NANAKO STREAM: DEVELOPING A COMPREHENSIVE STORMWATER SOLUTION

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ABSTRACT (500 WORDS MAXIMUM)

Pyes Pa West (commonly referred to as "The Lakes") has been one of the fastest growing and most popular residential subdivisions in the Tauranga area. Its location close to the city centre, Tauriko Business Estate for employment opportunities, Tauranga Crossing shopping precinct, easy access to SH36 (to Rotorua) and SH29 (to Hamilton/Auckland), as well as the diversity of housing choice and affordability has proved to be exceptionally popular and an attractive place to live and work.

The development area is located on the lower Nanako Stream catchment, which feeds into the Kopurererua Stream which then discharges into the Tauranga Harbour near Judea. Managing stormwater and flooding within this catchment has been very complicated due to several factors that have made reaching a suitable and appropriate solution difficult to achieve, these include:

- Several historical inappropriate development areas along and adjacent to the floodplain, including residential developments along Pengary Lane along the Nanako Stream and Judea Industrial area at the confluence of the Kopurererua Stream and Tauranga Harbour estuary;
- Historical and ongoing infilling of floodplain areas, both consented and non-consented, which has reduced the capacity of the floodplain to accept flood events;
- Steep escarpments either side of the stream with roading and residential developments either side subject to geotechnical risk and potential failure during flood events; and
- Several flood management and flow control devices (dams, ponds, culverts, treatment devices, etc) throughout the catchment creating flooding risks (e.g. due to dam break scenarios).

Tauranga City Council (TCC) has been developing a comprehensive stormwater solution, to effectively and sustainably manage stormwater and flooding in the catchment of the Nanako Stream.

In order to understand the flood attenuation and stormwater treatment needs of the catchment, hydraulic modelling has been undertaken to determine the volume of water that needs to be attenuated so as to protect downstream properties from flooding effects, as well as the ecological values of the stream.

Through the evolution of this work, a proposed solution has been developed. With these works in place, there is predicted to be no increase in peak flood levels or an increase in maximum flow rates.

Additionally, the works will improve the stability and resilience of existing embankments, increasing safety for downstream properties and the public. All existing and new dams will be designed and constructed in accordance with the New Zealand Dam Safety Guidelines.

KEYWORDS

Stormwater management, flood management, dams, flood modelling

PRESENTER PROFILE

Robert Kelly – Robert is an Associate and hydraulic modelling lead at Aurecon. He has 20 years' experience and specialises in stormwater management and hydraulic modelling.

Josh Hodson – Josh is a Water Resource Engineer with over 10 years' experience in stormwater management, hydraulic design, water sensitive design and catchment assessments.

1 INTRODUCTION

Tauranga is a rapidly growing city and The Lakes / Pyes Pa West area located to the west of the city centre is a popular and recently developed suburb of Tauranga. The planning rules for the development of this area is detailed as part of Structure Plan 13 (SP13), which includes the need to ensure that there are no adverse downstream stormwater effects from the development(s).

The Kennedy Road area is one of the last greenfield areas to be developed in this growth area and previous (consented and non-consented) developments have seen these requirements getting harder to comply with, especially due to infilling of floodplain areas, reducing the amount of stormwater storage available during major events.

At the time this project started, some development of the Kennedy Rd Area had started (since 2015) and some stormwater management devices had already been constructed however no overarching stormwater/flood management solution had been identified. Furthermore, there was further development planned and started but could not have titles issued until the stormwater/flood management issues were resolved.

The aim of our project was to find an integrated solution for stormwater and flood management that incorporated existing stormwater infrastructure and site constraints and identified what new infrastructure/upgrades were required to meet TCC's stormwater/flood management objectives to allow these development to be completed.

2 SITE DESCRIPTION

The "Kennedy Road Area" within the Pyes Pa West Urban Growth Area is generally bound by Te Ranga Memorial Drive to the west, Pyes Pa Road to the east, Audax Lane to the North and the online detention dam known as Dam 2 to the south (refer *Figure 1*). This area is approximately 70 ha. This area is the subject of this paper and is herein referred to as 'the site'.

Figure 1: Site Layout

2.1 CATCHMENT SETTING

The site is located within the lower third of Kopurererua Stream Catchment in Tauranga on the Nanako Stream Tributary (refer Figure 2). The Kopurererua Stream catchment is a narrow catchment approximately 7,400 ha in area. It flows from the Mamaku Plateau in the south and discharges to the Tauranga Harbour via the Waikareao Estuary to the north.

The Kopurererua Stream (approximate 29 km in length) and the Tautau Stream (approximate 18.5 km in length) are the two major watercourses in the catchment with their confluence located near Gasson Lane in Pyes Pa. The site is located about halfway up the Nanako Stream subcatchment, which is the next largest watercourse in the catchment (7.5 km in length and 450 ha in area). The Nanako stream passes via a 1200 mm culvert under the State highway 29A (SH29A) embankment and soon after joins the main Kopurererua Stream branch.

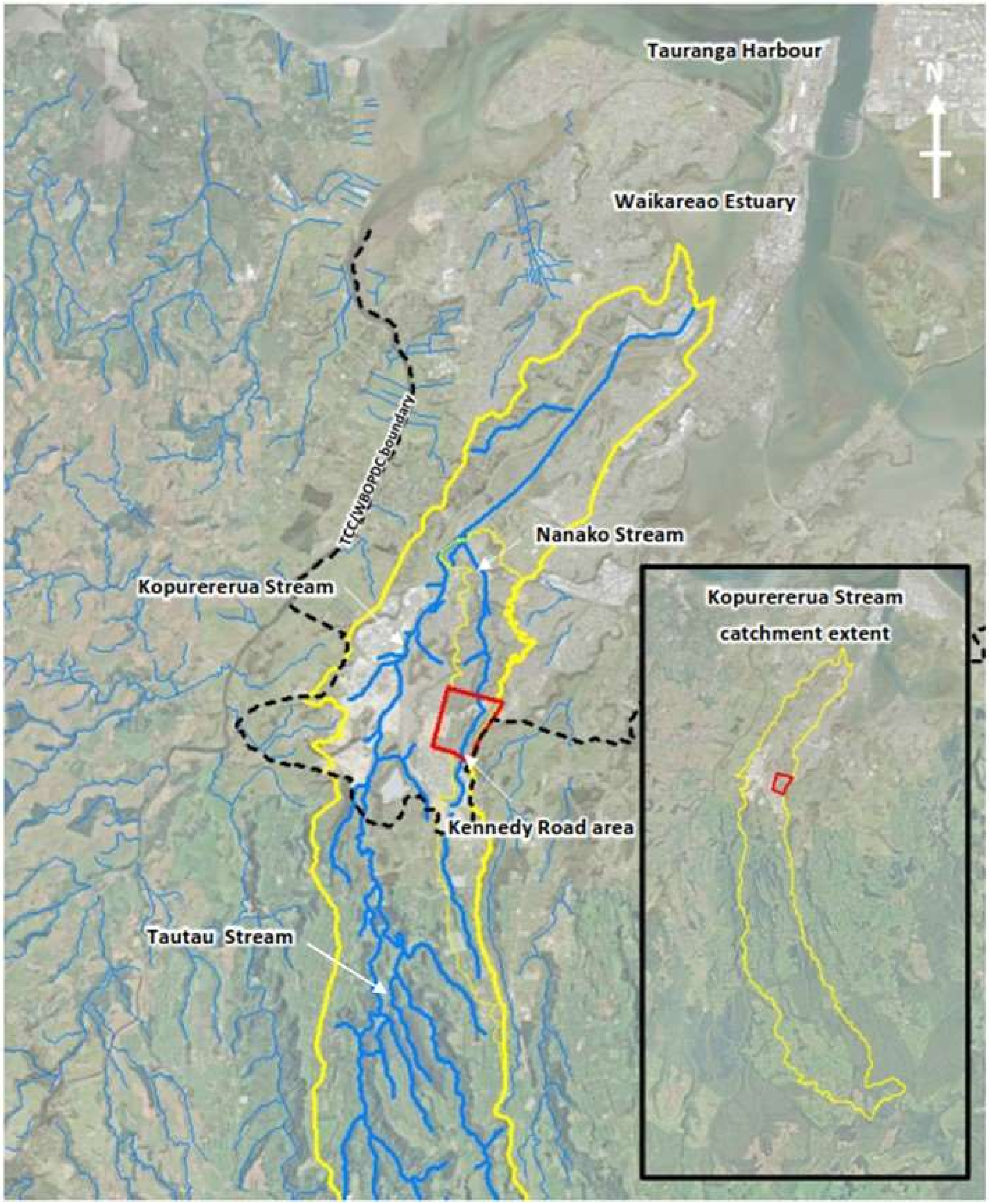

Figure 2: Catchment Setting

The lower urban half of the Nanako catchment is shown in *Figure 3*. There are several large ponding areas in series as a result of new and previously developed city infrastructure, including:

i. Behind the recently constructed Dam 2 developed for stormwater management;
ii. Behind the existing Kennedy Road embankment; and
Behind the State Highway 29A (SH29A) road embankment.

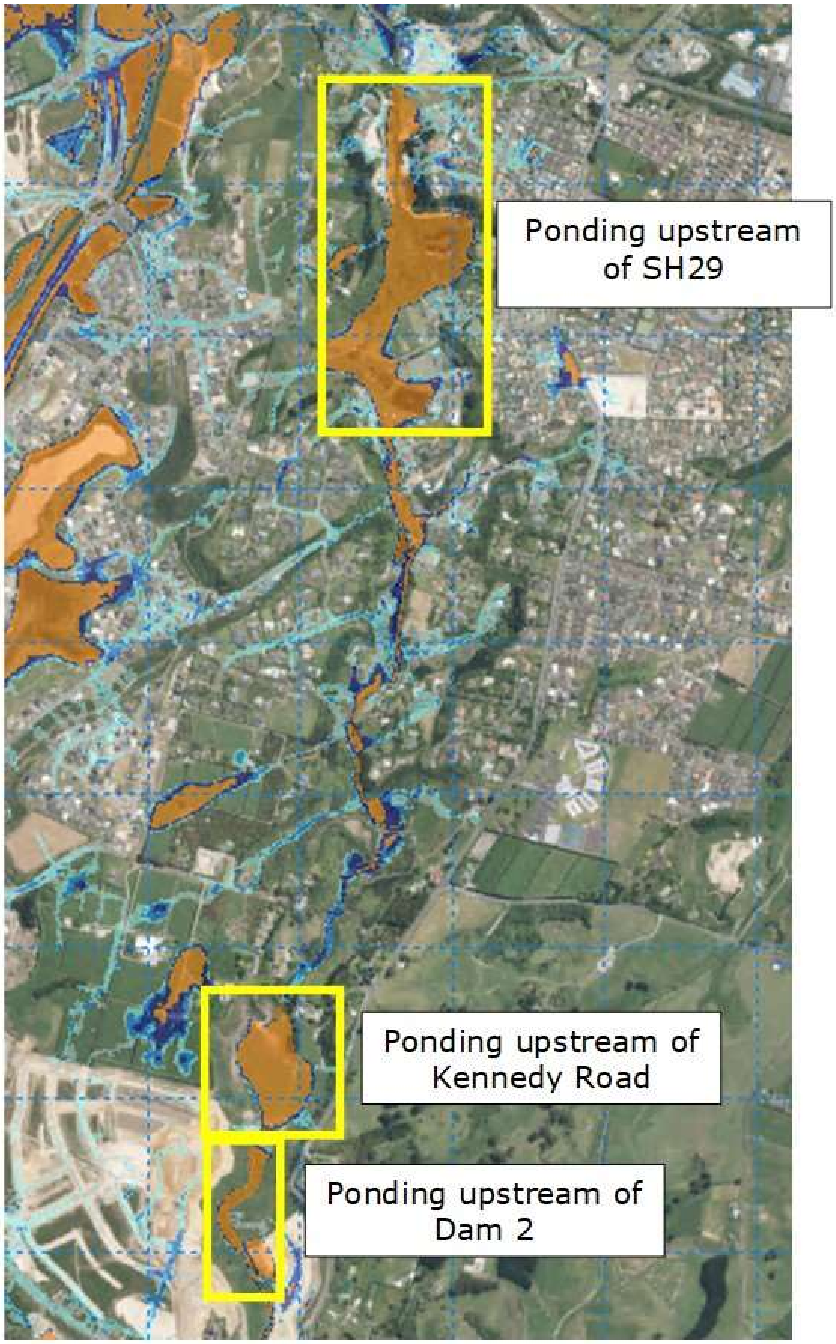

Figure 3: Lower Nanako Stream

2.2 EXISTING FLOODING ISSUES

As with many urban catchments in New Zealand, this catchment has a number of flooding issues. *Figure 4* shows the flood extent for the 1% AEP flood event for the existing climate and catchment development. Two particular areas of concern where several properties are shown as being inundated are noted on *Figure 4*, namely

i. Pengary Lane in the Nanako catchment; and
ii. The Judea industrial estate at the bottom end of the Kopurererua catchment.

These areas of flooding are shown in more detail on *Figure 5* and *Figure 6*, respectively.

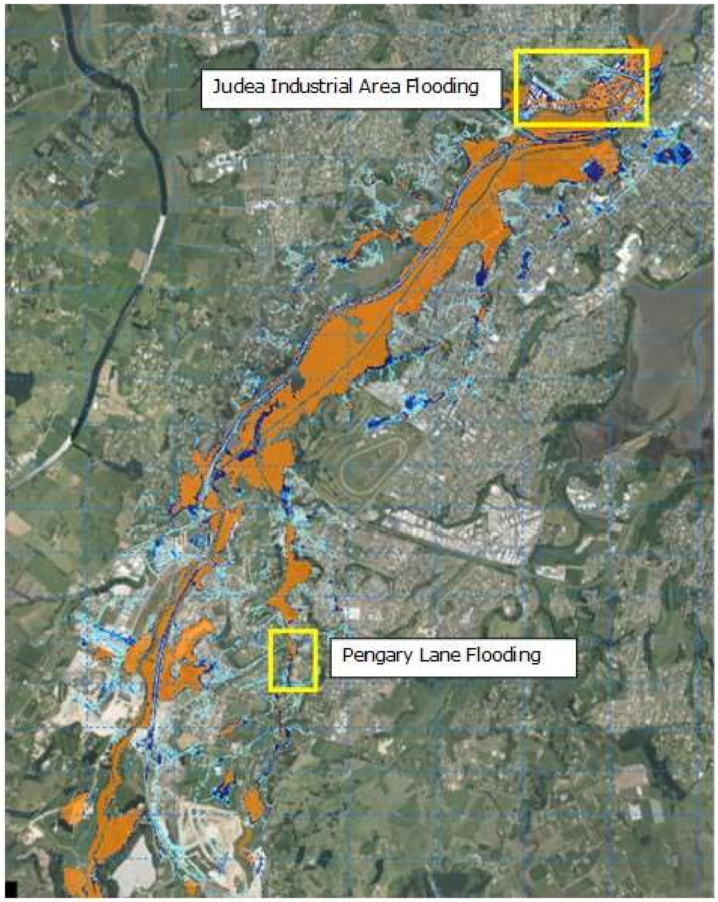

Figure 4: 100y Existing Flood Extents

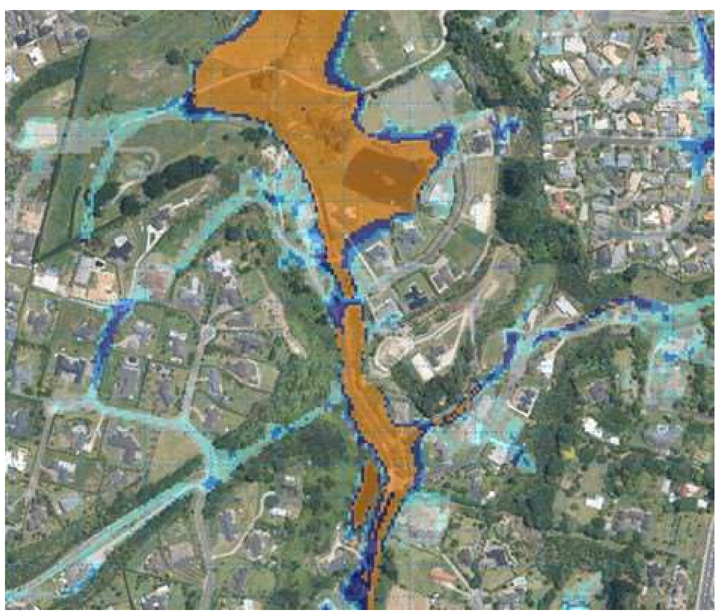

Figure 5: Pengary Lane Flooding

Figure 6: Judea industrial Area Flooding

2.3 EXISTING LANDUSE AND INFRASTRUCTURE

Prior to development of the site (commencing around 2015), the land use was generally horticultural on the flatter areas to the east and west of the site and pasture and scrubland in the stream gully that runs through the middle of the site (refer Figure 7).

Prior to development of the site, the only significant stormwater infrastructure was the existing Kennedy Road embankment and culvert (refer Figure 1 above for location). Upgrade works were undertaken on the Kennedy Road embankment between 2017 – 2018 to facilitate a wider road carriageway and installation of additional underground services. Drainage through the embankment after these upgrade works consisted of a 30 m long section of 1050 mm diameter concrete pipe installed upstream of the main road embankment, followed by a 900 mm diameter concrete culvert under the main road embankment that was existing prior to the upgrade works.

Figure 7 also shows the 1% AEP flood extents prior to any development. The large ponding area in the gully behind Kennedy Road previously mentioned can be seen, but also noticeable are two large ponding areas to the west that existed prior to development of the site. These two areas are unusual in that they are not located in natural gullies but rather in depression areas on the upper plateau. For the 1% AEP flood event the peak storage in these depressions areas is 30,000m^3 for the southern one and 25,000m^3 for the northern one.

Since 2015, and prior to the beginning of this project, development of several parts of the site had commenced. This included the following developments which are shown in *Figure 8*:

- Construction of The Lakes Primary School. This involved filling of part of the large depression to the north;
- Development of the Paradiso Holdings residential subdivision on the eastern side of Te Ranga Memorial Drive, and to the west of the Nanako Stream. This included filling of the large depression to the south; and
- Preliminary earthworks undertaken as part of planned Takhar Trust residential subdivision at 642L Kennedy Road.

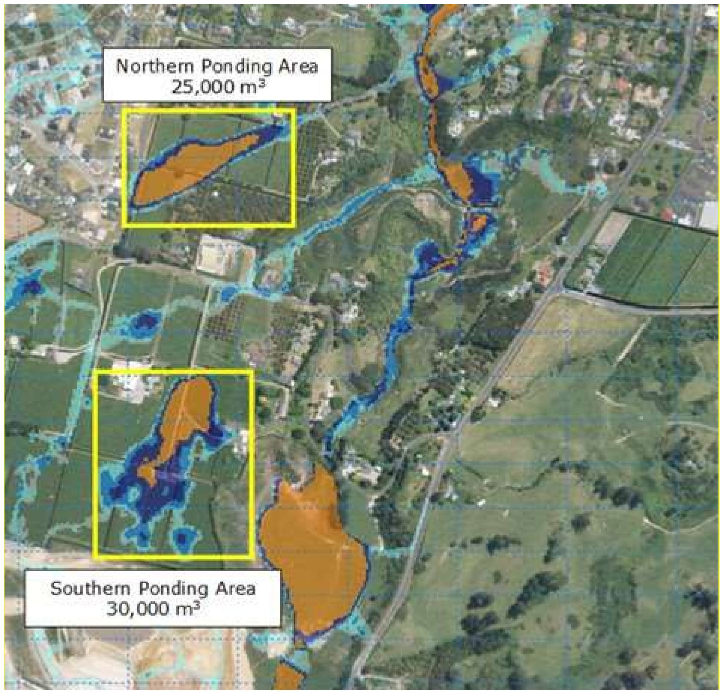

Figure 7: Depression Storage Areas

Figure 8: Landuse as of 2019 (existing land use at project commencement)

Since development of the site has commenced several other pieces of stormwater infrastructure had been consented and constructed to facilitate the ongoing development. These include:

- The 'Pond 7' stormwater treatment pond;
- The 'Wetland 25' stormwater treatment wetland.

- An 8 m high earth embankment to the south of the site (referred to as Dam 2) has been constructed to act as a flood detention dam for Stage 3 of The Lakes subdivision, but does not provide any flood mitigation for the Kennedy Road Area.

The locations of these devices are shown in the previous Figure 8.

3 PROPOSED DEVELOPMENT

Structure Plan 13 for Pyes Pa West (SP13) was updated in 2015 and shows the existing and planned infrastructure for the growth area. This includes the area that is the subject of this paper known as the Kennedy Road area.

For the purposes of stormwater management, the Kennedy Road area is divided into three main areas of development (refer *Figure 9*):

- Zone A – 13.8 ha zoned as suburban residential, including the 4.4 ha Lakes Primary School site.
- Zone B – 20.7 ha zoned large lot residential and 4.5 ha zoned suburban residential, with Takhar Trust being the majority landholder.
- Zone C – 17.7 ha zoned suburban residential, with Paradiso Holdings being the majority landholder.

As noted above, at the time the project began development of a large portion of this area had already commenced and some stormwater infrastructure had been constructed, which had to be included as part of the overall stormwater and flood management solution.

Figure 9: Proposed development zones

4 POTENTIAL STORMWATER AND FLOOD EFFECTS

Creation of impervious surfaces associated with urban development, such as that proposed for the Kennedy Road area, can lead to an increase in contaminants in stormwater runoff and an increase in the rate and volume of runoff. In this particular case the impact of development also includes the removal of significant existing depression storage (refer to previous Figure 7). These changes can pose a number of potential risks to the downstream environment if not properly mitigated, namely:

- A decrease in water quality in receiving environments;
- Stream erosion and scour; and
- An increase in the frequency or severity of flooding in extreme rainfall events.

The proposed approach to mitigate these potential effects for the subject site is summarised in the sections below.

A distinction has been made between 'stormwater management' which is generally focused on the potential effects resulting from smaller, more frequent rainfall events (namely, adverse effects to water quality and stream erosion) and 'flood management' which is focused on the potential for an increase in the frequency or severity of flooding for larger, less frequent rainfall events. This distinction is drawn due to the difference in mitigation approaches. That is, stormwater management can be achieved in relatively local-scale "devices" which, when designed in accordance with consenting authority guidelines, are assumed to achieve the required mitigation objectives (i.e. a best management practice approach). Flood management on the other hand often requires a catchment-scale analysis with sizing of any mitigation being developed through detailed flood modelling to demonstrate flood management objectives are met.

5 STORMWATER AND FLOOD MANAGEMENT REQUIREMENTS

The stormwater and flood management requirements that TCC agreed with the consenting authority (Bay of Plenty Reginal Council, BoPRC), and were the basis of the new consent application for discharges from the site, were as follows:

- Water quality treatment of all impervious surfaces to remove 75% total suspended solids (TSS) on a long-term average basis;
- Extended detention of the 90th percentile storm;
- No increase in predicted peak flowrates at the downstream end of the site for both the 2 year and 10 year ARI events with allowances for climate change; and
- No increase in predicted flood levels on land not owned by TCC for the 2, 10 and 100 year ARI event with allowances for climate change.

Currently, the Tauranga City Plan requires development within this catchment to provide attenuation to 30% of the 2 year ARI event and 50% of the 50 year pre development flows to mitigate potential downstream flood effects (Rule 12B.3.1.8.a). However, because there was a detailed flood model for the catchment, a detailed effects-based assessment was undertaken based on the flood management requirements listed above in lieu of the City Plan rules.

6 STORMWATER MANAGEMENT APPROACH

The proposed approach to mitigate the potential water quality and stream erosion effects for development of the Kennedy Road area was to use stormwater treatment ponds/wetlands that provide both a water quality function as well as extended detention of the 90th percentile storm (to mitigate adverse effects on stream stability).

Based on site topography and development staging it was proposed that a total of three engineered stormwater treatment wetland/ponds were used to meet stormwater management objectives. These are as follows:

- Pond 7 which will manage stormwater from Zone A (previously constructed as part of development since 2015);
- Wetland 5 which will manage stormwater from Zone B (proposed as part of the current project); and
- Wetland 25 which will manage stormwater from Zone C (previously constructed as part of development since 2015).

The location of these wetlands/ponds and respective development zones is shown in *Figure 10*. The proposed flood detention dams are also shown on this figure and discussed in more detailed below.

Figure 10: Location of stormwater management devices

7 FLOOD MITIGATION

7.1 MODELLING APPROACH

TCC has developed nineteen catchment models covering the city using 3-way coupled models using MIKE FLOOD software. The models are highly detailed including the 2d surface in MIKE 21; river channels, culverts and bridges in MIKE 11; and all manholes sumps and pipes in MIKE URBAN. The Kopurererua catchment model was used for this study.

7.2 FLOOD MITIGATION CONSIDERATIONS

7.2.1 PEAK FLOW MITIGATION

Initially mitigation was aimed at maintaining peak flows in the Nanako stream downstream of the development area at or below existing flow rates.

The method utilised for this was to use a new road crossing at the downstream area of the development as a dam to constrict flows.

Another complication however was that due to concerns over the stability of the Kennedy road embankment water levels there needed to be maintained at or below existing levels. This required the culvert size at Kennedy Road to be increased from its existing size of 900mm diameter. This impacted on the flow at downstream new dam.

An iterative process was therefore needed adjusting first the Kennedy road culvert size and then the culvert size at the new downstream road embankment.

The size of the outlets was initially estimated using engineering calculations, but these needed to be checked using the catchment model. Tauranga City Council's catchment model is a complex 3-way coupled MIKE FLOOD model and takes around 3 days to run.

Due to the iterative nature of sizing of the culvert, first at Kennedy Road and then at the new dam structure, a trimmed catchment model was developed. *Figure 11* shows the full model extent and trim model inset. The trim model could run in less than 6 hours and the culverts at Kennedy Road and the new dam structure were sized to mitigate post development flows to at or below pre-development flows for the 2y, 10y and 100y events.

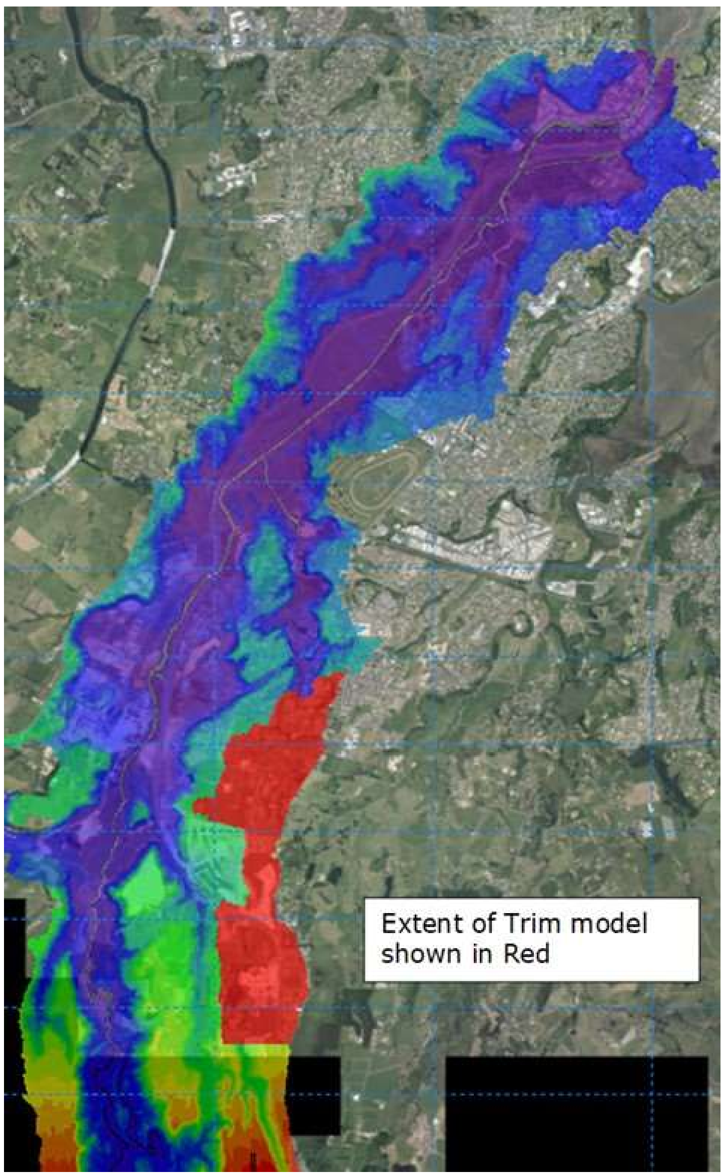

Figure 11: Full and Trim Model Extents

Once this solution was obtained, the full model was run with the enlarged Kennedy Road culvert and new dam structure.

Figure 12 shows the impacts from this with greens showing benefits compared to existing and red showing impacts compared to existing. From this it can be seen that immediately downstream of the development improvements at Pengary Lane occur. This is due to flooding in this area being conveyance dominated and only peak flows dominating.

But further downstream there are significant impacts at the ponding area immediately upstream of SH29A where both flood flows and volume dominate.

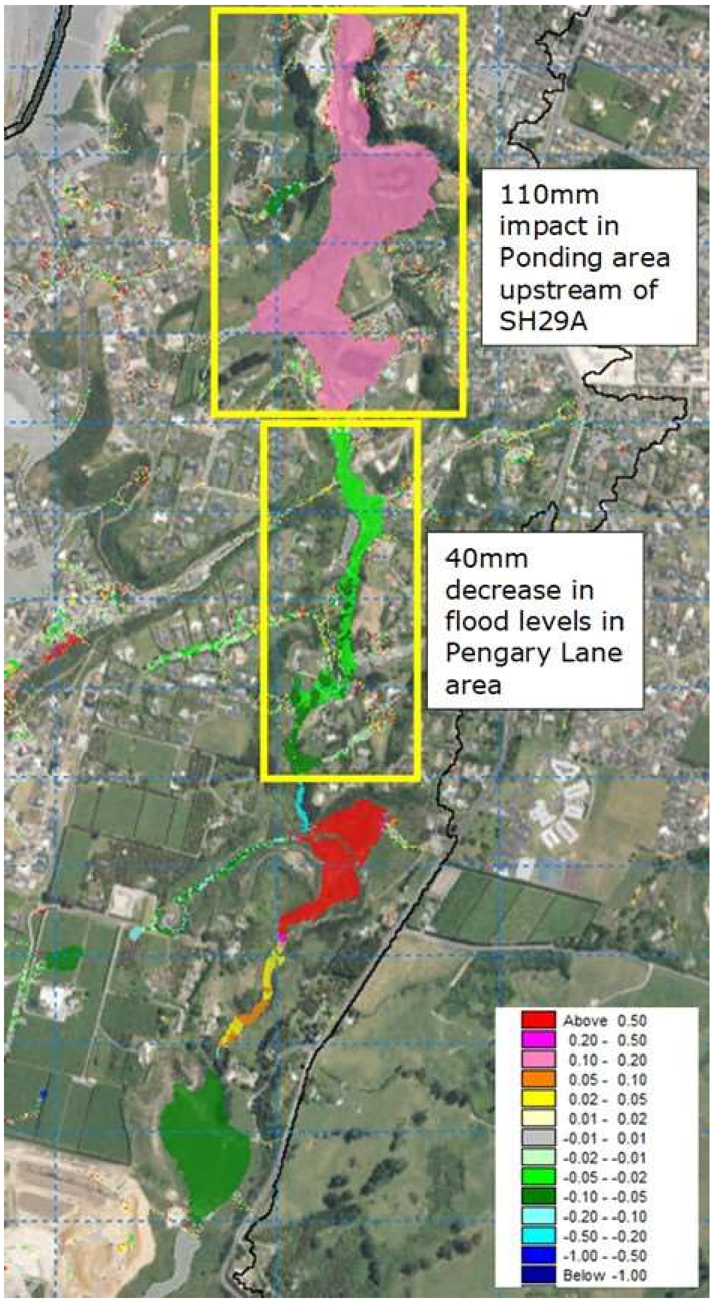

Figure 12: Impacts after attenuating peaks to at or below pre-development

A more detailed analysis of the impact in the ponding area upstream of SH29A can be seen in *Figure 13*, *Figure 14* and *Figure 15*.

Figure 13 shows the water level in ponding area upstream of SH29A for the 100y existing scenario. This shows the peak water level immediately upstream of SH29A occurs at 15:30 hours

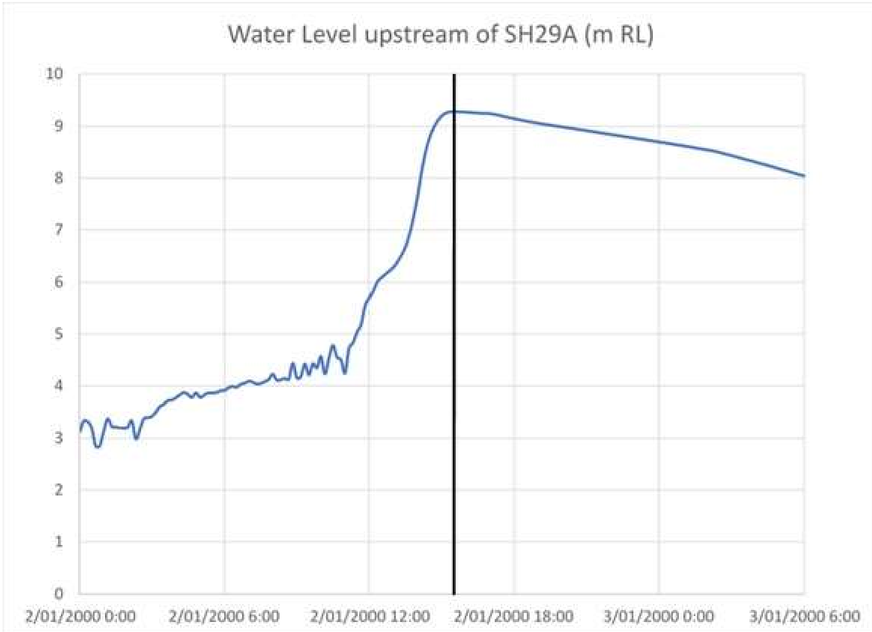

Figure 13: Water Level upstream of SH29A

Figure 14 shows the peak flow immediately downstream of the subject development area for both the pre and post development scenarios.

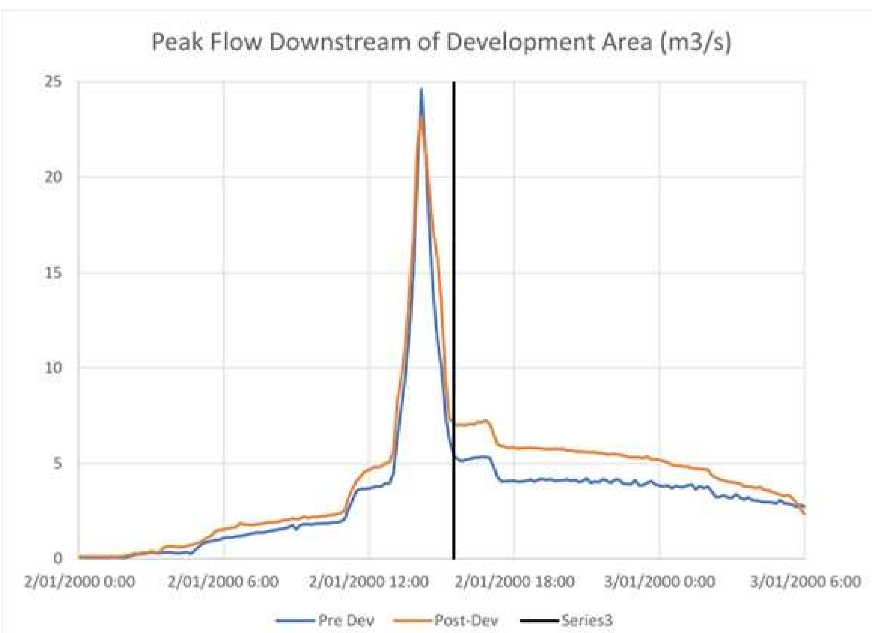

Figure 14: Peak flows immediately downstream of development areas

Figure 15 shows the cumulative volume of flow. This shows that while peak flows are reduced, the cumulative volume is increased (this is unsurprising given the increased imperviousness and decreased depression storage.)

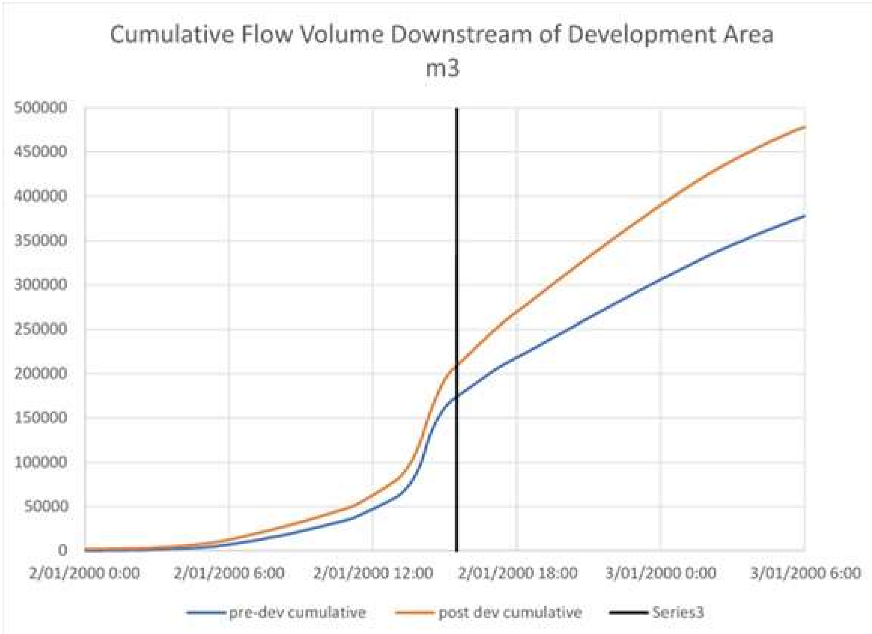

Figure 15: Cumulative Flow Volumes Immediately downstream of development area

7.2.2 POTENTIAL TO INCREASE CULVERT AT SH29A

One option considered to reduce the impacts upstream of SH29A was to increase the culvert size at SH29A. However, this has the potential to increase the flooding at Judea industrial estate at the bottom end of the catchment.

Figure 16 shows the flows at the confluence of the Nanako and Kopurererua Streams for the 100y existing scenario. (It is noted this is based on an idealised spatially uniform storm with the peak rainfall intensity based in the middle of the storm throughout the catchment.) From *Figure 16* it can be seen that the peak from the Nanako Stream is much smaller and earlier than the peak of the Kopurererua stream. This would indicate that increasing the culvert size at SH29A would not impact on the peak flood at the Judea industrial area downstream.

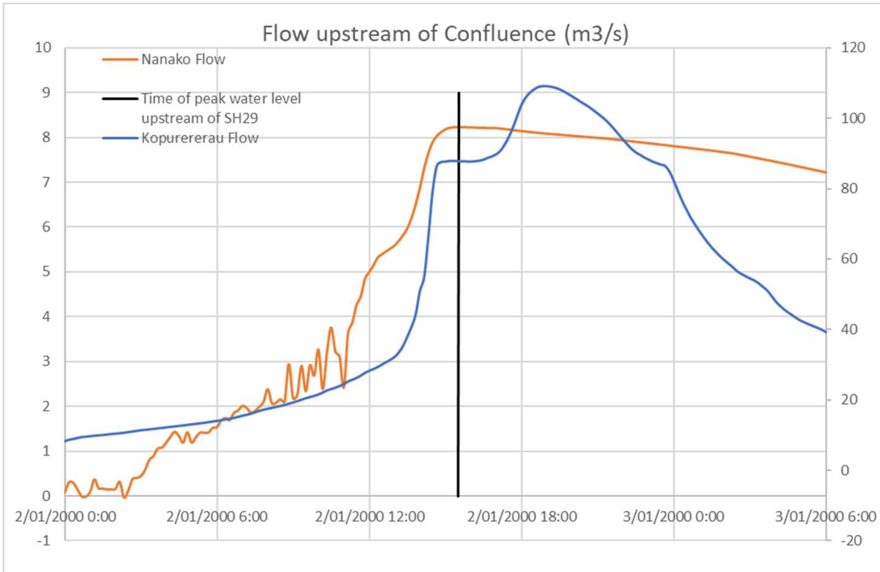

Figure 16: Flows at Nanako and Kopurererua Stream confluence

7.2.3 COINCIDENCE OF PEAKS

Enlargement of SH29A culvert could not proceed however due to BOPRC's requirement to consider coincidence of peaks as set out in BOPRC's "Hydrologic and Hydraulic Guidelines" (BOPRC 2012)

This required consideration of the 100 year flow in the Nanako stream coinciding in timing with the 10 year storm in the Kopurererua for both pre- and post-development. With the 10-year peak in the Kopurererua being the same for both pre-and post-development, coinciding it with the 100 year peak from the Nanako meant that any increase in culvert size under SH29A would lead to an increased total flow and hence impacts downstream.

For this reason, this option was not considered further.

7.3 MITIGATION SOLUTION

The only means to achieve mitigation, therefore, was to delay the increased volume from the development for long enough that the peak ponding at SH29A had passed.

The selected approach to mitigating the potential flood effects for development of the Kennedy Road area was to provide online flood storage within the Nanako Stream gully using flood detention dams. The locations of the final proposed detention dams are shown on Figure 10.

It was proposed to utilise the existing Kennedy Road earth embankment to continue to throttle flows up to a 100-year ARI event. Given that catchment flows would increase because of development, some modifications to the culvert and storage area were required to mitigate the flow increases while maintaining pre-development peak water levels behind Kennedy Road. In order to provide the required flood mitigation, the following modifications were required:

- Increasing the diameter of the culvert that passes low flows from a 900 mm diameter pipe to a 1000 mm diameter pipe. Fish passage was also considered for the new culvert.
- Excavating an additional 23,000 m^3 (approximately) behind the embankment to increase the available flood storage.

In addition to the Kennedy Road embankment, a second flood detention dam was proposed to be constructed within the Takhar Trust development (referred to as "Dam 5") to throttle flows up to a 100 year ARI event (refer to previous *Figure 10* for location). In order to provide the required flood mitigation an earth embankment dam with the following was proposed:

- A 12 m wide embankment crest set at 20.6 m RL. The embankment was proposed to have a road on top of it to service the Takhar Trust Subdivision and enable access to the eastern side of the Nanako Stream; and
- A low-level pipe with a diameter of 1400 mm to pass stream baseflows and to attenuate flows up to the 100 year ARI flood.

Both embankments operating together were demonstrated to provide sufficient throttling and flood storage such that the proposed land use changes could occur while meeting the flood management objectives outlined above (i.e. no increase in predicted peak flowrates at the downstream end of the site for both the 2 year and 10 year ARI events and no increase in predicted flood levels on land not owned by TCC for the 2, 10 and 100 year ARI events).

While this approach met the flood mitigation requirements of the development there were still numerous challenges from a dam safety perspective. These are discussed further in the sections below.

8 FLOOD DETENTION DAM DESIGN

8.1 DAM BREAK ASSESSMENT

Both the Kennedy Road embankment and the proposed Dam 5 were proposed to be flood detention dams. That is, the dams would only begin to impound water during rainfall events and would be dry or empty in between events, other than conveying stream base flows through the dam.

Under the Building Act (2004), a Large Dam is a dam has a height of 4 or more metres and holds 20,000 or more cubic metres volume of water. Both embankment dams were classified as Large Dams in accordance with Kennedy Road storing approximately 134,000 m^3 in the 100-year ARI event and Dam 5 storing approximately 31,000 m^3. The upgrade works to the Kennedy Road embankment and the proposed Dam 5 were designed in accordance with the New Zealand Society of Large Dams (NZSOLD) Dam Safety Guidelines (2015).

A dam break assessment was undertaken for a range of rainy-day cascade dam break scenarios. The dam break assessment was used to inform the Potential Impact Category (PIC) of each embankment. The conclusions of the dam break assessment identified that both the Kennedy Road embankment and the proposed Dam 5 had a Low PIC. The recommended Inflow Design Flood (IDF) for a Low PIC dam in the NZSOLD Guidelines is between a 100-year ARI to 1,000-year ARI flood event.

One key consideration for assigning the PIC was the potential for the PIC of the dams to increase because of future downstream development. Currently there are several lifestyle/rural properties downstream of the dams that have potential to be further subdivided into urban densities. Generally, there are no planning rules that enable councils to prevent buildings to be constructed in a dam break hazard zone and doing so may increase the population at risk or potential loss of life, thereby changing the PIC of a dam. Therefore, for this project an assessment was undertaken to determine whether the dam break flood extent where flood depth is greater than 500 mm (the threshold for population at risk in the NZSOLD guidelines) was larger than the TCC 100-year ARI floodplain that has planning controls associated with it. It was found that the 100-year ARI floodplain was completely contained within this dam break flood extent on properties that had the potential to subdivide so TCC would have the ability to control development in this area.

8.2 DAM SPILLWAY DESIGN

Both embankment dams were designed to impound the 100-year ARI event before the spillways operate, and are designed to convey 1,000-year ARI flood event without overtopping of the embankment (based on the required IDF for Low PIC dams). For Kennedy Road the 1,000-year ARI flood event was approximately 19 m^3/s after accounting for attenuation in the reservoir.

An optioneering process was undertaken to determine the proposed spillway arrangement for Kennedy Road as it is an existing embankment with several constraints. Given the steeply incised gully did not allow for a spillway to be located in natural ground on either side of the embankment, the three main spillway options considered were:

- Utilise the top of the embankment and downstream face as the spillway;
- Construct a large box culvert spillway under the road with an energy dissipation structure such as a stepped spillway on the downstream face of the embankment; and
- Create a large drop manhole in the reservoir upstream of the dam and have a large culvert under the dam act as the spillway.

Given the existing embankment was not originally engineered as a dam, the risk of an overtopping failure was considered too large to utilise the top of the embankment as the spillway. Site investigations show liquefiable materials up to 8 m deep underneath the embankment so installation of rigid structures at height within/on the embankment was also deemed too risky. Therefore, the option of a large drop manhole and culvert was selected for the spillway for both Kennedy Road and Dam 5. Both dams had 3.2 m dia. manhole risers on the upstream side of the embankment connected to 2.5 m dia. culverts that passed through the bottom of the embankment. The culvert was sized such that the culvert did not pressurise and aeration was able to occur. Buttresses and ground improvement were also proposed on both the upstream and downstream side of the dams to improve geotechnical stability.

8.3 KENNEDY ROAD CULVERT INSTALLATION

A key objective for TCC was to be able to undertake the dam upgrade works for Kennedy Road without requiring closure of the road. Kennedy Road is a key link across the Nanako Stream valley between the Lakes subdivision and Pyes Pa Road and the recent upgrade works had required a long closure of the road for local residents. Therefore, being able to install the culvert using trenchless technology was a key part of the brief for the culvert design.

The proposed installation methodology for the Kennedy Road culvert was to install the 2.5 m dia. culvert by thrusting a steel pipe through the embankment. The steel pipe was to be installed in 6 m long sections with each subsequent section of pipe being welded in the drilling pit before being thrust into the embankment. At the time of writing this paper installation of the pipe is still ongoing.

9 CONCLUSIONS

The proposed approach to mitigating the potential water quality and stream erosion effects for development of the Kennedy Road area was to construct stormwater treatment ponds/wetlands that provide both a water quality function as well as extended detention of the 90th percentile storm.

The proposed approach to mitigating the potential flood effects for development of the Kennedy Road area was to provide online flood storage within the Nanako Stream gully using flood detention dams. Two flood detention dams are proposed which will throttle flows and provide flood storage in events up to the 100-year ARI event:

- Kennedy Road – existing road embankment earth dam which will be upgraded to provide more flood storage and to meet dam safety guidelines; and
- Dam 5 – proposed earth dam within the Takhar Trust development which will also act as the road crossing to service the proposed residential lots on the eastern side of the Nanako Stream.

The detailed flood modelling was used to test various mitigation options and ultimately demonstrate no material increase in predicted peak water level for a 2, year, 10 year or 100 year ARI event on any parcels of land that are not currently owned by TCC or which TCC have, or are in the process of establishing, stormwater designations over (post-mitigation). Therefore, the flood modelling demonstrated that the land use and terrain changes associated with the proposed development of the Kennedy Road area can be sufficiently mitigated with the proposed flood detention dams.

9.1 LESSONS LEARNT AND KEY TAKEWAYS

Some of the lessons learnt and key takeaways from this project include:

- Removal of significant natural ponding areas in the topography as a result of development can have a large effect of flood response in a catchment and need to be including in flood assessments in addition to landuse (i.e. surface cover) changes;
- Similarly, the removal of natural flood storage in the floodplain (through infilling for development) results in need to create altenative (and often very costly and complex) flood attenuation structures. Avoiding and prohibiting any floodplain infill in advance of development will help preserve these natural buffer areas for urban developments;
- Peak flow management cannot always be used as a proxy for no increase in downstream flood levels where there are downstream hydraulic controls. In this case the detention area behind SH29A culvert was sensitive to changes in total runoff volume and downstream flood level increases were observed even when the peak of the mitigated hydrograph was no higher than the unmitigated case;
- Possibility to use Monte Carlo analysis rather than the "coincidence of peak" approach. This may give a better representation of the joint probability of peaks in the two sytems occuring together;
- Prior development can "paint us into a corner" with regards to flood management solutions - e.g. if there wasn't development in Pengary Lane or at Judea than attenuation of large storm events may have been able to be avoided entirely given that TCC own the majority of the Nanako Stream floodplain. This should be considered for relatively undeveloped catchment where there is opportunity to reserve stream floodplains as "green corridors";
- "Non-structural" flood management approaches (e.g. enlarging the SH29A culvert) should be considered as part of optioneering as often they can be much less costly than "structural" solutions such as dams and stopbanks. When considering flood management solutions the entire catchment needs to be assessed as the solution is not always within the development site for which mitigation needs to be provided; and

- City councils have limited ability to prohibit downstream development to prevent worsening of dam break consequences. The potential for downstream development worsening the PIC of a dam needs to be considered in any dam break assessment.

ACKNOWLEDGEMENTS

We acknowledge TCC for funding of the project and permitting the material to be presented in this paper.

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