MANAGING THE OAKLEY CATCHMENT MODEL BUILD AND OTHER CLIENT-SIDE FRUSTRATIONS - AUCKLAND, NEW ZEALAND

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ABSTRACT

The Oakley stormwater catchment (1230 ha), is one of the most flood prone, high profile and challenging catchments in Auckland City. Attempts to analyse, identify and implement solutions dates back several decades, and until recently were banished to the too hard basket.

To take advantage of flood mitigation opportunities offered by working with concurrent large projects such as State Highway 20 and the proposed wastewater central interceptor, a renewed effort was made to prepare a high confidence hydraulic/hydrological model. Whilst providing some foundation work, past efforts were unable to adequately reproduce field observations due to Oakley's complexity. With the availability of new software, LIDAR topographical data, and computer power, the latest model achieved accepted results through the dynamic linking of pipe, river and surface models.

The road has been long, however we now have the capability to model whole catchment solutions for Oakley alongside highway drainage to solve flooding, whilst preserving the environmental character and amenity value of the catchment.

This paper takes you on our journey of past and present attempts to develop a reliable tool from a client's perspective including lessons learnt and suggestions for improved management of stormwater modelling projects.

KEYWORDS

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

PRESENTER PROFILE

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1 INTRODUCTION

Oakley catchment has it all. Complex geology, hydraulics, governance and development history, flooding history, and a state highway right through the middle. It is both fully urbanized, and the only river based catchment in the Auckland City Council area. All these things have conspired to make flood mitigation and environmental planning challenging and at the same time very interesting.

This paper outlines the history of modelling attempts, their shortcomings, and how this latest attempt has seen some success and a way forward for the catchment. The objective of this paper is to convey the lessons learnt on key client-side issues of procurement of professional services, approach to methodology and project management against a backdrop of steadily increasing computer power, data, and software advances.

A further message is the benefits of undertaking both catchment flood mitigation and highway drainage modelling activities concurrently to achieve catchment outcomes.

2 THE HISTORY OF OAKLEY CATCHMENT

2.1 CHARACTER

The Oakley catchment is long and narrow in shape, with a watercourse running for some 11km across the Auckland City Council Isthmus from near the Manukau harbour in the South to the Hauraki Golf (Waterview inlet) in the North East. The catchment is almost fully urbanised with mainly residential and some pockets of business zoning. The watercourse is the main controller of surface flooding in residential areas and has a relatively flat slope in the upper areas of 0.3% leading to steeper lengths in the lower areas of 0.9%.

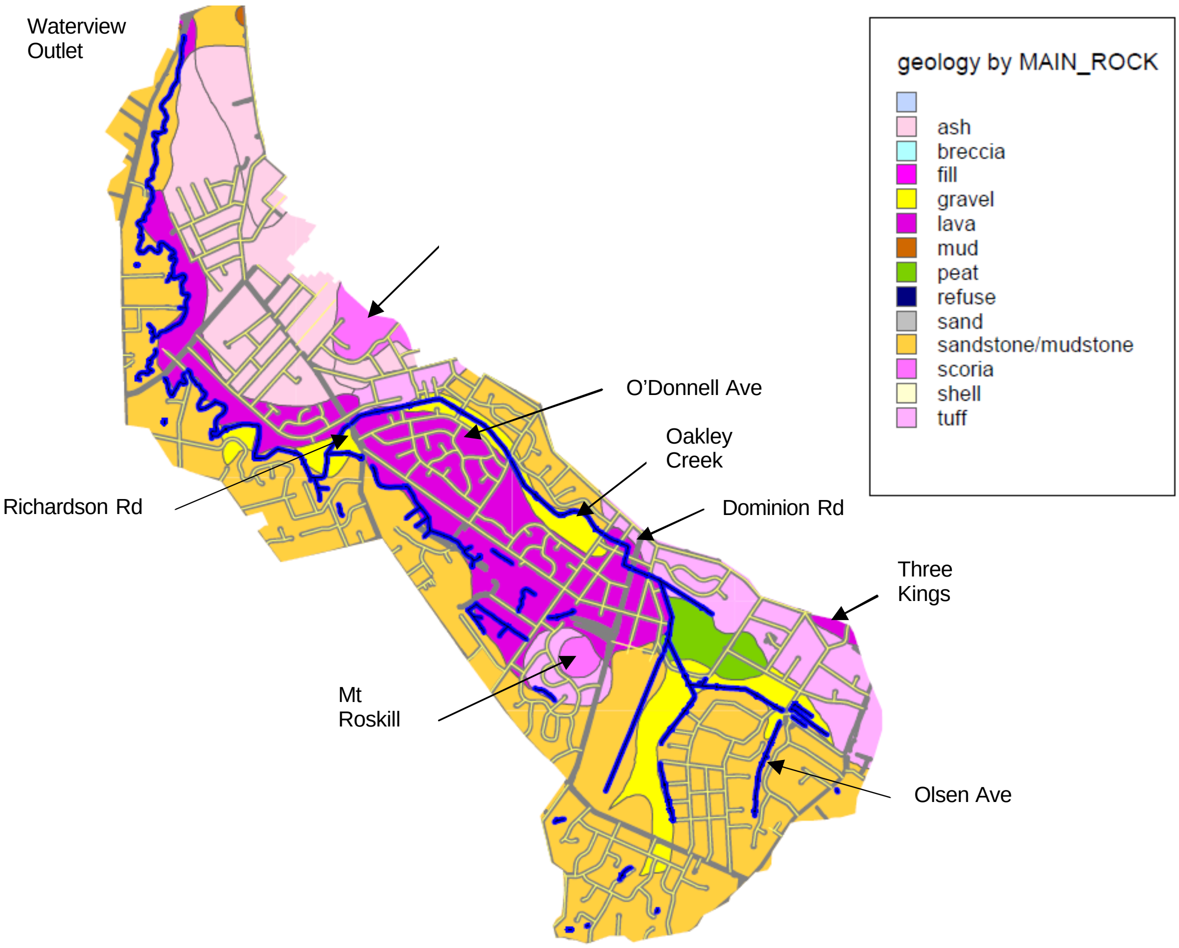
It has a state highway and rail designation (circa 1960s) running the length of the catchment over many parts of Oakley creek. The state highway has been built in the upper half of the catchment with the lower half well advanced into planning and design stages. The second stage of the highway has a high public profile around effects on private property and property purchase issues.

Figure 1 shows the geology and prominent landscape features of the three volcanic cones of Mt Albert, Three Kings and Mt Roskill. The lava flows from these volcanoes created a mixed lithology comprising rock, alluvium and swamp areas some of which have been reclaimed. Consequently drainage methods have included reticulated stormwater over significant areas and ground soakage in the more permeable volcanic soils. The main tributary has regular alignment and is carried in man-made channels for most of its length. In a number of places the channel has been formed by rock cuts through the lava flows to drain the flat swamp lands that had established behind the lava flows (Oakley CMP, Beca, 1995).

The water level in the creek often constrains off creek discharges causing flooding. However, for many of these channels, buildings and residential property has been developed right to the edges limiting creek widening options without land purchase.

Plate 1 Stone lined channel near Dominion Road

Figure 1 Oakley Geology (Metrowater GIS 25/03/10)



These geological features, development patterns and watercourse modifications have in combination, resulted in large areas of "at risk" habitable floors (>400) with limited affordable and feasible mitigation options.

2.2 FLOODING ISSUES AND RESPONSES

Oakley catchment has a history of flooding dating back over 50 years. There have been numerous flood mitigation proposals over this time, some implemented, some not. From looking at this history, we see a cycle of storm events, flooding complaints, studies and various works, followed by further storms generating the next cycle. This Section lists out chronologically, the main proposals and solutions implemented together with the some of the various reported flooding events to illustrate the many failed attempts to achieve an acceptable standard of flood protection in the Oakley catchment.

Between 1954 and 1960, the watercourse between Richardson Rd and May Road was enlarged, shaped and paved to reduce flooding in the O'Donnell area. However, we see from Plate 2 below this had limited success. In 1955 and 1956 the Rock cut between May Rd and Winstone Road was deepened and widened with 5 road culverts being built (Oakley Creek and Catchment Report, ARA, May 1981). With today's levels of development, this area has also experienced flooding and is a major bottle neck in the creek.

Large storm events in 1979 and 1981 prompted a study by the Auckland Regional Authority (ARA) jointly funded by three local authorities of the day Mt Roskill Borough Council, Mt Albert Borough Council and Auckland City Council. The 1981 ARA study stated "Principle causes of flooding are the development of higher land increasing storm runoff and the draining of the two large swamps eliminating the original storage…".

Plate 2 Flooding 1979 Lorraine Rd (opposite O'Donnell)

Historical Flooding - July 1979

The three Councils, ARA, and the then Water and Soils Board responded with a study proposing storage at Keith Hay Park, and various culvert and stream upgrades as preferred options.

Many of the flatter areas in the upper catchment experienced flooding in the mid to late eighties and early nineties after these works were implemented, leading to commissioning of a comprehensive catchment management plan (CMP) by Beca in 1995-98. This study used a SWIM/FINCH computer model to assist understanding of flooding conditions and proposed a series of local improvements to the stream and areas of flooded habitable floors. The works were aimed at improving overland flows around houses, and increasing culvert capacity at New North, May, Memorial and Dominion Roads. This was followed up with physical model studies at other main creek culverts and other minor works projects. It is interesting to note feedback from one submitter following consultation "How many times has Roskill seen titivating happening on tributaries while the main problems on the Oakley Creek remain in the too hard basket".

The 1995 CMP proposed not to upsize local reticulation to the creek, but rather accept property flooding as storage, only attending to habitable floor flooding. The same submitter also pointed out "Flood water will invade gulley traps and sewerage lids in lower lying areas will pop and sewerage spew over lawns and lie under houses." This can be seen happening 2nd February 2004 in Plate 3 and Plate 4 which also resulted in a Watercare manhole spilling in War Memorial Park.

Plate 3 Flooding at 44a Mt Roskill Road

Plate 4 Flooding at WSL Manhole 55 War Memorial Park

Dominion Road culvert was upgraded to a bridge in 2001 yet this also had limited success as shown in Plate 5, Plate 6 and Plate 7, where we see the typical scenario of creek full backing up off creek reticulation for a 2-5 year ARI event (2/2/04). Following the February 2004 storms the catchment was again high in the Auckland City Council political agenda resulting in a local drainage investigation and commissioning of the next CMP and series of model build projects.

Plate 5 Dominion Road bridge (2/02/04, 2-5 year ARI event)

Plate 6 Stream at 64 Olsen Ave (2/02/04, 2-5 year ARI event)

Plate 7 Olsen Ave Road Drainage (2/02/04, 2-5 year ARI event)

A review of this history highlighted the following key issues which need to be considered for future flood mitigation planning work:

- Development has occurred in flood susceptible areas
- Mitigation solutions have been quickly overtaken by further development
- Each cycle of mitigation attempts has not addressed the fundamental flood conditions of the creek
- The catchment is long and complex, with many control points, and surface, pipe, and creek elements interact dynamically
- Historical piecemeal solutions have not provided acceptable flood protection

3 MODELLING ATTEMPTS AND SHORTFALLS

This Section provides a summary of various estimates of flood conditions carried out since the 1979 floods. The primary area of concern is modelling tasks completed from 2004 to 2008 which failed to reproduce observations and the fundamental reasons for the shortfall in confidence.

Table 1 below shows the main model build efforts of the past and the variation of flooding conditions reported for large ARI events. Flow and level at a key location in the Oakley creek is chosen to illustrate the different results reported over the years.

Table 1 Hydraulic/hydrological modelling of Oakley Catchment

Study/Model	Creek flow (m3/s) and level (m) upstream of Richardson Rd Culvert (At Wainwright)		Comment
ARA 1981	25	46.2	25 yr ARI, rationale method, ED
Beca 1995 CMP	36.4	45.6	100 yr ARI, SWIM/FINCH ED
Connell Wagner 2005	As per Beca 2006	As per Beca 2006	
Beca 2006	17.9[1]	46.6	100 yr ARI, DHI Mouse 2003, MPD
MWH 2008		45.7	Mouse, MIKE11 and MIKE21, 100 yr ARI, MPD
AECOM 2010	46	47.2	Mouse, MIKE11 and MIKE21, 100 yr ARI, MPD

These are described over the next subsections.

3.1 AUCKLAND REGIONAL AUTHORITY 1981

The first calculation of flood conditions in the creek is referred to in the 1981 ARA report. This work used a version of the rationale method and claimed to reproduce flood levels observed in the 1979 flood. Solutions were designed to leave building foundations free from flooding in a 25 year ARI event. A 50 yr ARI level of protection was considered impractical given the catchment was largely already developed.

This work was followed up by a flooding study for the Stoddard tributary by Fraser Thomas and Partners in 1990 again using the rationale method to create design hydrographs at key points along the stream.

3.2 BECA 1995 CMP (SWIM/FINCH)

The first computer model was prepared by Beca in 1995 as part of the comprehensive CMP using SWIMM and FINCH software. A lot of effort was applied to reproducing observed flows and flood levels along the main creek. It was observed that the gauged water levels rose and then seemed to stop rising as off creek reticulation was constrained

[1] A review of the CW/Beca model by MWH in 2007 identified very high roughness values were used (confusion of ‘M’ vs ‘n’) in the open channel sections resulting in low velocities and high water depths.

by outlet water levels. A key challenge was to replicate this backing up of off creek reticulation due to creek water levels with the limitations of the software. However an adjustment was made and this simple model provided reasonable results which formed the basis of the Type 'B' FHM used for official public release today. According to the modeller of 1995, although relatively simple, the model could be run quickly and was therefore refined through numerous scenarios and iterations during calibration/validation to match historical observations.

3.3 CONNEL WAGNER 2005 ICS MOUSE

As part of the model build stage of the Integrated Catchment management Study (ICS) Connell Wagner (CW) were commissioned to prepare a 1-D pipe model of the wastewater and stormwater drainage systems for Oakley using DHI Mouse software. The ICS project provided stream gauge data at three sites plus data from the permanent gauge at Richardson Rd culvert from the summer of 2002/03. The CW model development report is 121 pages long excluding appendices and dominated by wastewater content. Although not explicitly clear and highlighted, a thorough read of this document indicates the model was not fit for FHM purposes nor calibrated and validated. The following commentary is found scattered throughout the calibration, conclusions and limitations sections:

"...possible discrepancies between levels, asset information and hydraulic parameters used in the FINCH model and the Mouse model. Such differences will impact on computed water levels and peak flows in the streams."

"However, comparisons have been made with measured flows, levels and volumes to provide a degree of model validation and provide some understanding of the sensitivity of the model"

"As the TP108 approach was adopted, and because modelling and calibrating the Oakley Stream were outside the scope of work Connell Wagner were commissioned to carry out, the stormwater hydrological model was not calibrated."

"Comparison between modelled and observed stormwater flows showed differences were outside of target tolerances."

The report recommended survey of cross-sections and culverts to close the stated discrepancies.

A QA/QC process as part of the final deliverable, stated the calibration 'seemed not acceptable'. It is not known how this was resolved by Metrowater.

3.4 BECA 2005/6 MODEL UPDATE AND FHM

Beca were commissioned in 2005 to provide a flood hazard map (FHM) and flood mitigation options as part of further ICS stages. They added new survey information for the flatter areas in the catchment, altered some constrictions in the river channel banks ("glass walls") thought to be significant, and made some changes to channels and overland flow paths.

Having resolved the asset and channel levels data, Beca compared the Mouse and Finch flows and levels which indicated anomalies in the Mouse model predictions. The Beca FHM report states in the limitations section "These were discussed with Metrowater however it was decided to progress with the model in its current state." No comment was made in the FHM report on the calibration limitations CW stated in their model build report. Interesting to note that a subsequent review by MWH identified 'n' values had been used for the Mouse channel sections when the model required 'M' values. This resulted in very high roughness, low velocity and high water levels. This explains in part the results shown in Table 1 above.

An FHM was developed using this Mouse model which under Metrowater review was not accepted. Again it can be seen in hind sight that at the time, there was a failure on both the consultants and Metrowater's part to understand the importance of, and address, the calibration issues stated in the CW report. It is possible that time and budget pressures played a part in progressing to optioneering stages without establishing a solid model foundation.

A set of flood mitigation options were then developed using the Mouse model. The solutions were analysed at a high conceptual level leaving detailed practical local considerations for future design stages. The solutions addressed the creek capacity issues with widening full length, large storage tanks, plus a diversion tunnel from Hendon Park to Waitemata Harbour (Waterview). This was neither optimised nor practical and remained low confidence due to FHM and model issues.

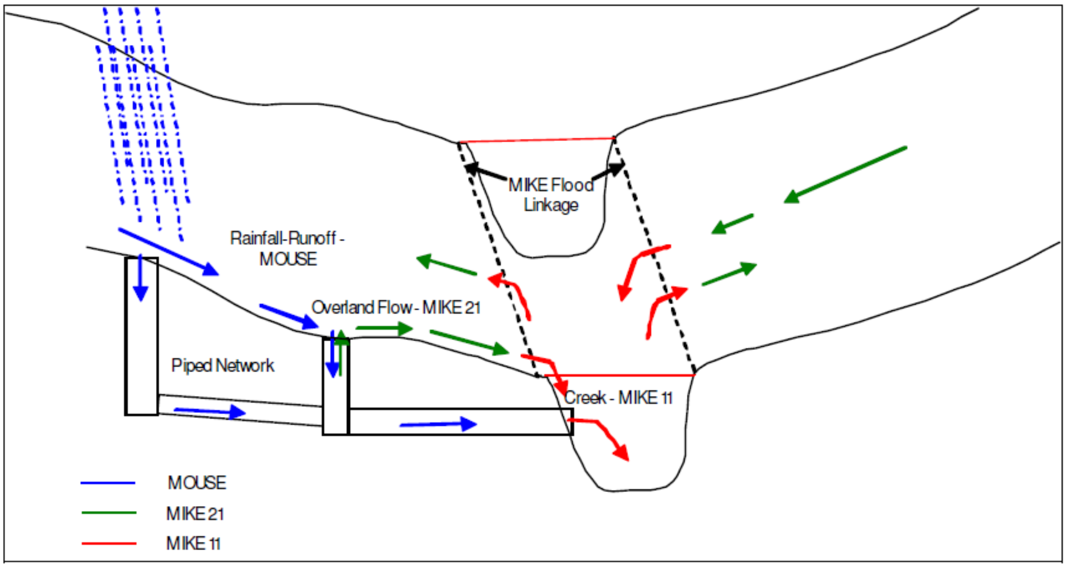
3.5 MONTGOMERY WATSON (MWH) 2007/08 2-D SURFACE AND RIVER MODELS

In 2007 a decision was made that to seek a reliable high confidence Stormwater model for Oakley, a 2 dimensional (2-D) and a river model were required to be added to the 1-D Mouse pipe and creek model to achieve a sufficient representation of the complexities of Oakley. MWH were commissioned to build a dynamically coupled surface, river and pipe model using DHI MIKE21 (2-D Surface), and DHI MIKE11 (1-D River).

Figure 2 below is a schematic showing the three DHI MIKE model components and how they represent dynamic interaction of water flows and levels. Rainfall runoff hydrology is loaded to the Mouse pipe nodes which are coupled to the MIKE 21 surface grid cells (based on LIDAR bathymetry) via two way weirs. MIKE21 is coupled to the MIKE11 river model via left and right edge markers. At this point in time Mouse could not be coupled dynamically to the MIKE11 river, so it was connected via Mouse outlet flows as source points. All components were run in MIKE Flood.

The decision to add a 2-D and river model components to Mouse was an appropriate one although implementing this proved to be difficult and time consuming for the consultant. A large amount of time was applied by MWH to setting up the model coupling, incorporating the motorway bathymetry and resolving model instability issues.

Figure 2 Schematic of dynamically coupled surface, river, pipe model



Once stability issues had been resolved, the model had a 60 hour run time. A decision was then made to calibrate the Mouse hydrology only using the MIKE11 river model to reduce run times. This was based on an assumption that calibration events were small (< 1yr ARI) therefore flows are not expected to spill beyond the MIKE11 river banks. This assumption was incorrect, and the primary reason that flooding predicted by the model for high ARI events (10, 50, 100 yr ARI), did not reach historically observed levels of spread.

In 2008 Metrowater commissioned an expert modeller from DHI to review the MWH model to identify technical issues and recommend a task list to resolve these. At the same time as the review Metrowater focussed on collecting visual flood spread evidence from site inspections during rainfall. Plate 8 and Plate 9 clearly show flood spread beyond the creek channel banks for a 6 month to 1 yr ARI event.

Plate 8 Flood spread downstream of Richardson Rd culvert 20/02/09 12.40pm

Plate 9 Flood spread downstream of Sandringham Road culvert 20/02/09 12.20pm

The main finding of the DHI review was that the model used for calibration and model used for FHM were not the same. The calibration model comprises cut down MIKE11 with bank markers pulled in effectively creating a river model with constrained banks “glass walls”. Thus the MIKE11 model for calibration had a narrow cross section for flow generating higher water levels than gauged. Mannings ‘n’ was then adjusted to force the level down to match observed levels. The adjusted ‘n’ was then used in the fully coupled model for 10, 50, 100 yr ARI events for FHM, with the result of much lower water levels and less flood spread than historically observed. Figure 3 and Figure 4 illustrate the effect of this, showing the difference in flood extent at the O’Donnell area between the MWH model and the latest AECOM model (refer 3.6 below).

Further, the DHI software had improved in late 2008 to allow dynamic coupling of the Mouse pipe network to the MIKE river model. The DHI review consequently recommended stripping out the Mouse pipes network and re-coupling to MIKE21 and MIKE11 to achieve a fully 3-way coupled model and then revisit calibration validation using the full model.

Figure 3 MWH Draft FHM for 100 yr ARI MPD

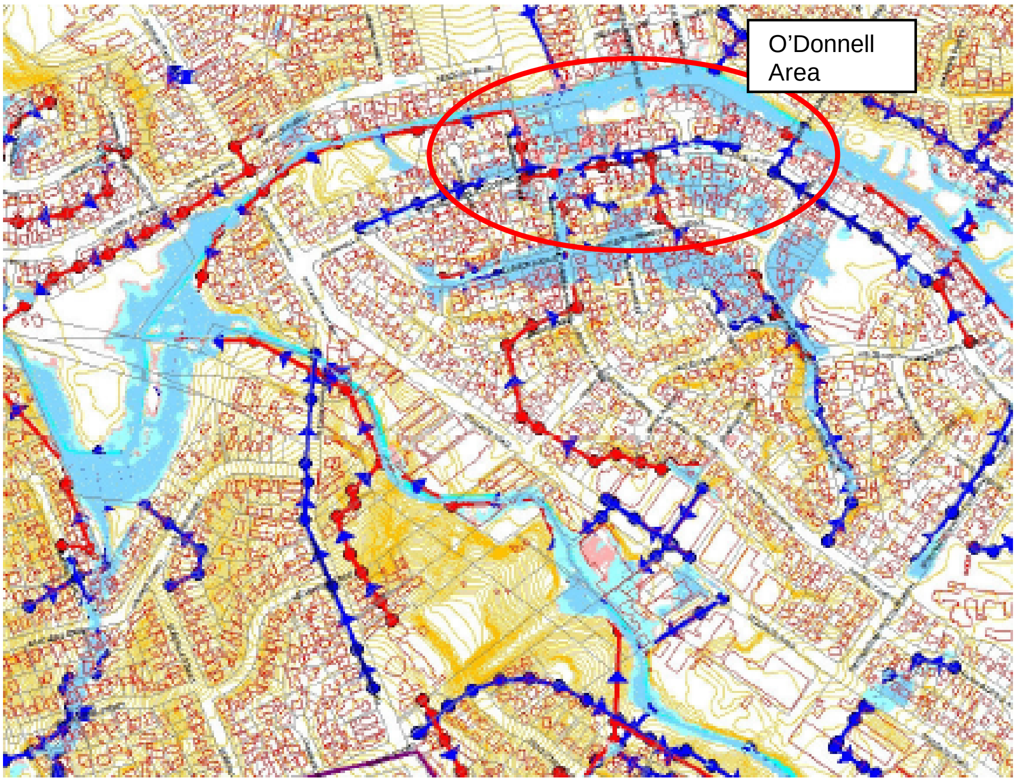
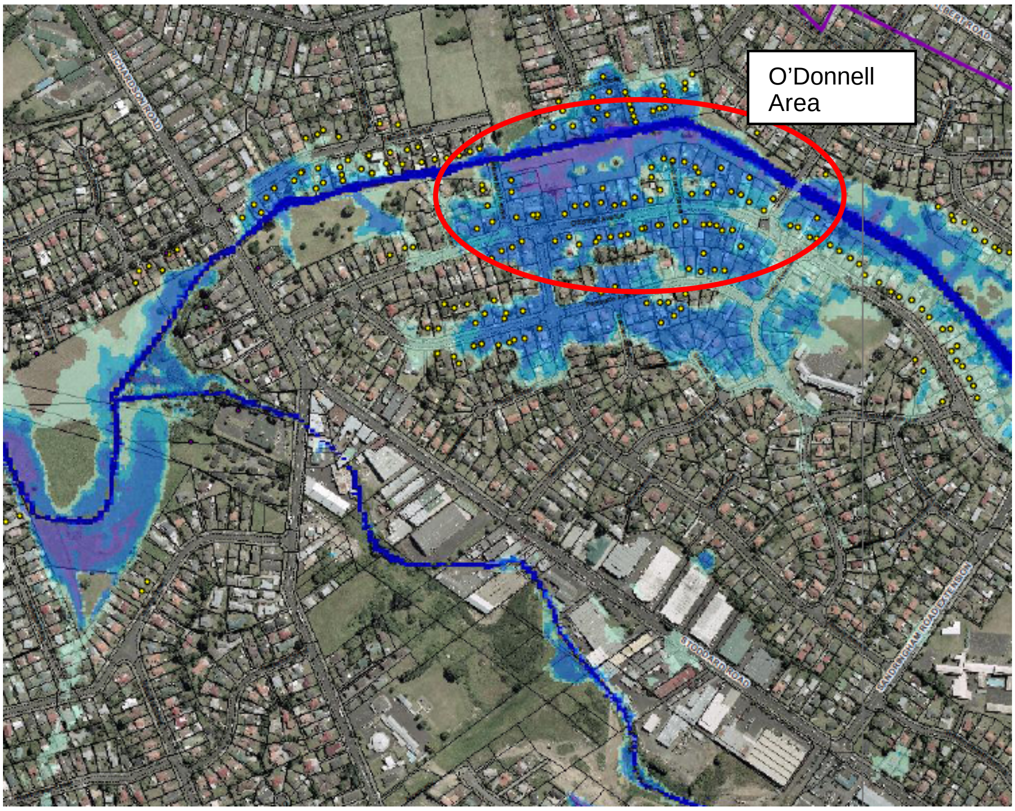


Figure 4 AECOM Draft FHM for 100 yr ARI MPD



3.6 AECOM LTD 2009/10 3-WAY COUPLED SURFACE, RIVER, PIPE MODEL

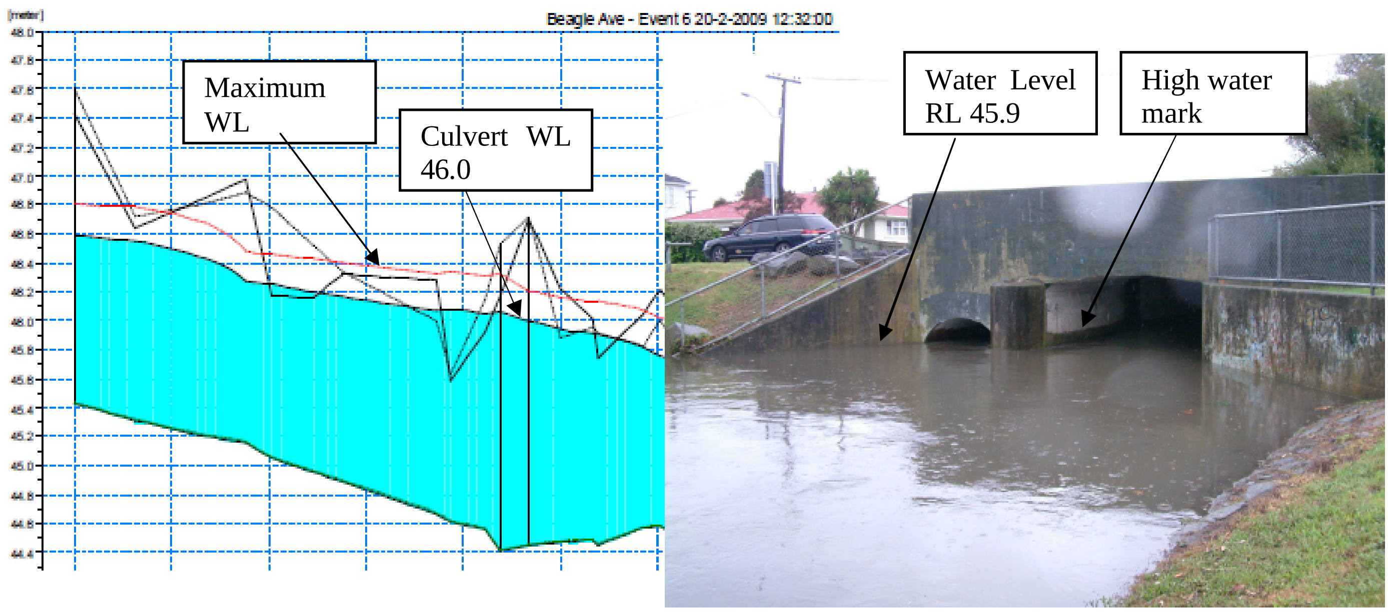
In 2009, AECOM Ltd were commissioned to carry out the tasks recommended by the DHI expert modeller's review. The main tasks included stripping out the pipes and hydrology from Mouse and re-coupling to MIKE11 and MIKE21. This in itself was a huge task requiring understanding of Mouse catchments, where and how they should be reconnected, and addressing key issues of soakage representation and associated non connected sub-catchments.

Additionally the pre-motorway (SH20 to Mairo Rd) bathymetry had to be reinstated to replicate the stormwater system at time of flow gauging.

DHI experts were retained on the project to provide expert advice on schematics, software technical issues, and hydraulic/hydrological theory necessary to achieve best practise for the final calibration model. DHI were also retained to workshop calibration of parameters, and undertake formal QAQC review.

A significant effort was made to achieve acceptable calibration and validation. Metrowater provided photos, videos, and surveyed levels of flood spread observed for the 6 month – 1yr ARI event of 20th February 2009. This was used to confirm the model at several key control points along the creek as shown in the example at Beagle Ave in Figure 5 which shows the water level receding following the peak.

Figure 5 Beagle Ave observed and modelled water level 20/02/09 12.32pm



This work provided a validated model which was then used to generate the flood extents shown in Figure 4 above.

3.7 MODEL BUILD LESSONS LEARNT

The Oakley catchment has seen the same fundamental flooding issues throughout its modern urbanised history. To understand and solve these flooding issues a series of hydraulic models of varying sophistication and quality, and solutions of varying scales and extent have been used. Over the last 5 years, a series of model build projects have each improved confidence in asset data, hydraulic representation, software, and computer power. All but the most recent model have not achieved calibration nor validation prior to advancing to FHM and options work. Considering this past experience, several key areas for improvement were applied in the latest model build project:

Understand previous work, especially model build reports	It is not enough to list out 25 volumes of previous work in a consultant's brief. The client should know what are relevant and key pieces of information from what can be thousands of pages of reports. E.g. physical models of key culverts were built in 1998 to prepare rating curves.
Include independent expert hydrology and hydraulic expertise	Spend time and effort work-shopping model set up and schematics early in the project. Retain the expert through and into QAQC stages. Revisit the theory regularly.
Obtain and use real world data	This aspect is always talked about as important. Follow through and persistence is also required to achieve it. Include sensibility checks by those who understand the catchment
Don't get lost in the software	Use expertise from the software company to confirm set up is appropriate and for efficiency in resolving problems. The software moves on quicker than the model build project requiring regular revisit of methodology.
Allow time to use the model to inform knowledge	The latest 3 way coupled model showed where key control points were, hydraulic anomalies and where water was moving in and out of the river channel.
Need to think carefully about the procurement method	Did lump sum serve us well? Better to divide into packages and reassess as work proceeds.

4 OPTIONS FOR FLOOD MITIGATION

As discussed in Section 2.2, options have been investigated following each major storm event dating back to the major flooding of 1979 and 1981.

All studies have included, to varying extents, options for increasing the capacity on the creek to pass forward flows from the upper to the lower areas of the catchment. Annex 1 shows a summary table of the various options analysed by each study. Since 1981 implemented solutions have included increasing capacity to culverts at New North Rd, Dominion Rd May Rd, Memorial Ave, and as a part of SH20 drainage works, a 3m dia culvert at Melrose Rd. Despite increasing the pass forward ability of culvert and some creek areas, water levels in the upper Oakley creek have remained high and continue to constrain outfalls from off creek reticulation in relatively small ARI events.

Past options have also included various diversions through to Manukau harbour to "behead" upper sub-catchments. These have mainly been discounted due to cost comparisons with pass forward options, and effectiveness at lowering creek water levels.

The most recent work has identified a solution set including a mix of additional storage in Keith Hay Park, a pipe diversion and widening through the Winstone to May Rd area, and pass forward widening to the O'Donnell area. It is interesting to note the 1981 ARA report proposal to increase storage at Keith Hay Park which may not have been fully implemented.

There is nothing really new in this latest options investigation apart from having now prepared a model with sufficient confidence to understand how solutions which are practical and achievable, will achieve quantifiable flood reduction benefits. Additionally it is planned to use the model to investigate a range of flood flow conditions post flood mitigation works, to investigate effects on ecological indicators from the 'Stream Ecological Values' (SEVs) work. Ecological audits of the creek may also be used to assess flood mitigation options.

5 SOLUTIONS INTEGRATED WITH SH20 DRAINAGE

State Highway 20 (SH20) is a project of national importance in connecting an alternative route through the Auckland region. The route intersects a large length of Oakley creek from Hillsborough through to Waterview interchange and has therefore identified stormwater drainage as a significant issue to be managed. The Waterview connection project is currently being designed.

The drainage designs for the Motorway (from Maioro to SH16 at Waterview) consider water quality, flood height for 100 yr ARI plus climate change, and effects from changes to imperviousness. As the motorway drainage has a significant influence on the stormwater system for Oakley, these issues were analysed in conjunction with Council's flood mitigation objectives to achieve an integrated solution set which would ensure future proofing of the motorway drainage design.

The Oakley 3-way coupled model was used to model the whole catchment including SH20 proposed drainage to ensure future flood mitigation options can be accommodated within the SH20 designs. This required a regular exchange of data and information between Council's consultant and New Zealand Transport Agency's (NZTA) consultants to ensure consistency of modelled flows and levels and to resolve any anomalies. Future changes to sub-catchments, storage and treatment ponds, creek diversions, new culverts/bridges and flood walls were all incorporated into the Oakley model to predict flood conditions for the future network state.

Three scenarios were investigated, one with the existing stormwater system, a second with the new motorway drainage, and a third scenario with new motorway drainage and future catchment flood mitigation options. These analyses were fed into NZTA's Assessment of Environmental Effects (AEE). It is interesting to note the SH20 proposal includes a water quality pond in Hendon Park which was originally proposed under the 1995 CMP.

SH20 in the upper parts of the catchment may have already provided increased culvert conveyance in some areas which has partially relieved flooding near Olsen Ave. The next stage of SH20 running through to a tunnel portal in Allen Wood reserve has the potential to improve pass forward flows to the lower areas of the catchment which has more capacity to convey large infrequent storm events. Hence designing the SH20 drainage system concurrently with flood mitigation analysis work, could create opportunities for resolving flooding which would not have been possible had the two been done independently.

6 CONCLUSIONS

1	**Know the catchment and support the consultant**	Oakley has a long and involved history. This needed to be fully understood by the client to appropriately brief and manage modelling effort. Lump sum procured modelling effort has not allowed the flexibility nor the depth of understanding by consultants to achieve fit for purpose results. For the recent modelling work, client, consultant, and independent expert worked closely and regularly together.
2	**Know the complexity and tailor modelling effort to suit**	Oakley is a river based catchment. The river controls local reticulation flooding and itself is an open channel flow system. It is only recently that software and computer power has enabled sufficient model representation to fully understand interactions between various storage, divert, pass forward solution sets.
3	**Solid foundation before FHM, options developed**	A feature of the latest model development effort was flexibility to focus on key aspects of the model one at a time without the consultant feeling the urge to take shortcuts to achieve arbitrary time and budget constraints. Hydrology, hydraulics, calibration and testing were all separate work packages reassessed as the project progressed.
4	**Read model development report with a fine tooth comb**	If updating an existing model, the capability, appropriateness, and limitations of that model should be fully understood before proceeding. This sometimes requires fresh expert eyes.
5	**Keep the software experts involved throughout the model build stage and spend time up front on agreeing schematics**	Following expert review, the expert was retained by the client to advise on update tasks, workshop schematics and software tricks of the trade. Once grunt work was done, the expert was brought back to assist with calibration, testing and QAQC review. The client needs to carefully consider if the consultant has sufficient expertise, or if extra skills need to be brought in to work along side. This proved invaluable for Oakley.
6	**Real world data very important**	Oakley is a long complex catchment. Confidence in the model could only be achieved when real world data had be collected including photographed flood spread with associated rainfall and river depth data.
7	**Master plans are a good idea, but must be realistic to be useful**	A catchment master plan for flood mitigation is essential given the dynamic interaction of pipe, surface and river elements, and the effect of river back water. This required considerable effort at the model build stage to achieve credible solutions which went further than blue sky thinking.
8	**A lump sum procurement approach did not achieve a useable model**	The challenge facing most clients procuring complex catchment modelling work, is how to get an appropriate quality for an appropriate fee. Lump sum works well when combined with a prescriptive brief, however, this approach did not deliver acceptable results for Oakley and a different approach was required.

9	**Use the model to gain knowledge and focus refinements**	The model was run at many stages of the build project to plot long sections and flood extents. These runs and plots were used iteratively throughout the project to understand control points, undertake sensibility checks, and focus model changes. Previous efforts had plotted out maps as the last task and delivered them to meet tight timeframes.
10	**Cooperative approach between agencies**	A cooperative approach between Metrowater and NZTA has been essential for progressing the latest studies. This has involved client/consultants from both organisation meeting regularly (weekly) to share information, results, and progress.

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Annex 1 Options and solutions from various studies for Oakley flood mitigation

	Study			
Issues	**ARA 1981**	**Beca ICMP 1995**	**Beca 2005**	**AECOM 09**
Channel at rear of Olsen Ave properties fills up. Private drainage ineffective, water enters WW manholes causing surcharging		Remove Hayr Rd culvert restriction and construct stop bank at entrance. Highway drainage diversion installed 3m dia. Pipe at Melrose Rd in 2005.		Flood wall plus additional storage in Keith Hay Park. Diversion along existing motorway alignment from Keith hay Park to Onehunga Bay
Channel behind Carr Rd business area (old swamp)				
Property flooding reported in Vic Butler and Gregory.	Divert flows below Cameron Pool into Keith Hay Park, store using raised bunds then release through control valves Somerset Rd	Shape secondary flow paths 15,17 Gregory, new pipe system to take CPs from #17.	Attenuation pond in Keith Hay Park. 10,000m3 tank in 80 Olsen Ave. 280,000m3 tank in War Memorial Park.	
Channel cut through Lava overtops in extreme events. Secondary flood waters reported flooding low lying properties between Dominion and May	1.8m pipe from Frost Rd to Norton St, tunnel Norton to stream below Aldergate Rd (16m3/s, 1963). Railway to Bollard Ave diversion Tunnel. Ponding in Walmsley Park (by lowering floor of Park). Culvert enlargement at the NIMT Railway embankment, New North Rd and Beagle Ave. Various channel improvements	Lower the invert of Memorial Ave culvert (Done). Replace May Rd culvert with a bridge (Done). Replace Dominion Rd culvert with a bridge (Done 2001)	Various 3m dia. tunnels • Keith Hay Park to Manuaku Harbour diversion Tunnel. • Keith Hay Park to War Memorial Park to Manukau Harbour Tunnel Diversion • War Memorial Park to Manukau Harbour Tunnel Diversion • Hendon Park to Waitemata Harbour Tunnel Diversion (preferred) Duplication of Oakley Creek and Restrictions (various lengths Hendon to Keith Hay)	• Pipe augmentation and stream widening with property purchase
3 culverts in Richardson Rd undersized or could block. Development in Roma Rd has cut off OLFP - ponding in Motorway/Rail corridor. OLF from Freeland Reserve.		Construct Flood Bank at rear of properties Marion Ave		Flood wall to protect houses at Marion Road
War Memorial Park - Sandringham Ext, Gifford, Plumpton, Denny. **Walmsley Park** - Aurora, Sheppard, Thomson, O'Donnel. **Underwood Park** - Lorraine, Delphine, McGehan, O'Donnel, Parkinson, Potter, Shearer, Buccaneer. All culverts (May, Sandringham, Beagle) contribute to flooding.		Upgrade pipe system in Westminster St		Stream widening
Hendon Park, Allan Wood Reserve - Hendon, Valonia properties at risk. Large flood plains			Hendon Park Attenuation Pond	Stream diversion and culvert duplication at Richardson Road, designed in conjunction with the new motorway
New North Rd and railway culverts undersized. Large number of dwellings affected.				
If Great North Rd culvert blocked or undersized, a major St becomes impassable. WSL PS near the outlet inundated. 46 Craddock St to low plus stream bank stability. Growth on stream banks slows velocity.		Railway and Newmarket culverts - review options with physical model study. (only New North Rd culvert was upgraded as a result of the physical model studies). Earthbund around Stream at 46 Craddock St. Gabion basket protection to various lengths (some done/not done?)		