Water levels:
  - along the stream
  - in the wetlands/attenuation basins
  - at weir crests
  - though the pipe network
- Flow velocities for use in evaluating the suitability of the southern stream route for fish passage.
- Water volumes being conveyed through the development for pre and post development scenarios.

Using a dynamic hydraulic model allowed each aspect of the concept design to be tested in combination for each flow scenario. Pipe capacities (for 20% AEP flows), invert levels, wetland sizes and levels, stream outfall levels, weir widths and crest levels, culvert diameters and stream cross-sections were all estimated using the hydraulic model. Any levels causing issues with pipe grade, wetland and attenuation pond levels and insufficient capacity with the stream could be assessed and then re-modelled in MX. This iterative process of terrain and hydraulic modelling resulted in an effective concept design that should meet all of the design criteria and has provided evidence of doing so, to the client and consenting authorities.

4.2 MX MODELLING

As MX is a civil design tool rather than a stormwater specific design tool, only an overview of the work carried out has been provided.

MX modelling is widely used to design general site and road grades, such that habitable land is not flooded and roads can act as secondary stormwater flow paths. It is also used to determine volumes of cut and fill, so that the designer can determine whether fill will need to be imported or cut exported, in order to develop the site. This type of modelling was carried out as part of the concept design of the Ravenswood site, in conjunction with the InfoWorks modeling, so that the various design requirements could be balanced in an integrated way.

The MX modelling used LiDAR data to develop the existing ground model of the site. Subsequently, the proposed development plan was then laid over the top and the wetlands, stream route and secondary flow paths (roads) were cut down and graded. More detail by way of cutting down roads to sub-base level and building up of lots to final building platform level, was also included before cut and fill quantities were assessed. A number of iterations using design levels from InfoWorks produced a final site ground model that suggests a cut-fill balance could be achieved.

5 OPTIMISATION

5.1 OVERVIEW

In developing the concepts for the Ravenswood stormwater system and stream realignment, there were two key areas that required an iterative approach to achieve the desired outcomes. Firstly, balancing the cut-fill requirements against flood risk and flood conveyance, and secondly, balancing attenuation against flood conveyance and the requirement to discharge to two locations downstream (flow split).

The initial stages of developing the concepts for the site involved carrying out a first cut of the site layout including stream levels, routes of the primary stormwater conveyance system and secondary flow paths, as well as treatment and attenuation systems. This first cut was used to develop both the MX model of the site, from which volumes of cut and fill were calculated and input levels for the InfoWorks model provided. This first cut required that a significant volume of fill be brought in to the site to be able achieve the design levels. As this was not a viable option from a cost and traffic impact perspective, alternative layouts needed to be evaluated.

5.2 BALANCE CUT/FILL AGAINST FLOODRISK

In developing the concept design, the new realigned stream path through the development, the existing levels and locations at the upstream and downstream ends of the site were fixed. The existing stream path has a reasonably consistent gradient between these two points, however some steeper riffle sections are present. The new stream also needed to provide a variety of stream gradients to provide good habitat for the local flora and fauna.

Changing the stream location provided a significant opportunity to lower the stream long-section, and generate cut while also lowering the resulting peak stream levels during storm and flood events. The optimum alignment resulted from the stream being set at a steeper grade at the upstream end and then having a flatter grade to the downstream discharge point. Providing a narrow low flow channel with a wide floodplain berm, also resulted in a small channel well-suited to ecological requirements during dry weather flow conditions, whilst providing a large overall flow cross-section in which to convey flood flows. Constraining this stream concept and the associated cut, was the requirement for the adjacent developable land to be raised, such that it was above the nearest stream bank level, and hence above the design peak flood level. A second constraint was that all developable land was required to be above SH1, to minimise the risk of flooding if the SH1 culverts block, causing water to flow over the state highway.

A number of iterations of stream and secondary flow path levels were modelled using InfoWorks, with the resulting levels at critical locations along the stream used to reassess the cut and fill volumes in MX.

After the initial iterations, the MX modelling showed that modifying the stream levels alone was unlikely to be able to achieve the cut-fill balance, so options to lower another part of the site (north of the realigned Taranaki Stream) to create a separate secondary flow path and pipe route were assessed. As the lowering of an area in the northern part of the site resulted in ground levels being lower than the realigned stream bank, it was necessary for the concept design to provide two levels of protection. Firstly, the stream banks needed to be set high enough to avoid the Ashley breakout flow from escaping the stream corridor. As a fallback, secondary flow paths were provided along streets, so that should any water overtop the stream banks, it is appropriately managed so that developable land is not flooded. InfoWorks again enabled the concepts be tested against design criteria.

Figure 5 shows the final cut and fill areas for the site, with pink areas indicating the deepest cut, and shading in red and orange areas indicating the deepest fill.

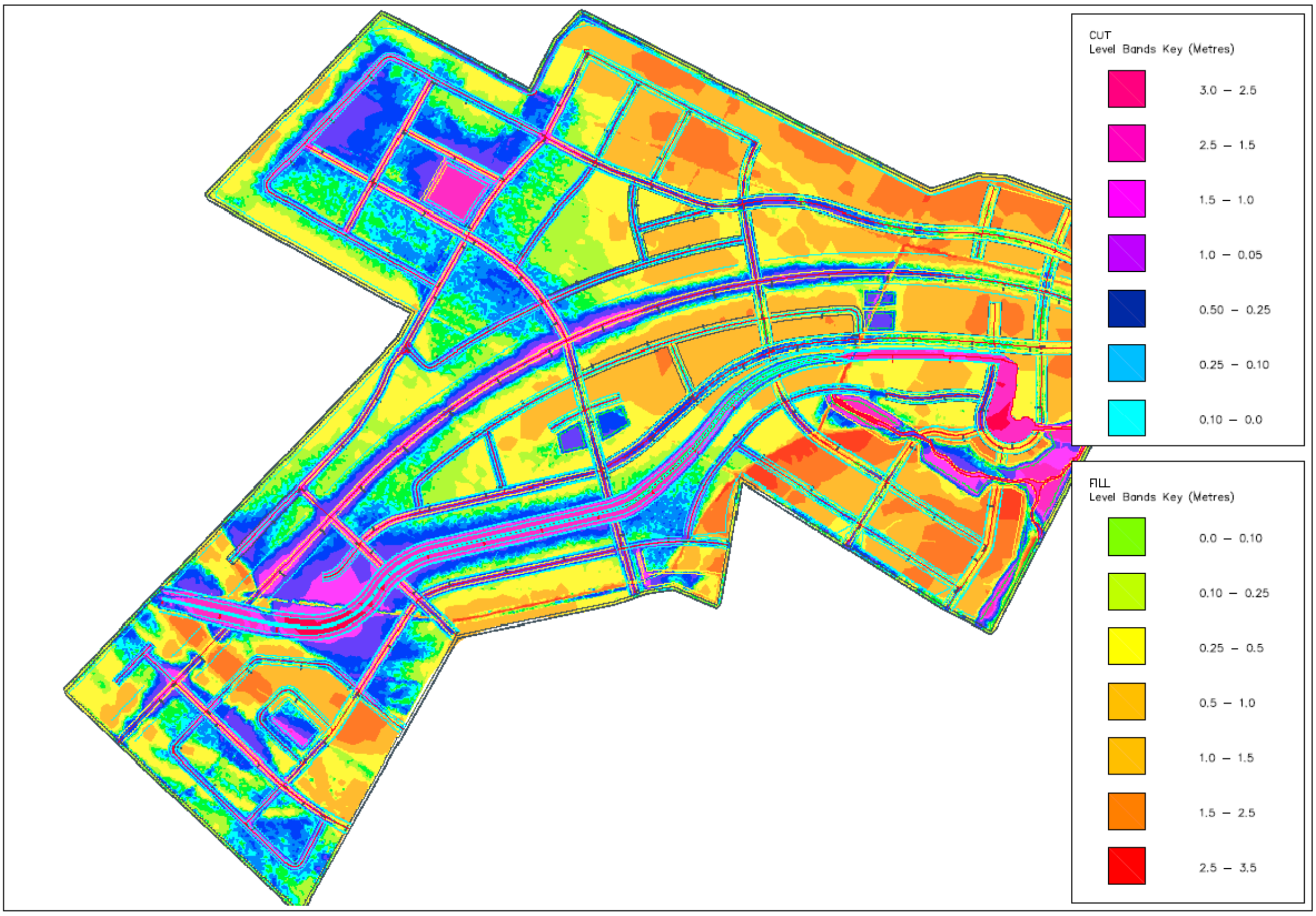

Figure 5: Final Cut-Fill Ground Model.

5.3 ATTENUATION

A major effect of developing land is the increase in hard-standing areas, including roads and roofs,. This has the effect of increasing the peak stormwater flows that are generated by that piece of land. Increases in peak flows can result in downstream flooding if the existing channel capacity cannot cope with the increased flows. Erosion of the stream bed and banks can also occur due to increased flow velocities.

Note that at Ravenswood, ground conditions mean that it is not possible to discharge roofwater to ground to reduce the volume (and peak flow) of stormwater discharged from the site. Consequently, it needed to be combined with other stormwater for treatment and attenuation.

The conceptual design of the proposed peak flow mitigation at Ravenswood needed to take into account the WDC performance requirements, which are for attenuation of peak flow rates in the "100 %" (1 year), 20% and 2% AEP storms to pre-development peak rates for the critical storm durations. It is normal practice for this attenuation to be carried out in conjunction with the stormwater treatment system, whether by way of a single device for the whole development, or at numerous locations around a development, as is proposed for Ravenswood. Under this approach, the WDC performance requirement would normally be met at the point where the drainage system discharged to the receiving environment. Within the proposed development, only mitigation of up to the 20% AEP event could be carried out in this manner. It was therefore not practicable to meet the WDC requirement at each wetland discharge point.

In addition to the attenuation achieved in the wetlands, it was therefore proposed to attenuate larger storms (up to the 2% AEP event) by providing a series of ponding areas within the two stream channels passing through the Town Centre area. To achieve this additional attenuation, it was proposed to install a series of weirs within the southern flow path through the Town Centre, and a single weir within the northern flow path. Additionally, culverts under each weir along the southern flow path maintain fish passage. Providing a single weir in the northern flow path meant that the client's requirement for a permanent larger open water area could also be met.

Figure 6 shows an artists impression of the Town Centre ponding area during normal dry weather flows.

Figure 6: Conceptual view of the Town Centre area (Northern flow path).

Along the southern flow path, culverts located on the stream bed below each weir, would allow fish passage at all times, but in higher flows the culvert capacity is exceeded and water ponds behind the weirs, providing significant additional storage and hence attenuation. The balance of flows between the two flow paths was controlled by the relative width of the upstream weir at the stream bifurcation (Weir 2, Figure 7), to the weir in the northern flow path (Weir 1, Figure 7). These two weirs were set at the same height, facilitating consistent management of the flow split through a range of flows.

By providing attenuation in both the wetlands and stream channel and having several wetland discharge points, attenuation needed to be demonstrated where the stream leaves the development, rather than where stormwater from each of the wetland/attenuation areas enter the stream. InfoWorks provided a simple and robust demonstration that this could be achieved.

Figure 7 indicates the location of each of the weirs along the northern and southern flow paths.

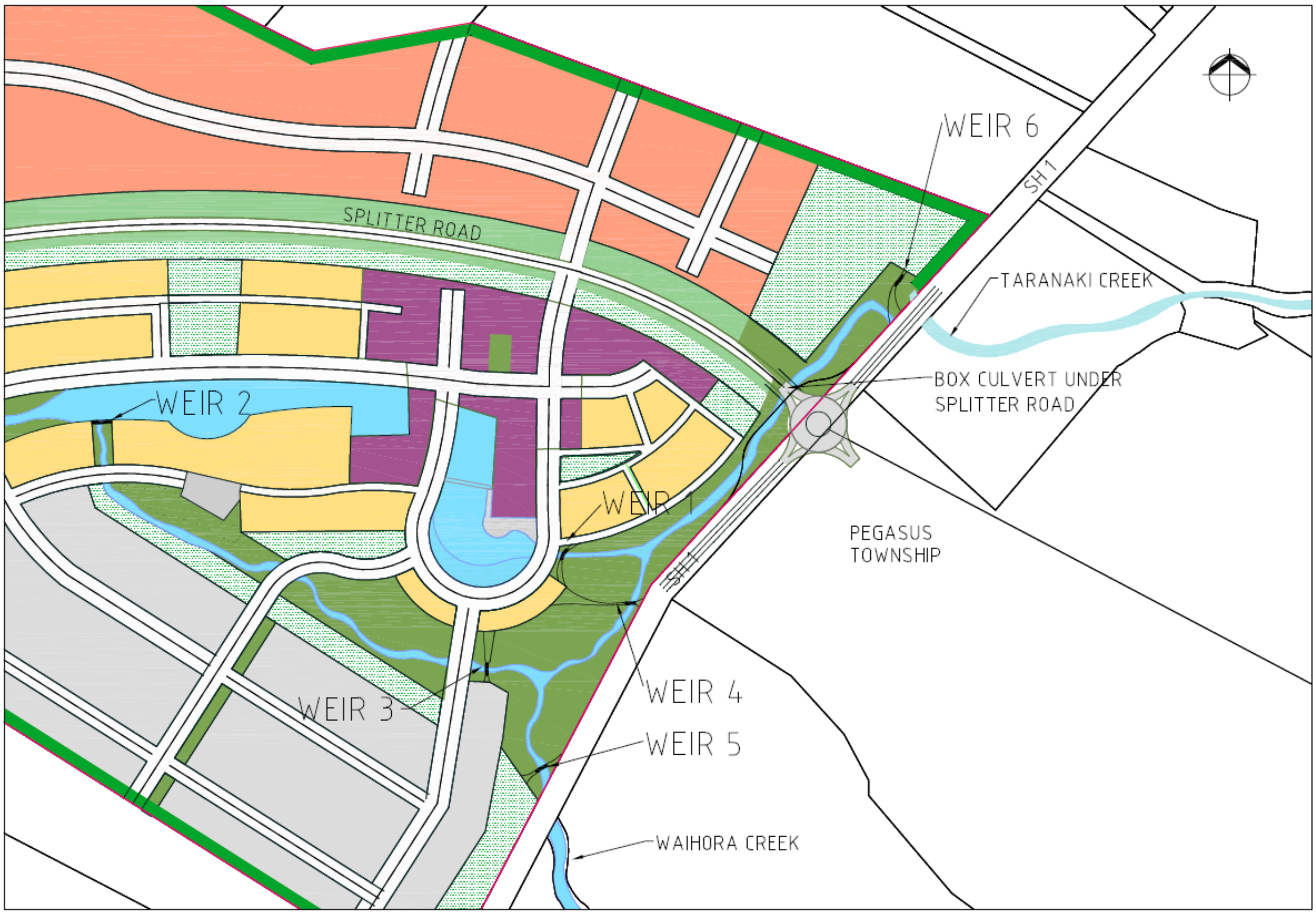

Figure 7: Layout of weirs within the Town Centre Area

In addition to controlling attenuation of larger events, the two flow paths needed to jointly convey flood events resulting from a breach of the Ashley River and to control the split of flows down the main Taranaki Stream and the Waihora Creek overflow path during such an event. To control the flow split, weirs 4 (including underlying culvert) and 5 were used. As overflow down the Waihora only currently occurs during a large event and not in normal flows, no culvert was provided beneath weir 5.

Due to the numerous combinations of weir and culvert levels and dimensions that were possible, combined with the numerous flow scenarios, modelling in InfoWorks enabled each combination to be quickly tested against each of the design requirements.

Figures 8, 9 and 10 show InfoWorks output long-sections through the southern flow path for the dry weather, 20% AEP storm event and Ashley River flood scenarios tested. These show the large variation in water level that the system can effectively manage.

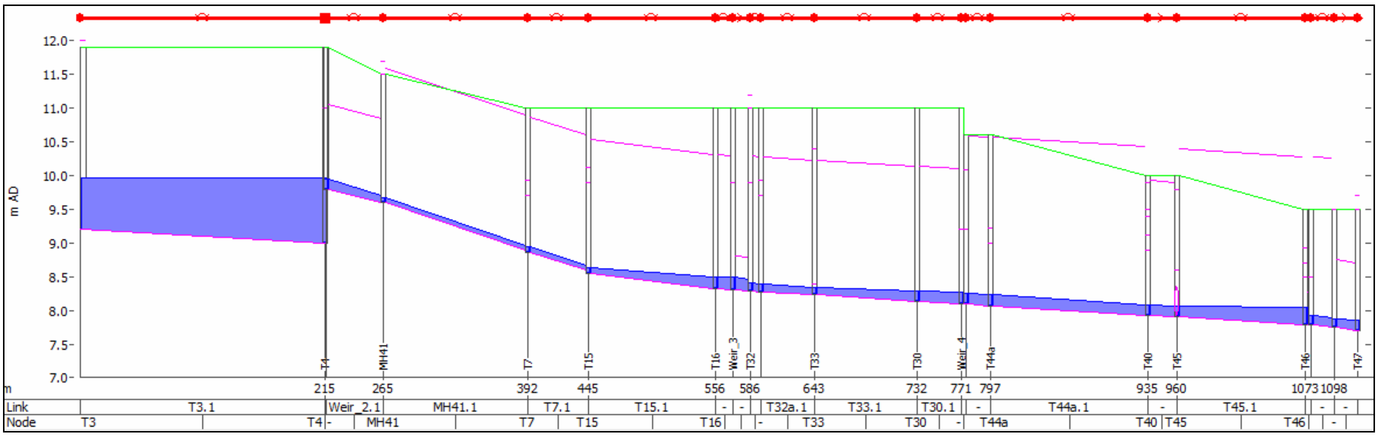

Figure 8: Southern flow path long section during dry weather flows

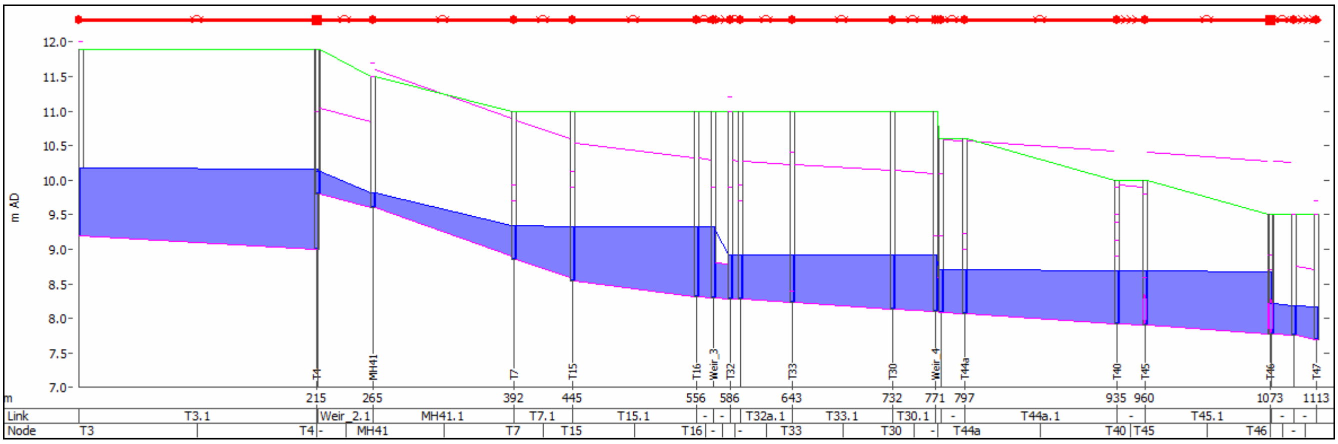

Figure 9: Southern flow path long section during 20% AEP flows

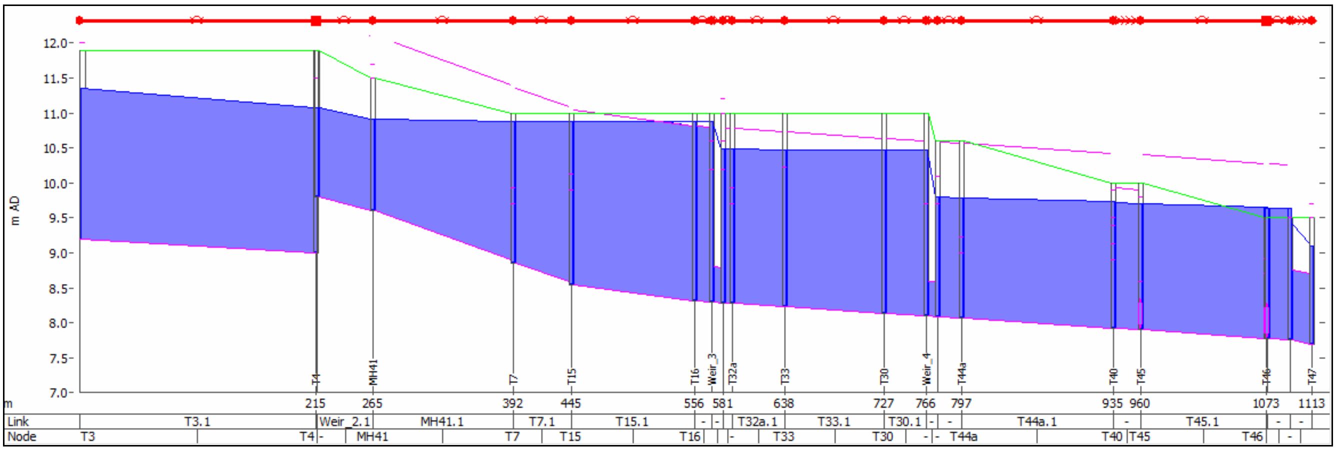

Figure 10: Southern flow path long section during Ashley breakout flows

6 CONCLUSIONS

The concept design of the stormwater system for the Ravenswood development required that a number of client and legislative requirements be met. As a number of the concept design elements, such as the proposed realigned stream channel, needed to achieve multiple purposes, an InfoWorks model allowed each element to be tested and to demonstrate that each objective could be achieved.

A major client requirement was for the site development to achieve a cut-to-fill earthworks balance. This needed to be balanced with the requirements to convey a significant Ashley River breach flow and other local flood events through the site, while mitigating the risk of flooding of developable land. InfoWorks used in conjunction with an MX model of the whole development, effectively and efficiently enabled various combinations of ground levels, flow, stream dimensions and stormwater system components to be tested and changed until the cut-fill balance could be achieved alongside the other design requirements.

Like many development projects, attenuation of stormwater peak flows to pre-development rates, was required at Ravenswood. It is normal practice for this attenuation to be carried out in conjunction with stormwater treatment, prior to discharge to the receiving environment. Space constraints within the development required a slightly modified approach to be taken at Ravenswood. As the attenuation requirements could not be met prior to each wetland/attenuation area being discharged to the realigned Taranaki Stream, the stream itself was utilised to provide the additional attenuation required in-channel, with compliance measured where the stream leaves the site. The InfoWorks model was used to demonstrate that the attenuation should be met at this point.

At the time of writing this paper, the plan change has been granted but resource consents from Environment Canterbury are still being processed.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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