USING A DYNAMICALLY COUPLED MODEL FOR HAZARD MAPPING AND OPTION ASSESSMENT

Shaun Jones, Mike Summerhays, Nadia Nitsche–AECOM, Auckland

Richard Smedley, Xeno Captain, Grant Ockleston – Auckland Council, Auckland

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ABSTRACT

The Oakley Catchment is a long narrow stormwater catchment on the Auckland Isthmus, which experiences significant stormwater flooding issues. The stormwater response to extreme events creates flooding across a broad floodplain adjacent to the creek. State Highway 20, Stage 1 was completed in 2007/08 and is now programmed for extension to Waterview starting in 2011. NZTA engaged AECOM to undertake modelling of the proposed extension, the results of which were used in their assessment of effects report to the Environmental Protection Agency (EPA). Concurrently, Auckland Council commissioned AECOM to undertake Flood Hazard Mapping and Options assessment to mitigate catchment flooding in the Oakley catchment. The programming of these complex (and interdependent) projects was time constrained and thoughtful sequencing was required to ensure timely delivery.

Flooding in Oakley results in complex flow regimes including a wide range of velocity profiles and flow directions in the creek. Recent advancements in modelling software allowed for complete dynamic modelling of flows by coupling the creek, pipe network (1D model) and floodplains (2D model) into one complete, higher confidence, dynamic model. This model has been used to determine flooding and subsequently options for the catchment. Options investigated included beheading the upper catchment, releasing water forward or by attenuating the water.

This paper outlines the initial options investigated and the model runs completed. It discusses the different applications the model was used for during the last 12 to 18 months. The paper also discusses the advantages and disadvantages of using a coupled 1D/2D model for option assessment and discusses the lessons learned.

KEYWORDS

Option Assessment, Hydraulic Modelling, Two Dimensional Model, One Dimensional Model, Flood Hazard Mapping

PRESENTER PROFILE

Shaun Jones – Shaun has 10 years diverse engineering experience in the Auckland region including environmental, geotechnical and civil engineering. His career to date has involved design and construction management of Stormwater management systems, hydrological assessments and stormwater modelling.

1 INTRODUCTION AND BACKGROUND

The Oakley catchment in the heart of Auckland City has historically experienced significant flooding in and around residential areas. The catchment is generally aligned along Oakley Creek with large flood plains that have been developed into residential land use. A number of roads have been constructed that traverse the creek with under capacity culverts causing back water and flooding. Catchment-wide urbanisation has also contributed to flooding with larger impervious areas draining directly to the Creek.

In order to assess the effects of flooding within the catchment and to provide a tool for flood mitigation optioneering, the Oakley Flood Hazard model was developed by AECOM for Auckland Council.

To achieve the best solution and to make the best use of the modelling software available, a hydrodynamically coupled 1D/2D model was developed using the DHI suite of software. This included the pipe infrastructure in Mike Urban, the open channel and culverts in Mike 11 and the 3D terrain in Mike 21 to simulate 2D overland flow. These independent models were coupled in Mike Flood. Hydrology was represented in a combination of Mike 11 for the catchments in the direct vicinity of Oakley Creek and Mike Urban for the remaining catchments where Rainfall Dependant Infiltration (RDI) losses are more significant.

Concurrently, the Waterview Connection, the last link in Auckland's Wing Route and termed a Road of National Significance by the New Zealand Transport Agency (NZTA), has been progressing through the Environmental Protection Agency (EPA) for resource consent. As part of the SH20 Assessment for Environmental Effects for stormwater and stream works, NZTA engaged AECOM to undertake flood modelling of the concept design to provide evidence of the effects of the proposed development. During this modelling program the proposed stream realignment was optimised to ensure the effects of the development were no more than minor.

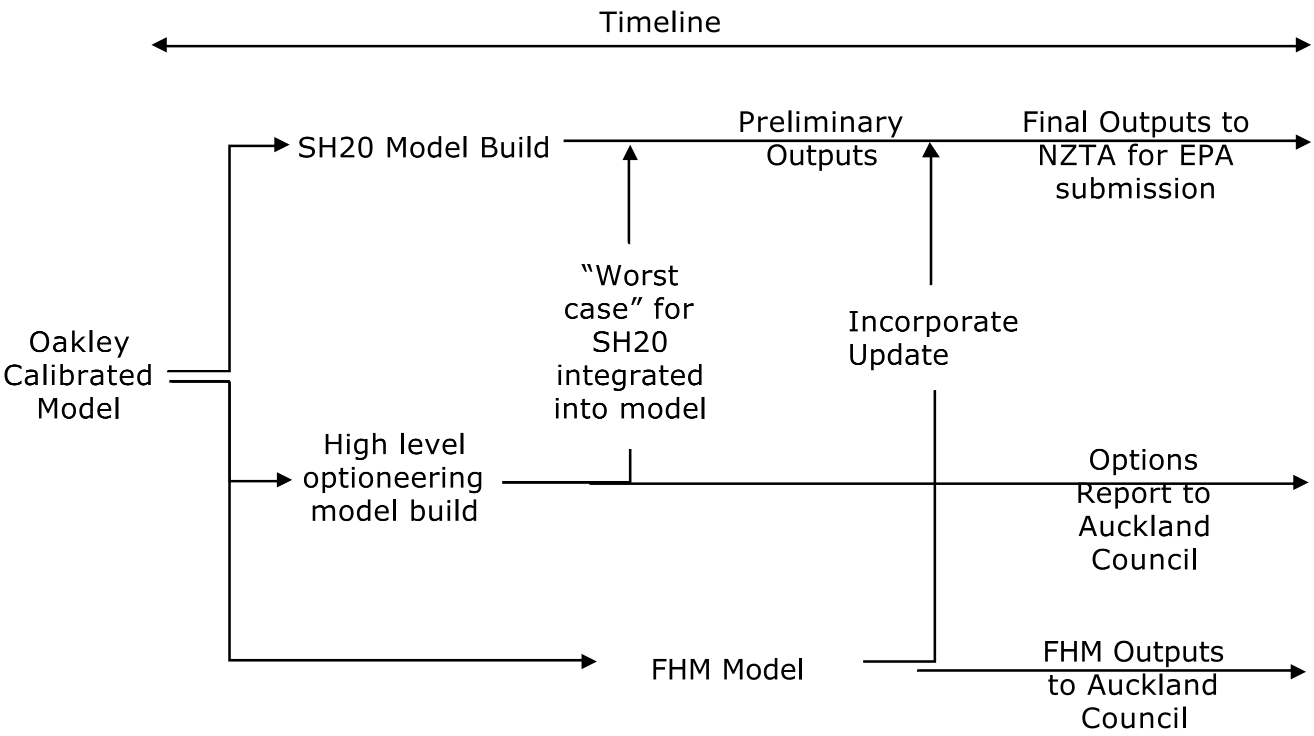
The majority of this work was undertaken during 2010 within a restricted timeframe. The work completed by AECOM for the Oakley catchment included:

- Model Build and Calibration
- SH20 Extension Modelling for NZTA
- Flood Hazard Mapping and Reporting
- Options Analysis

Figure 1 below shows the interdependence between these projects. With numerous deliverables required in a restricted timeframe, project planning was critical.

Throughout the project there have been significant issues with programming and managing numerous interdependent project parts while maintaining a critical work flow and timely delivery of outputs.

Figure 1: Schematic Showing Connectivity



2 SH20 MODELLING FOR NZTA

The proposed SH20 Waterview extension is currently before the EPA for consent to construct a motorway and tunnel connecting SH20 to SH16. The proposed motorway extension crosses Oakley Creek in Alan Wood Reserve and encroaches on the flood plain in that area. Consequently, NZTA were required to assess the effects of this proposed development on the flood plain and Creek. AECOM was engaged by NZTA to undertake modelling of the proposed motorway alignment and Oakley Creek realignment.

The calibrated Oakley model was updated to include the proposed development while ensuring the rest of the catchment was unchanged. Updates included:

- Incorporating the Waterview concept design into the 2D Bathymetry
- Incorporating the Mike 11 stream diversions through Alan Wood Reserve
- Update the Mike Urban pipe model to include the as-built SH20 drainage and the proposed drainage to be included in the Waterview connection. This included attenuation ponds and a tunnel portal sump and pump system
- Updating the hydrology to include the effects of climate change to year 2090
- Updating the hydrology to simulate a 1-in-a-2,500 year event

2.1 INTEGRATION OF SH20 INTO THE OAKLEY MODEL

The methodology for incorporating the SH20 design into the Oakley model was a complicated process. When the model was first developed the 'best practice' at the time was to rotate the 2D grid so the upstream and downstream ends of the catchment aligned with the top and bottom of the Mike 21 grid. This effectively rotated the grid by approximately 315°. As a result of this rotation, every conversion between ARCGIS and

Mike 21 was complicated. The rotation did not appear to be an issue until we began incorporating the SH20 design into the model with the intention of replicating exactly the same results outside of the area of consideration to allow for a precise comparison between scenarios.

In the end, a methodology was developed where the grid could be imported and rotated in ARCGIS without losing any of the accuracy in the bathymetry. This was essential to ensure the results were comparable.

The future bathymetry was created using a number of tools and processes in ARCGIS. This was an excellent environment for manipulating the various sources of terrain data including LiDAR, 3D design strings and topographical survey data.

2.2 PROGRAM INTERDEPENDENCIES

The SH20 modelling project commenced initially during the calibration phase of the Oakley model. This required the model to be subsequently updated with the final calibration results. This was accomplished by using a time stamped model. The updates to the calibration after that date were incorporated at a later date.

Once the calibration was complete, the flood mitigation optioneering commenced. This was critical as the worst case from the optioneering needed to be incorporated into the SH20 model once a working SH20 model had been developed. This phase proved to be difficult as the optioneering was an iterative process. Once a flood mitigation option was included in the model, the simulation needed to be run and the results interrogated before the next option could be incorporated. This process needed to be undertaken for all five of the hybrid options.

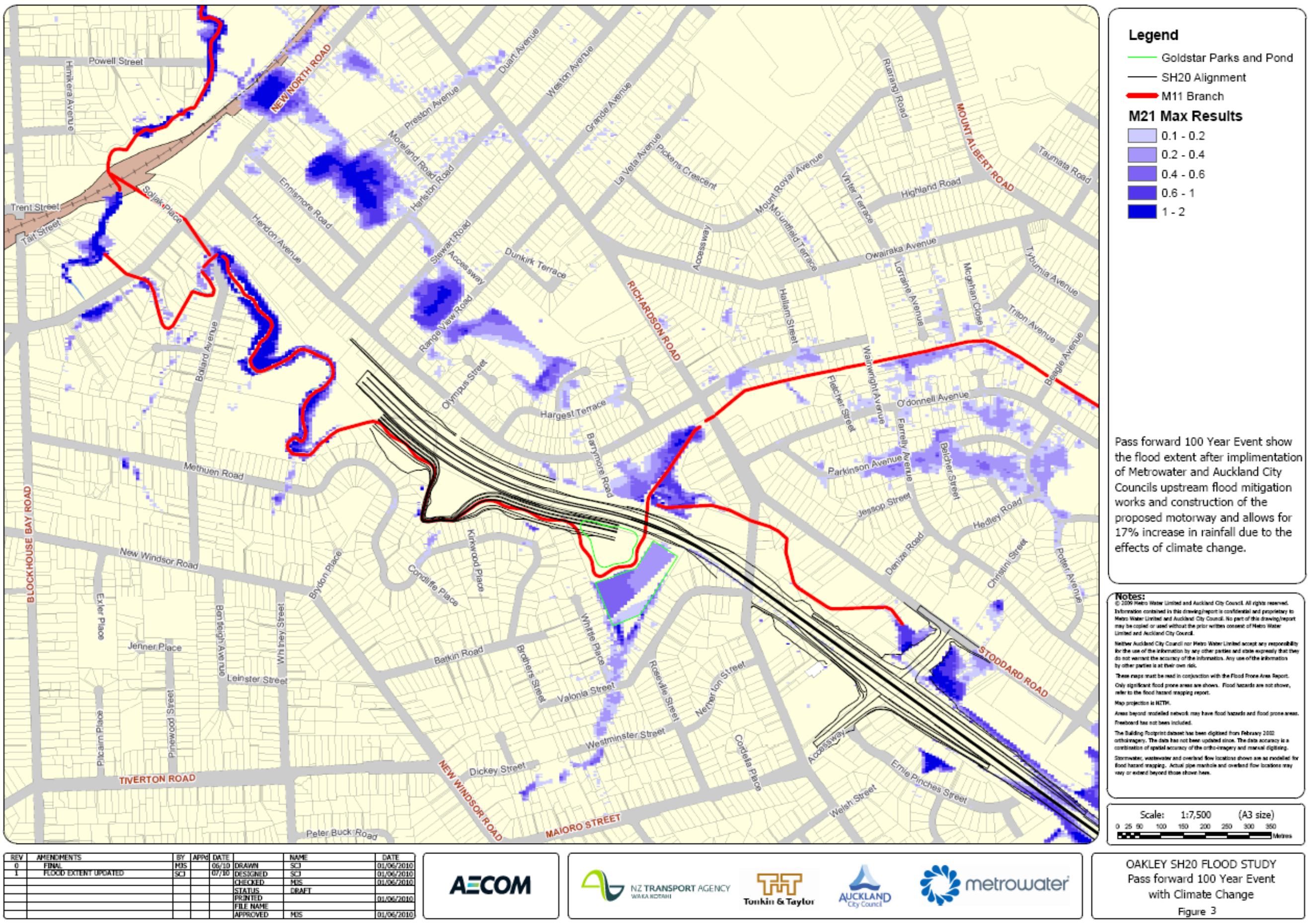
This was successfully overcome by focusing the modelling efforts on the option that would be the worst case for the SH20 model. The option that was used as the worst case was termed "pass forward" and included, amongst other things, the opening of Oakley Creek to provide extra conveyance and provide flood protection for habitable floors to the 1-in-a-50 year Annual Recurance Interval (ARI) event.

Once the optioneering had been completed the Flood Hazard mapping (FHM) modelling was completed. This also provided further refinements that needed to be included into the SH20 model. All these updates to the SH20 model were able to be undertaken prior to the EPA submission.

2.3 WHERE ARE THE OUTPUTS?

The results from the modelling for SH20 included flood maps, long-sections and a factual report. An example of the output can be seen in figure 2. In addition to this flood mapping for the initial EPA submission, NZTA engaged AECOM to undertake some specific modelling of a particular flood mitigation option. Due to the effort made developing the original model, these options could easily be incorporated into the model.

Figure 2: Typical SH20 Output for Inclusion in AEE



3 FLOOD HAZARD MAPPING

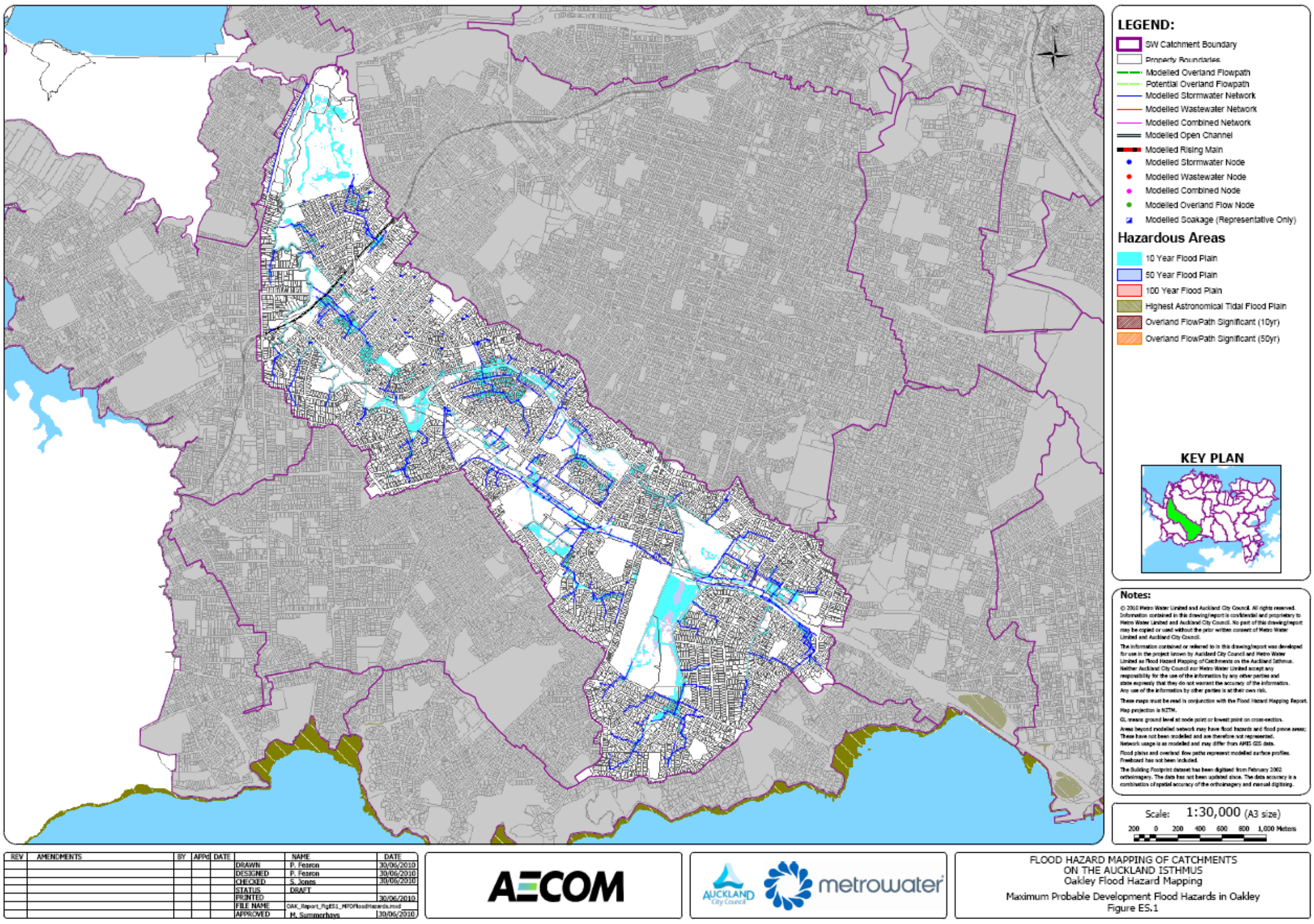
Due to time constraints in the SH20 Waterview connection EPA submission, the FHM process commenced after the SH20 assessment was started. The modelling for SH20 provided an opportunity to accelerate the FHM program for this catchment; however there were issues with co-ordination in the model build. Typically a completed FHM model would be updated to incorporate options for assessment. However, as this was not possible, the risks associated with fast tracking the process were accepted and the project proceeded as planned.

The calibrated model was updated to include the final SH20 alignment. Issues then arose when the FHM model was completed because we started looking in more detail in the model and noticed some issues that needed to be resolved. This in turn altered the SH20 model which needed to be updated and re-run.

The FHM project was very successful, being the first 2D FHM to incorporate a hazard risk assessment process and a property level analysis of floors at risk of flooding. This FHM has set a new benchmark for the 2D FHM projects to build on going forward.

Figure 3 shows the overall catchment with the 1-in-a-100 year flood plain for the Maximum Probable Development (MPD) scenario.

Figure 3: Oakley MPD Flood Plain



3.1 FROM CALIBRATION TO FLOOD HAZARD MAPPING

The calibration of the Oakley model used gauge data from stream gauges located within the main water course of the catchment. Consequently, there were significant errors identified in the model when we started looking at the detail required for the FHM phase. These included incorrect connectivity and catchment delineation. These errors were not identified during the calibration as the effects of incorrect connectivity do not manifest in the model when looking at the results where the gauges were located, typically in the Oakley Creek where flows are in excess of 10 cumecs. Updating the model to be fit for purpose for the FHM required an extensive review of the model. This process included the following:

- Checking pipe connectivity for critical network
- Undertaking a mass balance of the catchment areas
- Sense checking of the predicted flooding

This process proved to be valuable and increased the accuracy of the predicted flood extents. The FHM results did not have a significant effect on the results for SH20, however, to ensure consistent outputs the changes were incorporated into the SH20 model.

3.2 FLOODED FLOOR COUNT

During the FHM program, a methodology was developed for assessing which floors were at risk or potentially at risk of a flood hazard. When assessing which floors would be reported, and the degree of confidence there was in each type of prediction we considered:

- How the floor level was obtained (i.e. survey, site assessed, assumed)
- Whether the floor was in an overland flow path or flood plain (as defined by the hazard classification – refer section 3.3)
- The type of floor being considered (i.e. habitable, non-habitable etc)

This resulted in a much more accurate picture of the floors at risk of flooding within the catchment. The number of floors at risk was increased moderately from previous modelling efforts; however, there is more confidence in the revised predictions. This in turn improves confidence in the cost benefit analysis undertaken when considering the benefit of various flood mitigation options.

3.3 HAZARD CLASSIFICATION

Extensive surface ponding, as well as significant overland flow with unsafe depths and/or velocities were identified and defined as "significant" flood hazards (NSW, 2001). Prior 1D FHMs adopted depth vs. velocity relationship curves to categorise overland flow as a hazard with the following relationship:

- Velocity greater than 2m/s (Vtn > 2.0m/s)
- Depth greater than 0.3m (Dtn > 0.3m)
- Depth * Velocity relationship (Dt * Vt > y = -20x+6)

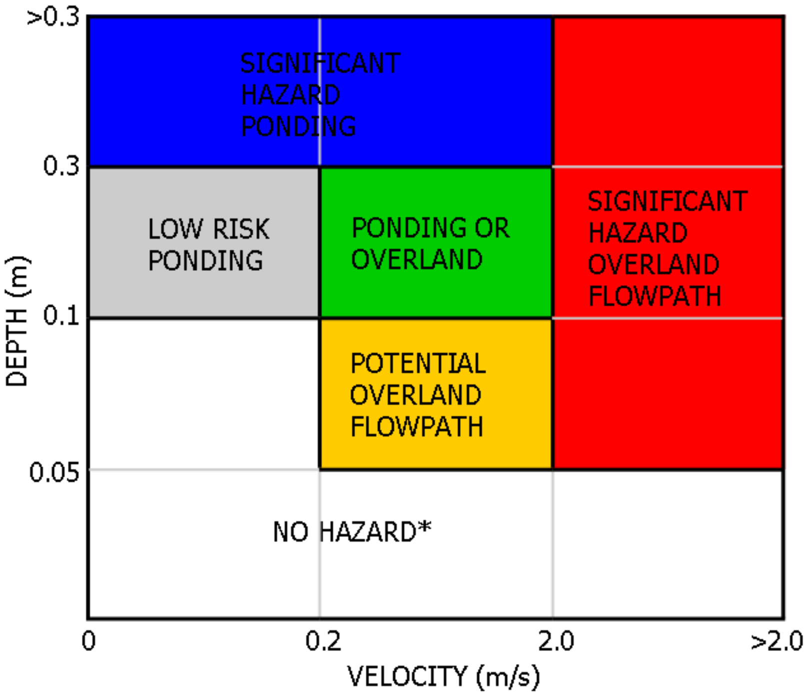
2D Hazard Methodology

In an effort to better use the reporting capabilities of 2D modelling, the following flood hazard classification methodology was developed. These classifications are intended to complement existing flood hazard classifications previously developed under the ICS program using only 1D modelling methods. A hazard classification was developed for the project which is being rolled out for all 2D models undertaken in the Auckland region.

The Significant Flood Hazard areas were identified using the Depth vs. Velocity relationship curves specified in the Metrowater Modelling Framework (Metrowater, 2005a) and customised for use with 2D model outputs.

To determine the Hazard classification as defined in Table 1, the velocity and depth for each cell is used at each time step during the simulation to determine the hazard category at the given time step.

Table 1: Flood Hazard Classification



The model results were analysed using this classification and the results were used to map the worst case hazard for each cell in the model extent. This methodology was developed for use in 2D modelling as part of the Oakley FHM programme and is now being used in other FHM models around Auckland and Hamilton.

4 FLOOD MITIGATION OPTIONEERING

Flood mitigated in the catchment needed to be considered for the EPA application; therefore AECOM was engaged to assess the effects of different high level catchment-wide flood mitigation options. The purpose of this study was to recommend a selection of options for Metrowater and Auckland Council scoping studies as well as providing NZTA with an understanding of the Auckland Council's worst case for flood mitigation. These options were broadly categorised as follows:

Beheaded: This involved installing a new diversion pipeline from Keith Hay Park to the Manukau Harbor. There were some sub sets of this option which included extending the interceptor to other critical points within the network.

Pass Forward: This option provides protection to Keith Hay Park during storm events up to the 1-in-10-year ARI event. Storm events in excess of the 1-in-10 year event would flood the park and provide attenuation for downstream properties. The main reason this option was considered is due to the limited capacity of Oakley Creek channel. To combat this, the capacity of Oakley Creek would be increased to convey flood flows through the catchment to the Waitemata Harbour without causing habitable floor flooding for the 1-in-50-year ARI event.

These two overarching options were then developed into five hybrid options as outlined below. These hybrid options have been analysed by investigating the accumulative benefit of reducing the flooding downstream.

4.1 HYBRID OPTIONS

Five hybrid options were agreed in conjunction with Auckland Council. Each option was modelled and costed. The results were then used to evaluate the number of habitable floors protected from flooding should these options be built.

The five options considered were:

- Hybrid Option 1 – (Existing Keith Hay Park) – This option investigates options to mitigate habitable floor flooding without any changes in Keith Hay Park. Oakley Creek conveyance capacity was increased to accommodate flood flows in order to mitigate floor flooding

- Hybrid Option 2 – (Pass Forward 1-in-10-year flows from Keith Hay Park) – In addition to the flood mitigation works identified in Option 1, conveyance from Keith Hay Park is increased to pass forward the 1-in-10-yearr design storm and landscaping the park to store the 1-in-50- and 1-in-100-year flood

- Hybrid Option 3 – (Tunnel Diversion from Keith Hay Park) – This option provides for a tunnel beheading the upper catchment at Keith Hay Park and diverts the upstream flows to Manukau Harbour

- Hybrid Option 4 – Option 3 with the tunnel extended to Winstone Road

- Hybrid Option 5 – Option 3 with the tunnel extended to Sandringham Road

The options investigated are hybrid options and consist of a scenario of options, which have an accumulative effect on the stormwater. Cost estimate for the options range from $33-$69 million.

4.2 FLOOD PLAIN EXAMPLES

Below are three examples of the high level flood mitigation options that were agreed with Auckland Council and subsequently incorporated into the model.

4.2.1 O'DONNELL AVE

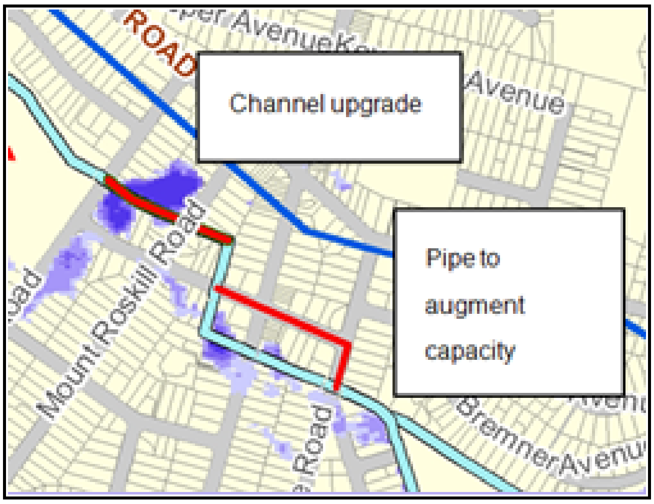
The worst residential flood plain is located within and around O'Donnell Avenue. The flood levels in the O'Donnell Avenue flood plain are predicted to put 49 floors at risk in the 1-in-100-year ARI MPD event and a further 50 floors within 500mm.

Figure 4: O'Donnell Flood Plain

4.2.2 MT ROSKILL ROAD

Other areas where additional work was required was in the Mt Roskill Road area (see figure 5 below) where channel widening and pipe augmentation is required and at the Railway Culvert (see figure 6 below) where a second overflow culvert could be constructed.

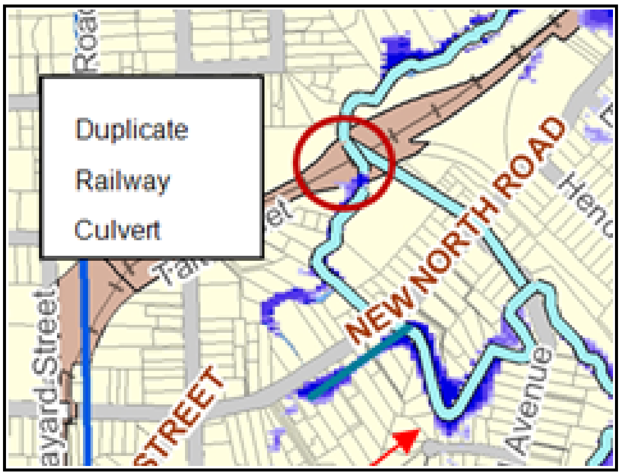
Figure 5: Mt Roskill Road Flood Plain



4.2.3 RAILWAY CULVERT

Significant flooding is predicted in the section of Oakley Creek between Bollard Ave and New North Road. To alleviate this flooding a bypass culvert was constructed under the railway. With the increased flows generated by passing flood flows forward from O'Donnell Ave flood plain an additional overflow culvert will be required to augment the existing overflow culvert.

Figure 6: Railway Culvert Second Overflow



4.3 OUTCOMES

The Draft Oakley Options Report has recently been delivered to Auckland Council and their preferred option is pending. The project did, however, provide outputs to be used in the SH20 modelling programme. This proved valuable in terms of assessing the effect, not only of the proposed motorway and associated stream works, but in assessing the effect of that development on a worst-case upstream flood mitigation scenario where flood flow is passed forward through the development.

5 LESSONS LEARNT

5.1 COMPLEX FLOW REGIME

The various assessments of this catchment have required the use of a dynamically coupled model due to the complex flow regimes throughout the catchment. Flood plains, severely restricted channels, and under-capacity culverts all contribute to an environment where predictions of flood plain extents and hazard classification become very difficult. Hydrodynamic modelling is a very powerful tool for assessing these effects. The degree of accuracy obtained from this model far exceeds that shown in previous modelling efforts.

5.2 1D VS 2D MODELLING

Although time consuming, the value added to Council's understanding of the catchment by developing this fully coupled 2D model has been immeasurable. Additionally, the ability to use the model for other value adding projects such as optioneering and the SH20 Assessment for Environmental Effects project has proven invaluable. The accuracy obtained for the 2D approach has exceeded that obtained from a 1D model. This is particularly true in the flatter flood plains. All subjectivity has been removed when the 2D terrain is allowed to determine the direction of flows.

5.3 IT'S NOT A BLACK BOX

The model itself must be thoroughly checked and the outputs need to be verified and validated. The old modelling phrase "rubbish in, rubbish out" still applies when completing a 2D model. Always 'truth check' the results.

5.4 PROGRAM

The SH20 modelling, optioneering and FHM programme was so tightly programmed that there was very little room for errors, and errors are inevitable in 2D modelling. Although unavoidable in this case, undertake the programme in the preferred order if possible.

5.5 CUT DOWN THE MODEL

When a discrete area of a catchment model is being assessed the time required to 'cut-down' the model to the subject area is very often worth it. Thorough checking including mass balance should be undertaken on the base cut-down model before proceeding with additional model runs.

6 CONCLUSIONS

In conclusion, the Oakley modelling programme was successfully executed. The SH20 model provided outputs that have been unchallenged in the EPA hearings. The FHM has produced excellent quality outputs and has set a benchmark for other 2D FHMs to reach and the optioneering has defined multiple options with cost benefit for Auckland Council to consider.

In addition, the project provided an opportunity to re-define how flood hazards are defined and mapped. This hazard classification methodology provides a benchmark and will be built on and developed to increase the degree of accuracy we have in predicting flood hazards in the future.

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