A DECADE OF FLOOD INUNDATION ASSESSMENT UNDER CLIMATE CHANGE IN THE AUCKLAND REGION

Matthew D Davis, Auckland Regional Council
Peter Kinley, The Aqua Modeller Ltd
Terry van Kalken and Carl Johnson, DHI Water and Environment
Nick Brown and Jahangir Islam, North Shore City Council
KG Dayananda, Tauranga City Council
Jagath Pathirana, Town of Gawler

ABSTRACT

Increased rainfall intensity and variability due to climate change are projected to increase the risk of flooding and operation of water infrastructure, such as stormwater collection and flood defence systems. Rainfall is a principal input in rainfall-runoff and floodplain delineation studies. This paper chronicles the efforts from 2000 to 2009 to downscale global climate models to local scale rainfall intensities and assess the expected flood inundation under climate change. Existing climate design storms are based on depth-duration-frequency relationships that are documented in the Auckland Regional Council's Technical Publication 108 (TP108). TP108 represents adaptation of the Soil Conservation Service rainfall-runoff method to the Auckland region. It uses a 24-hour nested alternating block centred probabilistic (Chicago) design storm. Twenty-four hour design storms were derived from the climate change rainfall scenarios. Two global climate downscaling exercises were undertaken. In 2000, the global climate models based on the Intergovernmental Panel on Climate Change (IPCC2) were downscaled and combined with extreme value theory to generate depth-duration-frequency statistics for the Albert Park raingauge in Auckland City, the gauge with the longest period of record in the Auckland region. The projected depth-duration-frequencies in 2050 varied from a 29.8% increase at 10-minutes to 16.8% increase at 24-hours as compared to the TP108 1% annual exceedance probability (AEP) storm event. In 2004, global climate models again were downscaled for the Auckland region using IPCC3 scenarios. The analysis included extreme value theory and consideration of atmospheric moisture content. The projected depth-durations varied from existing climate by 16.8% for the 1% AEP storm event for the most probable scenario in 2090. The most probable scenario for rainfall and sea level rise were simulated in a number of catchments in the Auckland region using DHI Water and Environment software (MOUSE, MIKE-11, MIKE-21 and MIKE-FLOOD): (1) three highly urbanised, small residential and industrial catchments in Auckland City, (2) a medium sized residential catchment that is developing with generally larger individual property sizes in North Shore City, and (3) a larger, mixed land use (predominantly rural) in the Papakura Stream catchment that bisects Papakaura District Council and Manukau City Council. The studies show mixed response in predicted flood inundation under climate change. Predicted flood levels remained largely the same in two of the Auckland City study areas, principally due to the relatively steep nature of the catchments, lack of storage and quick rainfall-runoff response. In the Papakura Stream, simulations of updated climate change intensities for 2090, predict an expansion of the expected floodplains at lower extreme rainfall events (10% and 20% AEP) yet similar floodplains at higher AEP rainfall events (1% AEP). However, simulations of Lucas Creek and Onehunga predict a marked increase in the floodplains in the flatter portions as compared to the existing floodplains. Overall, the findings debunk the general understanding that future climate rainfall translates into more extensive flood extents in every case. The implications for future climate rainfall is that it must be assessed carefully and systematically, and considered together with land use, drainage infrastructure, and the provision of the level of service desired (e.g., provision of primary stormwater network and protection from extreme events). Sea level rise was considered but is not reported herein.

KEYWORDS

Flood inundation, rainfall, runoff, climate change, modelling, depth-duration-frequency, TP108

INTRODUCTION

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extend period of time, which can be determined through using statistical tests, for example. The Intergovernmental Panel on Climate Change (IPCC) found that the temperature increase is widespread over the globe (Bernstein et al. 2007). The observed warming, furthermore, has been linked to changes in the large scale hydrological cycle, including increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. In addition, rainfall changes show substantial spatial and inter-decadal variability (Bates et al. 2008). Two main factors causing climate trends on decadal scales or longer are the Interdecadal Pacific Oscillation and the enhanced greenhouse effect (Salinger et al. 2001). The increases in rainfall intensity and variability are projected to increase the risk of flooding and drought in many areas. Moreover, the climate changes are expected to affect the functioning and operation of existing water infrastructure, including stormwater collection and flood defences (Bates et al. 2008).

To plan for the future climate and infrastructure requirements, the regional council and local councils in the Auckland region have undertaken flood inundation studies that consider climate change. Rainfall is a principal input in the rainfall-runoff and floodplain delineation studies.

In this paper, climate and heavy rainfall is first discussed, followed by description of climate change and extreme rainfall. The model platforms used in the case studies are explained next. Case studies are summarised prior to a general discussion and conclusions. The case studies are: (1) three highly urbanised, small residential and industrial catchments in Auckland City, (2) a medium sized residential catchment that is developing with larger individual parcel sizes in North Shore City, and (3) a larger, mixed land use (predominantly rural) in the Papakura Stream catchment that bisects Papakaura District Council and Manukau City Council. The case studies demonstrate the evolution over the past ten years in the understanding and ability to downscale global climate models and climate change scenarios to the local scale and fine time resolution (i.e., 5-minutes) and to map predicted floodplains.

Climate and heavy rainfall

The climate in the Auckland region is warm temperate. Surrounded by ocean, land temperatures are largely controlled by sea surface temperatures. The mean annual temperature varies between 15 and 16° C. The heaviest rainfall occurs with warm moist north to northeasterly wind flow over the Auckland region when there is a 'low' (depression) to the north or northwest of northern New Zealand, and a slow moving anticyclone to the east. These flows can produce about 60 percent of the annual rainfall in any one year. Stormy westerlies also produce rainfall. When the westerlies are strong, they may be accompanied by thunderstorms (Salinger et al. 2001)

Shorter duration rainfall events are often very local because of small scale weather systems such as weather convergence. These can also occur in the northeast airflows, with embedded thunderstorms. Furthermore, the localisation of extreme rainfall reflects the interaction of small scale meteorological phenomena with local orography. Sometimes very localised rainfall occurs mid-afternoon when sea breezes from the main east and west coast sweep inland and converge (Salinger et al. 2001).

Climate change scenarios

The case studies reflect two global climate downscaling exercises that were undertaken to account for climate change. In 2000, the global climate models completed for the IPCC2 were downscaled and combined with extreme value theory to generate depth-duration-frequency statistics for the Albert Park raingauge in Auckland City, the gauge with the longest period of record in the city and region (Salinger et al. 2001). The projected depth-duration-frequencies in 2050 varied from a 29.8% increase at 10-minutes to a 16.8% increase at 24-hours from the existing climate 1% annual exceedance probability (AEP) storm event. In 2004, global climate models were downscaled for the Auckland region based on the IPCC3. The analysis included extreme value theory and consideration of atmospheric moisture content. The projected depth-durations varied by 16.8% for the most probable scenario in 2090 (MfE 2008). Work is currently underway to downscale IPCC4 projections.

Auckland Regional Council's TP108 design storm and climate change

Current climate design storms in the Auckland region are based on depth-duration-frequency relationships that are documented in the Auckland Regional Council's Technical Publication 108 (TP108) (ARC 1999). TP108 represents adaptation of the Soil Conservation Service rainfall-runoff method (NRCC 1985) to the Auckland region. The SCS method is based on a dimensionless hydrograph, developed from a large number of unit hydrographs ranging in size and geographic location (Bedient and Huber 2007). The temporal storm pattern is a nested, alternating block-centred probabilistic (Chicago) 24-hour design storm (ARC 1999).

The temporal storm pattern was normalised based on regional depth-duration-frequency analysis. A rainfall design storm depth at a particular location is derived by combining the normalised regional intensity for a particular duration with a daily rainfall depth for a given AEP event. Twenty-four hour depths for various AEP storm events are provided at 10-mm contours for the Auckland region. An example temporal pattern is shown in Figure 1.

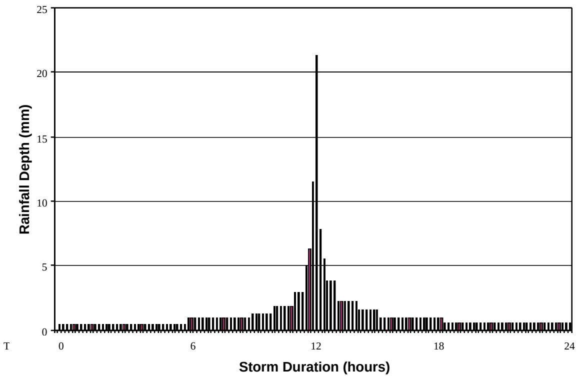


Figure 1. TP108 design storm

The current version of TP108 does not consider climate change (ARC 1999). However, the guideline is undergoing update and will incorporate the latest Ministry for the Environment guidance to account for the most probable rainfall intensity expected in 2090 (e.g., MfE 2008). In 2004, the Ministry for the Environment produced a series of documents to address the lack of guidance to local councils (e.g., MfE 2004). A second edition of guidance was produced in 2008, providing even more explicit instructions to local councils on how to incorporate climate change into planning and assessments (MfE 2008).

To assess flood inundation under climate change, 24-hour design storms were constructed using the storm shape from TP108 with future climate scenarios. The predictions by Salinger et al. (2001) were provided as depth-duration-frequencies, whereas the Ministry for the Environment (MfE) provided recommendations of percentage increases that were then applied to the existing climate TP108 depth-duration-frequencies (ARC 1999; MfE 2008; Salinger et al. 2001). Salinger et al. (2001) and the ARC (1999) studies pooled different data sets to generate (different) existing climate statistics. Existing and future climate 24-hour design storms are presented in Table 1. Two additional existing and 2050 climate scenario are included in Table 1 that were not simulated yet shown for comparison purposes. For example, the 2050 depth-duration-frequencies computed using the Ministry for the Environment advice from 2008 (MfE 2008) are similar to what was computed as existing climate by Salinger et al. in 2001 for durations less than 2-hours (Salinger et al. 2001). Furthermore, Salinger et al. (2001) projections for 2050 exceed projections to 2090 using Ministry for the Environment advice (MfE 2008) together with TP108 existing climate depth-duration-frequencies (ARC 1999).

Table 1. Representative design storm depth-duration-frequency

	Depth-Duration-Frequency (mm)								
Rainfall AEP (%)	**10 min**	**20 min**	**30 min**	**1 hr**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**
Existing climate (ARC 1999) [a]									
1	20.8	32.0	39.6	56.0	75.6	76.5	116	151	185
Existing climate (from Salinger et al. 2001) – not simulated; shown for reference only.									
1	22.3	35.6	42.6	60.5	78.3	83.6	113	134.8	176.4
2050 Climate scenario (from Salinger et al. 2001)									
1	27.0	45.3	54.4	74.4	90.7	100.8	131.1	146.9	197.7
2050 Climate scenario (derived from MfE 2008 percentage rainfall increase and ARC 1999 storm shape) - not simulated; shown for reference only.									
1	22.5	34.7	42.9	60.7	82.0	82.9	125.7	163.7	200.5
2090 Climate scenario (derived from MfE 2008 percentage rainfall increase and ARC 1999 storm shape)									
1	24.3	37.4	46.3	65.4	88.3	89.4	135.5	176.4	216.1

Note: [a] TP108 rainfall depths in the Auckland region incorporate spatial variability. Values presented are for the Onehunga drainage management area (Auckland City) as an example. The 24-hour depth for the 1% AEP for Mission Bay is 195 mm, Mt Wellington North 200 mm, Lucas Creek 220 mm and Papakura Stream 210 to 240 mm (a larger catchment bisected by various 24-hour depths).

MODEL PLATFORMS

The studies used the DHI Water and Environment software – MOUSE, MIKE-FLOOD, MIKE-11 and MIKE-21 (DHI 2008, 2010a,b,c). Software selection over the period of 2000-2009 demonstrates the principal focus of the individual studies (e.g., primary pipe network system performance and/or floodplain delineation); advances in modelling approaches, software development, and computing speed; and availability of fine resolution topographical data (LiDAR). Earlier models were limited to single software applications (e.g., MOUSE, MIKE-11 or MIKE-21). More recent software advances permit coupling of MOUSE, MIKE-11 and/or MIKE-21 through MIKE-FLOOD.

MOUSE is an urban drainage network model that simulates rainfall-runoff processes and routes flow through pipes and open channels. The hydraulic model is based on an implicit, finite difference numerical solution of basic one dimensional free surface gradually varied unsteady flow equations (Saint Venant) (DHI 2008). MOUSE now is incorporated into the MIKE-URBAN platform (DHI 2010d). MIKE-11 is a one dimension river model, similarly in which flow is routed based on approximate solution to the St Venant equations (DHI 2010a). MIKE-21 is a two dimensional hydrodynamic model. Solutions are determined based on the depth-averaged Navier Stokes equations (DHI 2010b). MIKE-FLOOD is an overarching platform that incorporates MOUSE, MIKE-11 and MIKE-21 modules, which can be drawn upon as appropriate to the study (DHI 2010c).

A variety of hydrologic methods exist within the DHI software. Two methods were utilised in the case studies: (1) Model B and (2) TP108. Model B reflects an implementation of the kinematic wave computation (Mannings equation) for overland flow (DHI 2010d). The surface runoff is computed taking only the gravitational (motivational) and frictional (retarding) forces into account. The runoff hydrograph volume is controlled by the size of the contributing area, the pervious and impervious proportions, and the quanitification of the various hydrological losses (initial and continuing losses). Continuing losses are represented using the Horton loss model. The runoff hydrograph shape is controlled by the catchment parameters: length, slope, and roughness of the catchment surface (DHI 2010a,b). Model B was used in conjunction with the TP108 storm shape and depths as input rainfall. In Lucas Creek, rainfall-runoff was undertaken using the full TP108 methodology (ARC 1999). The hydrological model is used to generate hydrograph timeseries for input into the hydraulic models.

CASE STUDIES

Flood inundation under climate change were simulated in several locations within the Auckland region: (1) three highly urbanised, small residential and industrial catchments in Auckland City; (2) Lucas Creek catchment – a medium sized residential catchment that is developing with larger individual parcel sizes in North Shore City; and (3) a larger, mixed land use (predominantly rural) in the Papakura Stream catchment that bisects Pakaura District Council and Manukau City Council (Figure 2).

The case studies demonstrate the evolution over the past ten years in the understanding and ability to downscale global climate models and climate change scenarios to the local scale and fine time resolution (i.e., 5-minutes) and to map the predicted flood hazards. The first case study in Auckland City was undertaken in the absence of Auckland Regional Council and central government guidance on what to consider or how to undertake flood and coastal inundation studies. Flood studies since 2004 have utilised guidance provided by the central government (MfE 2004, 2008).

Mission Bay, Mt Wellington North and Onehunga (Auckland City)

The first case study was undertaken in three urban drainage management areas within Auckland City in 2004. It assessed flood levels under existing climate versus the most probable 2050 climate scenario (Salinger et al. 2001). Three of 38 drainage management areas in the Auckland City were investigated: Mission Bay (MIS), Mt Wellington North (WELN), and Onehunga (ONE) (Table 2, Figure 3). These areas were chosen on availability of existing models, representation of a spread across the city and capture of some variability in catchment and downstream conditions.

MOUSE models were constructed in each drainage management area (Table 3, Figure 4). The models were not fully calibrated. However, previous flood hazard mapping in Mission Bay and Mt Wellington North were

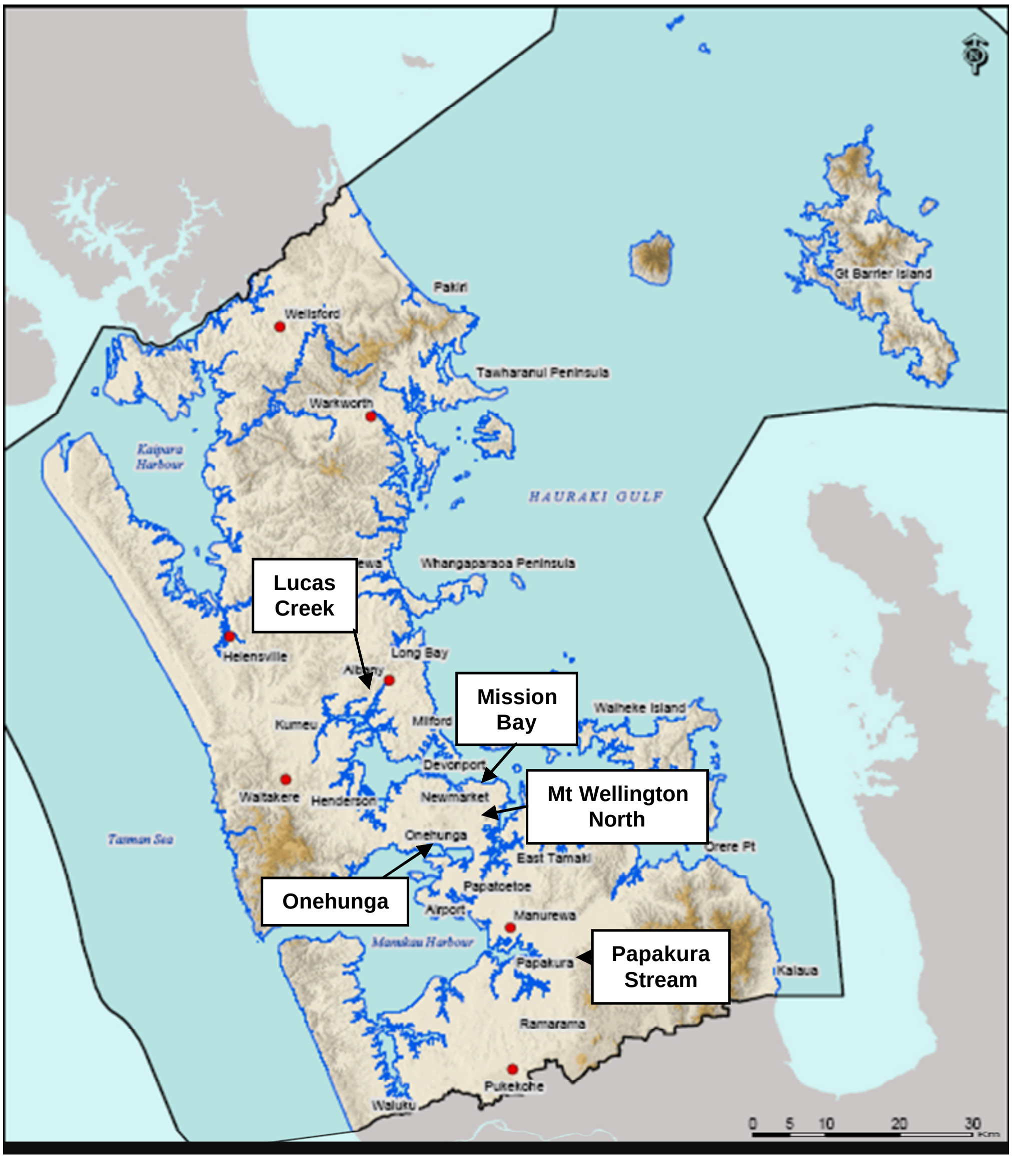


Figure 2. Auckland region and case study locations

Table 2. Auckland City drainage management area characteristics (Davis et al. 2005)

Drainage management area	Area (ha)	Land use	Drainage type	Topography	Receiving environment
Mission Bay	180	Residential; commercial along coastline.	Generally separate stormwater and wastewater with some pockets of combined.	Undulating hills with slope to coastline beach front.	Waitemata Harbour
Mt Wellington North	300	Residential; commercial and industrial lower catchment.	Generally separate stormwater and wastewater.	Undulating hills with slope to Panmure Basin.	Tamaki Estuary
Onehunga (far east sub-catchment)	80 (far east sub-catchment)	Residential upper catchment; commercial and industrial lower catchment.	Generally separate stormwater and wastewater.	One Tree Hill high point and reserve in upper catchment to long flat coastline and fill in lower catchment.	Manukau Harbour

Table 3. Model characteristics (Davis et al. 2005)

Drainage management area	Area (ha)	Modelled sub-catchments	Modelled nodes	Modelled pipe length (km)
Mission Bay	180	217	628	27.5
Mt Wellington North	300	250	1031	39.5
Onehunga (far east subcatchment)	80 (650 total)	12	53	1.8

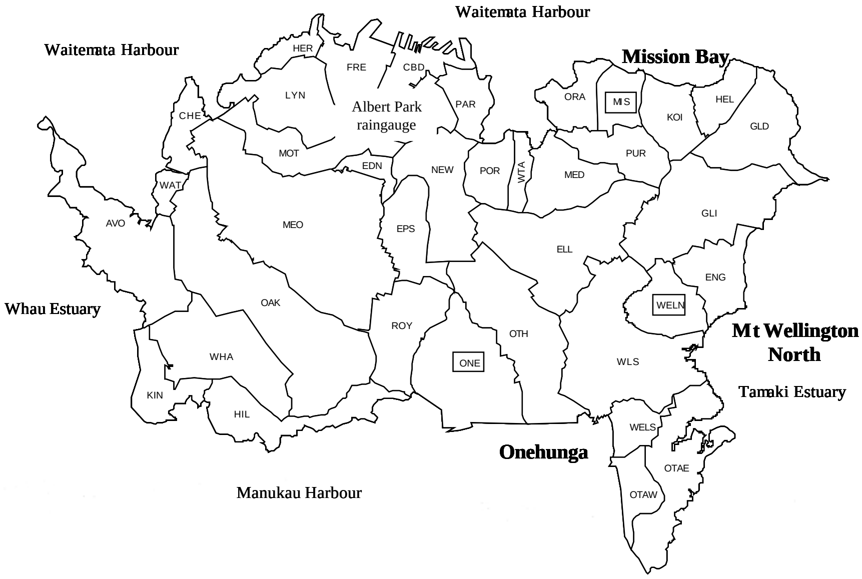
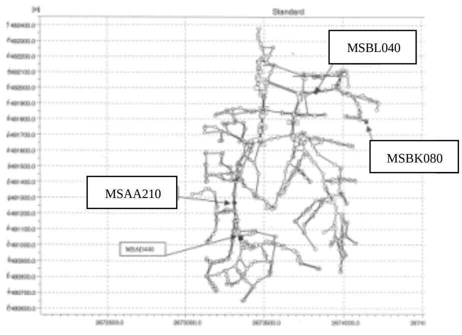
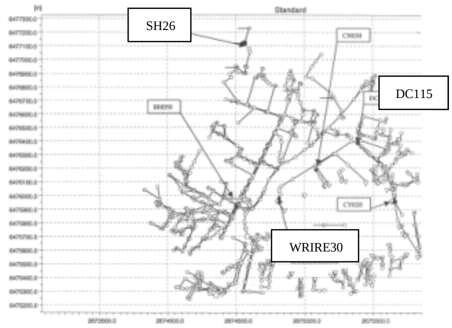


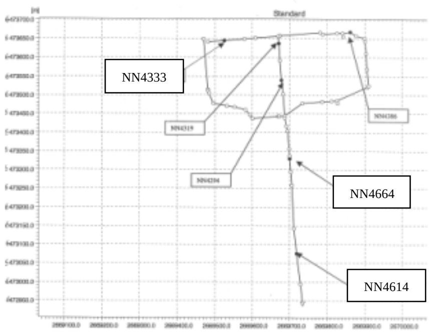
Figure 3. Auckland City drainage management areas and flood study location



(a) Mission Bay



(b) Mt Wellington North



(c) Onehunga (east subcatchment)

Figure 4. Mouse model configuration of flood study areas

qualitatively validated through approximate replication of historical flood events documented in questionnaire surveys and incident reports (City Design 2000, 2001). Furthermore, limited calibration of the Onehunga model was undertaken based on 10-week flow monitoring at mid-catchment to ensure that modelled flows and stormwater levels were reasonable (Davis et al. 2005).

The 10, 2 and 1% AEP design storm events were simulated for existing and 2050 climate scenarios, including design storms for positive, negative and hybrid Interdecadal Pacific Oscillation (IPO) scenarios. The hybrid scenario represents combined maximum depth-duration-frequencies from both positive and negative IPO, or a worst-case scenario (which, however, somewhat overpredicts the total runoff volume) (Dayandanda et al. 2005).

Due to the period in which the models were developed, they are comprised of dual networks, with one representing the underground stormwater pipe network and the other the overland storage and flowpaths. The above ground network depicts surface flow, including inability of water to enter the pipe network, as well as surfacing flow from surcharged pipes. All three models use Model B, using the TP108 storm shape for rainfall as input (Davis et al. 2005).

Overall, only minor flood level differences were observed between existing and future climate rainfall simulations, some of which lies within the modelling accuracy and should not necessarily be attributed to climate change (Table 4). The exception is in the Onehunga sub-catchment, which reflects a substantial stretch of flat, low lying land adjacent to the sea.

Table 4. Selected results (flood levels) of existing and future climate change simulations (metres above mean sea level)

	Model and node								
Design Storm	MIS MSBK080	MIS MSAA210	MIS MSBL040	WELN SH26	WELN DC115	WELN WRIRE30	ONE NN4333	ONE NN4664	ONE NN4614
ARC TP108 - existing	30.6	9.75	3.25	53.5	22.5	14.9	12.5	9.7	6.1
ARC TP108 - 2050 hybrid	30.6	9.80	3.25	53.5	22.6	15.0	12.8	10.0	6.3

MIS = Mission Bay, WELN = Mt Wellington North and ONE = Onehunga.

Lucas Creek (North Shore City)

The Lucas Creek catchment is located adjacent to North Shore City's northern boundary. The catchment is approximately 4.0 kilometres long with a contributing catchment area of approximately 625 hectares. The stream flows approximately northeast-southwest and discharges into the low energy Lucas Creek Estuary that forms part of the Waitamata Harbour, along with streams from eight other stormwater catchments. The majority of the stream network is unmodified; most modification is the result of historical farm ponds, water supply dams, and road culverts.

Lucas Creek has only recently started to develop from rural to residential landuse. The area to the north of the main watercourse is generally steep and area to the south of the main watercourse is relatively flat. The upper catchment is steeply sloped and mostly rural with small pockets of residential and recreational areas. However the catchment is developing at a rapid rate. The catchment land use comprises predominantly residential, and currently the catchment is approximately 20% impervious (NSCC 2008).

A hydrological and hydraulic model of the stormwater drainage network system in Lucas Creek Catchment was developed using MOUSE. The hydrological model was based on TP108 (ARC 1999).

The hydrological model comprises a total of 396 sub-catchments ranging from 0.04 ha to 27 ha with an average size of 1.5 ha. These sub-catchments are connected to 396 inflow nodes within the hydraulic model network linking the hydrological model to the hydraulic model. The Lucas Creek Catchment comprises Group C hydrological soil type that relates to sandstone and siltstones of the Waitemata Formation possesses low infiltration losses. A Soil Conservation Service curve number of 74 was used for developed/undeveloped pervious areas and 98 for impervious areas in the model. An initial abstraction loss of 5mm for pervious area and 0mm for impervious area was used (NSCC 2008).

The hydraulic model network is made up of two main components: the primary system, comprising the formal stormwater system made up of the pipe and open channel network, and the secondary system, comprising the overland flow paths. These two systems are linked by a number of weirs. The primary open channel data was compiled from a combination of the surveyed cross-sections and LiDAR data to replicate channel conveyance and storage. The majority of Lucas Creek and a few minor tributaries used ground-surveyed cross-sections from the most recent North Shore City survey to define the cross-sections used in the model. Between, and beyond the extent of the surveyed data, cross-sections were taken from the LiDAR digital elevation model (NSCC 2008).

Flood impacts were assessed for both existing and future climate change conditions for a range of AEP events. Design rainstorms were based on the Auckland Regional Council's 24 hour nested hyetograph (ARC 1999), with a spatial distribution of total rainfall depth. The future climate change scenario is based on 2090 rainfall, which was adopted for the study using the Ministry for the Environment recommendations (MfE 2008) and codified in the North Shore City infrastructure design standards (NSCC 2009).

The 1% AEP 24 hour rainfall depth for the existing scenario is estimated at 220mm with a peak rainfall intensity of 148.5 mm hr^{-1} (ARC 1999) and for future climate change scenario it is estimated at 257mm with a peak rainfall intensity of 178.2 mm hr^{-1} (NSCC 2009). Future climate change is used as standard for all flood prediction models in North Shore City (NSCC 2009).

Figure 5 shows the maximum flood extent for a 1% AEP storm event for existing and future climate change conditions for the lower portion of the Lucas Creek Catchment. The modelling under future climate change conditions predicts a marginal increase in water level and flood spread along the upper steep main stream but a higher flood spread in the flat areas. The modelling results also shows that the Oteha Valley Road (primary road) is overtopped due to insufficient capacity of the existing 1650mm diameter culvert to pass the 1% AEP design flow for future climate change conditions (NSCC 2008).

Figure 5. Flood hazard in lower Lucas Creek: current and future (2090) climate

Papakura Stream (Papakura District Council / Manukau city Council)

The Papakura Stream catchment is located in South Auckland. The catchment area is approximately 56 square kilometres. The stream system is characterised by a long (stream-wise) and narrow (cross-stream) drainage system with its headwaters in the Whitford forest draining through Brookby Valley, Alfriston, Takanini and discharging to the Manukau Harbour via the Pahurehure Inlet (Opus and DHI 2009b).

The catchment is drained by predominantly natural channels with the notable exceptions of the Alfriston aerodrome area, which is drained by man-made drainage channels following the rural road network, and the Takanini Industrial and residential area, which is drained by reticulated stormwater networks. Both the Alfriston and Takanini drainage systems discharge into the Papakura Stream (Opus and DHI 2009b).

There are a significant number of cross drainage structures located on the Papakura Stream, but there are no formal flood control structures. The cross drainage structures consist of nine single carraigeway road crossings (single-span structures) and the three major transport route crossings: State Highway 1 Motorway, the Great South Road and the North South Main Line Railway (including abutments of the disused railway crossing) (Opus and DHI 2009b).

The catchment land use comprises predominantly rural and forest land use in its upper to middle reaches and predominately urban land use in its lower reaches (known as the Takanini industrial and residential area). A previous report noted that it was apparent that a number of notable pre-1985 flooding issues existed on the catchment which have been significantly reduced since the 1980s (ARC 1993). The literature and local catchment knowledge indicates this is largely due to ongoing channel maintanence works undertaken in the lower reaches of the stream (downstream of Porchester Road) (Opus and DHI 2009a).

Hydrological and hydraulic models were developed to delineate the flood hazard resulting from flooding from Papakura Stream. The hydrological model is a physically-based, lumped, rainfall-runoff model ~ Model B. The hydraulic model is a dynamically coupled one dimenstional (1D)-two dimensional (2D) hydrodynamic model solving the St. Venant equations (1D) and the depth-averaged Navier Stokes equations (2D). The hydrological model is used to generate hydrograph timeseries for input into the hydraulic model. The hydraulic model is used to both route the catchment runoff downstream from the headwaters to the outlet and at the same time map the flood extent, depth and velocities (DHI 2010c). As quantitative flow level data only exists at the Great South Road gauging station, the hydrological-hydraulic model has been validated as a 'lumped' style model against historic flood events (Opus and DHI 2009a).

The Papakura Stream channel, within top of bank, has been represented as a one-dimensional MIKE-11 hydrodynamic flow using cross sections of the main channel to represent the channel properties and details of the cross drainage structures to represent hydraulic structure flow in the channel. The out-of-bank flood flow, originating from the Papakura Stream, was represented as two-dimensional depth-averaged flow using MIKE-21. The floodplain topography was represented by interpolating a detailed LiDAR digital elevation model onto a rectangular model grid. The one and two-dimensional models dynamically were coupled so that flow exchange between the main channel and the flood plain can occur at each simulation time step. Flow exchange between the two models is represented as controlled flow, that is, a weir equation. The hydrological model provides runoff hydrograph inputs to the one-dimensional model (Opus and DHI 2009b; DHI 2010c).

The combined hydrological-hydraulic model has been calibrated against the recorded flood events of February 1985 and May 1985. The pair of events represents summer and winter flood responses in the catchment. The calibration consisted of comparing the gauged water levels and flows to those predicted by the model. Key model parameters were then adjusted to achieve a suitable model calibration. As the only calibration data available was essentially at the bottom of the system, the hydrological and hydraulic models were calibrated at the same time, which is considered 'lumped' calibration. The hydrological parameters adjusted were percentage impervious / pervious to achieve calibration of volume, and stream channel roughness to achieve hydrograph timing and water level calibration. Generally the model was calibrated to the gauge flows and levels for both events. However, there were no recorded floodplain extents recorded during these events to corroborate the floodplain accuracy of the calibration. Consequently, limitations exists with respect to calibration at the local scale, particularly in the upper reaches of the stream (Opus and DHI 2009a)

Flood impacts were assessed for existing and 2090 climate change conditions for a range of AEP storm events. Figure 6 shows the maximum flood extent and depth for a 20% and 1% AEP events for existing and future (2090) climate conditions for a portion of the catchment just upstream of the main urban developed area. The modelling predicts a slight increase in water level and flood spread along the main stream, but with more noticable increases occuring in low lying areas adjacent to the airfield, due to limited drainage capacity on this tributary. Little difference is predicted for the 1% AEP event. Overall, in the Papakura Stream, an expansion of the expected floodplains is predicted at lower extreme rainfall events (10% and 20% AEP) yet similar extent of floodplains at higher AEP rainfall events (1% AEP) (Opus and DHI 2009a).

(a) (b) (c) (d)

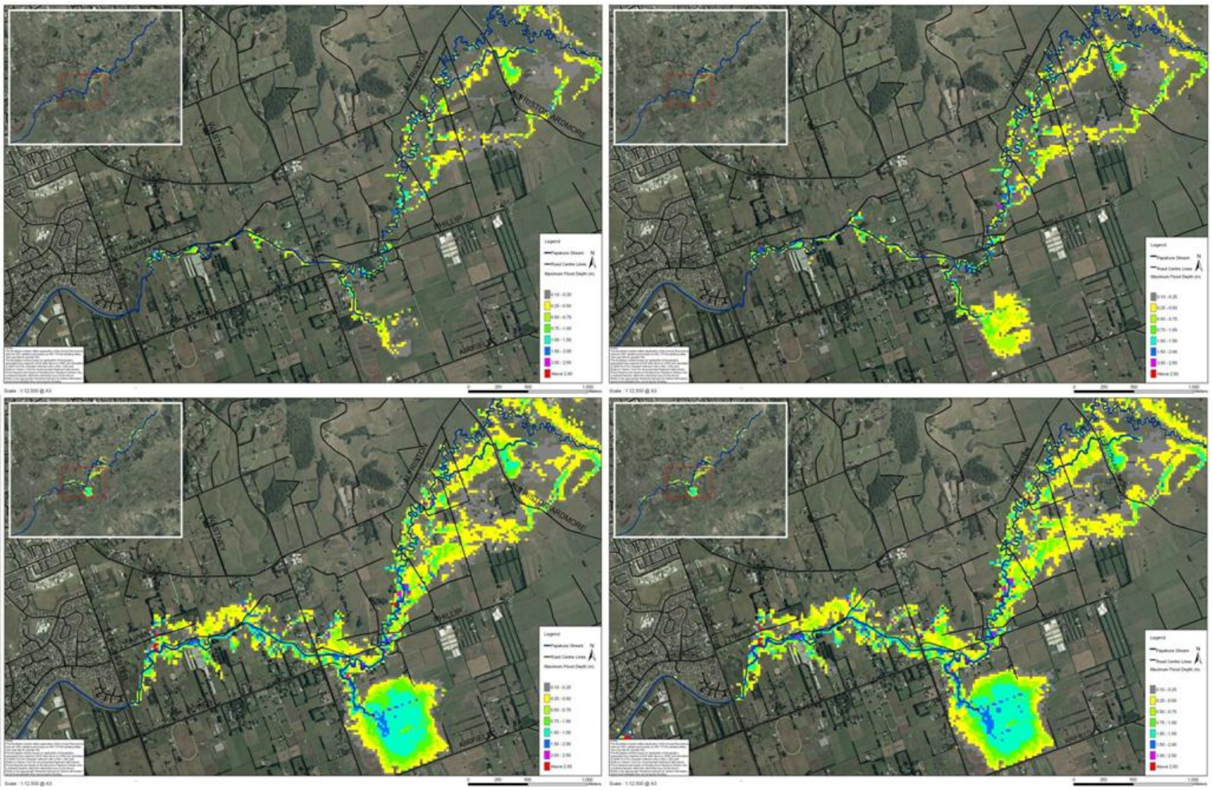


Figure 6. Flood hazards in Papakura Stream: (a) 20% AEP existing climate, (b) 20% AEP future (2090) climate, (c) 1% AEP existing climate, (d) 1% AEP future (2090) climate (Opus and DHI 2009b).

DISCUSSION AND CONCLUSION

The case studies demonstrate the evolution over the past ten years in the understanding and ability to downscale global climate models and climate change scenarios to the local scale and fine time resolution (i.e., 5-minutes). For instance, the first case study in Auckland City was undertaken in absence of guidance from the Auckland Regional Council and central government and whose timeframe extended to 2050 (Salinger et al. 2001), whereas later studies utilised guidance from the central government and projected to 2090 (MfE 2004, 2008) Modelling software advances, data availability and computing speed have permitted moving from establishing a dual network modelling technique (underground and surface) in which some flowpaths must be pre-judged by the modeller (e.g., Auckland City and North Shore City studies) to one that is fully two dimensional and utilises the full set of topographic data (e.g., Pakakura Stream study).

On face value of the results, the implications for floodplain mapping and flood risk when considering climate change to 2050 in Auckland City from the 2004 study are that no adjustment is necessary for increased rainfall depth-duration frequencies in many catchments. Similarly, at 1% AEP, little difference existed for the future climate scenario for the Papakura Stream study. However, within the same study, differences exist between existing and future climate at 20% and 10% AEP, which is important for more common flood events and provision of primary drainage levels of service. Furthermore, in the flat parts of Lucas Creek and Onehunga, differences are apparent for the 1% AEP event.

Overall, the findings debunk the general understanding that future climate rainfall translates into more extensive flood extents in every case. However, what it also shows is that the floodplain response differs depending on the catchment characteristics, drainage infrastructure and storm event of interest. The predicted floodplain under climate change also will be influenced significantly by future land use and drainage infrastructure changes. Consequently, the implications for future climate rainfall is that it must be assessed carefully and systematically, and considered together with land use, drainage infrastructure, and the provision of the level of service desired (e.g., provision of primary stormwater network and protection from extreme events).

While not reported in this paper, sea level rise poses added risk in downstream portions of catchments and must be explicitly addressed. Tidal inundation should be considered in conjunction with surface flooding, including through assessment of the joint probability of tidal and surface flooding (e.g., Opus and DHI 2009a). Last, an additional issue to be cognisant of is that climate change is expected to modify soil moisture.

Consequently, antecedent soil moisture and catchment storage conditions may have significant impact on the catchment rainfall-runoff processes under climate change. This issue will become more important when considering overall rainfall-runoff catchment response that can be analysed through continuous simulation methods (as opposed to discrete event analysis, which was presented in this paper).

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