KAEO RIVER CATCHMENT FLOOD RISK ASSESSMENT AND OPTION ANALYSIS

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ABSTRACT

Kaeo River Catchment located in Northland covers 12,600 hectares of land with a total stream network of 90 kilometres. Flooding of the lower catchment including Kaeo Township has been identified as a significant hazard for many years. Several flood risk reduction mitigation options have been proposed in the past by stakeholders but without any sound technical basis.

The Ministry of Civil Defence and Emergency Management (CDEM) has offered Northland Regional Council (NRC) conditional funding support to help facilitate a long-term solution. One of the conditions is the assistance for Kaeo would be provided in the context of a strategy being developed for long term flood risk by the Northland Regional Council.

NRC, with the assistance of a Kaeo, River Management Liaison Committee, is developing a flood risk reduction/mitigation strategy. This includes development of a floodplain hydraulic model, identification and mapping of the flood hazard and identification and development of potential flood risk reduction options.

The challenge for GHD was to develop a 1D-2D MIKE11/MIKE21 river and floodplain model that provides confidence in the assessment of the flood risk and long term solutions.

KEYWORDS

MIKE FLOOD, MIKE21, LIDAR, EMERGENCY MANAGEMENT, FLOOD HAZARD, AVERAGE RECURRENCE INTERVAL (ARI), 2D MODELLING AND MIKE11 RR.

PRESENTER PROFILE

Habib has extensive professional experience in the field of water resources engineering. This includes extensive knowledge of hydrological analysis of catchment; river and estuary modelling using MIKE 21; river modelling, MIKE 11; stormwater modelling, MIKE FLOOD; stormwater quality management including the preparation of catchment management plans and design of stormwater quality treatment devices. Habib is Team Leader – Stormwater modeling and leads a group of modelers.

Bruce Howse is a natural resource manager currently employed in the position of Land/Rivers Senior Programme Manager with the Northland Regional Council. His professional background is based in natural resource management, with application in river and coastal geomorphology, natural hazard management and sustainable land management.

1 INTRODUCTION

1.1 BACKGROUND

Flooding has been identified as a significant hazard in the lower reaches of the catchment for many years. Northland Regional Council (NRC) has a requirement to

accurately determine these floodplains and determine potential remedial options to mitigate flood risks.
This study aims at developing an integrated model of the entire Kaeo River Catchment including the river system in order to allow an accurate assessment of floodplains in the area. This study will enable NRC to manage future development and to manage remedial options to improve flood protection levels of services.

1.2 CATCHMENT DESCRIPTION

The Kaeo River has a catchment area of 114 square kilometres, with 88 square kilometers of the catchment area situated above Kaeo Township. Waiare Stream, a major tributary of the Kaeo River, drains the eastern and northern slopes of the Puketi Plateau, flowing in a bouldery channel through rolling hill country and an upper basin before passing through the Waiare Gorge. The upper portions of the catchment are steep, reaching a maximum elevation of 456 metres above sea level on Omataroa Ridge Road in Puketi Forest.

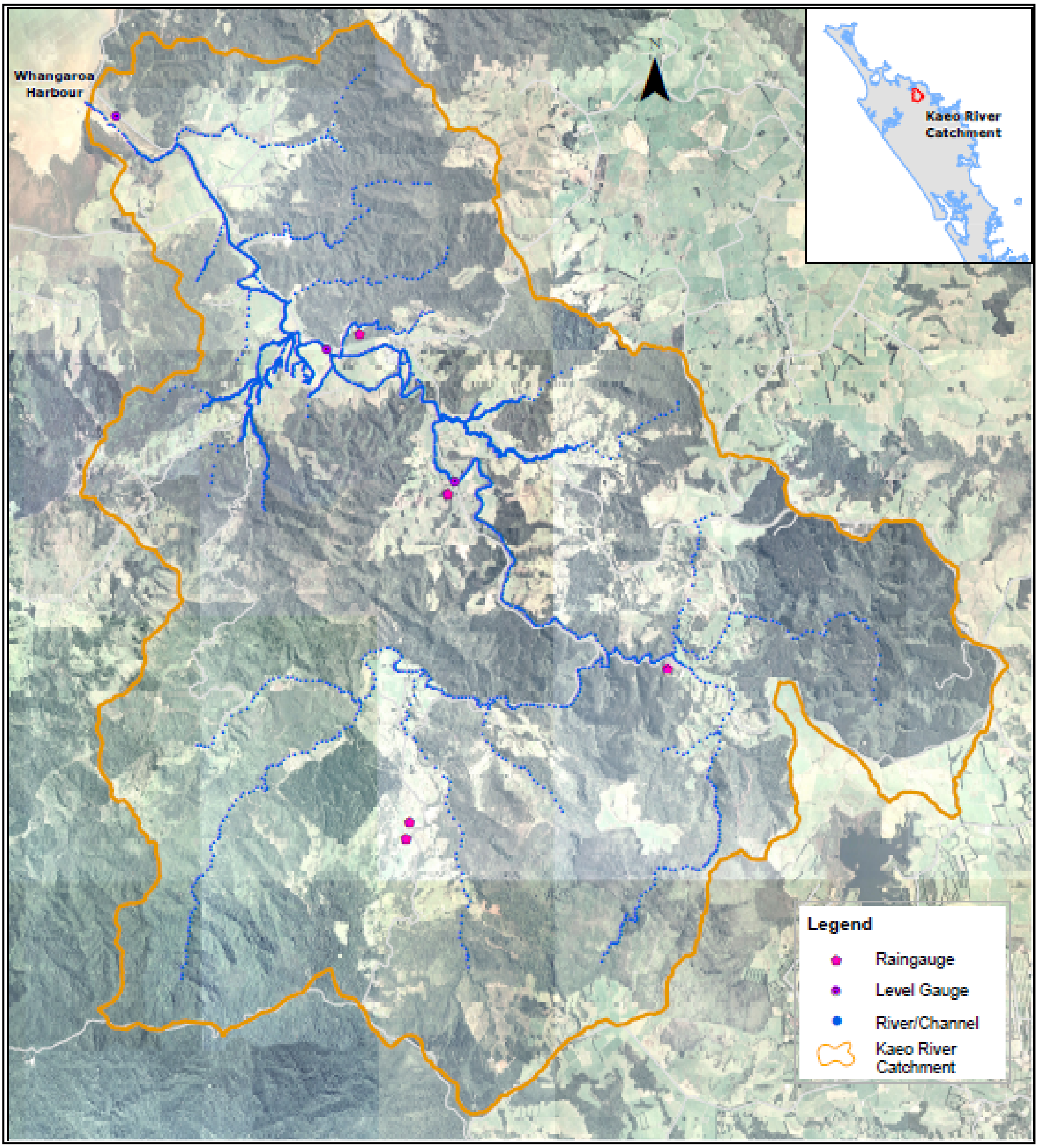
Kaeo River from the Opokorau Road area is joined by Waiare Stream as it emerges from the Waiare Gorge. The upper Kaeo River and its tributaries drain the north-western slopes of the Kerikeri-Waipapa Plateau and the south-western edge of the Taraire Plateau falling over soft shale rocks that have been eroded to produce steep slopes and deeply entrenched gullies. The Kaeo River then flows through a middle basin containing distinct terraces before passing under Waiare Road. Within the middle basin the river is joined by a number of short, steep-graded streams, each of which drops off the Taraire and the Kerikeri-Waipapa Plateau, and off a 300 to 400 metre high range on the western edge of the basin, south of Kaeo township, with high points at Haunga, Te Painga and Ngarahu. The middle basin is separated from the lower valley by a narrow gorge between Waiare Road Bridge and the end of Green Lane.

After emerging through a narrow gap at the end of Green Lane, the Kaeo River flows from just upstream of the schools for approximately eight kilometres on a 500 metre-wide floodplain past Kaeo Township and down to the Whangaroa Harbour. The river is tidal for the last five kilometres and, in the lower basin between SH10 Bridge and the harbour, is stop banked between reclaimed tidal flats.

The Puketi Plateau, at 456 metres above sea level and exposed to weather systems from both the east and the west, receives a high annual rainfall, an average of 2250mm per year with more than 190 rain days. The catchment, particularly the eastern half, is prone to high intensity, short duration rainstorms with over 134mm being recorded in two hours in 1974 and over 180mm in the same time in June 2002. From the severity of slipping and debris avalanches resulting from the July 2007 storm, it is most probable that there were even greater rainfall intensities in a band that tracked from west to east across the lower catchment from Takakuri to Huia.

The Kaeo Catchment along with its river systems are shown in **Figure 1**.

Figure 1 Kaeo River Catchment and its River System



1.3 HISTORICAL FLOODING

The Kaeo Township and surrounding land is subjected to regular flooding from the Kaeo River and tributaries, with a number of historic and more recent flood events documented in early photographs and newspaper reports from as early as 1901.

The two floods of March and July 2007 were unprecedented and extraordinary in the sense that 100 YR ARI rainfall predictions were exceeded twice in the space of four months (Niwa, 2007). These flood events fundamentally shifted the assessed riskscape for this area of Northland.

The March and July two day storm totals for the Kaeo automatic rain gauge were 323mm and 289mm respectively. Rainfall rates during both these storms exceeded the 100 YR ARI estimates. Whilst several river gauges have since been established on the Kaeo River since the 2007 floods, there is no gauged river flow record for these events. The most reliable indication of peak flood flows during these floods is based on flood level data on which the Kaeo computer model has been calibrated. A peak flow of 330 m^3/s has been estimated by the model for the July event, just upstream of the Kaeo Township.

The resulting floods inundated dwellings and commercial buildings, particularly in the township, including the school, and downstream along SH10, Dip Road and the Waikoura flats. The township was inundated both by fast flowing water from the Waikara Creek which runs under SH10, then by much deeper flood water from the Kaeo river. The flood depth on SH10 through Kaeo was approximately a metre deep. Following the March floods, many of the property owners invested considerable sums in repairing the damage and renovation, only for the properties to be inundated once again four months later. The floods in Kaeo caught the attention of the national media, and to some extent, the coverage of Kaeo encapsulated how the floods affected Northland as perceived by the public throughout the country.

Aside from the substantial damage to individual properties, the floods have had more enduring effects for the owners of flood affected property, especially in terms of loss in property value, difficulty of selling property, and in some cases obtaining insurance cover. Even where properties have been raised, potential issues remain given anticipated loss of access to dwellings, and ground level damage, in times of flood. A number of properties damaged by flooding have remained unoccupied since 2007.

The 2007 floods, and high rainfall measured during these events, have also had a bearing on the assessment of flood risk, not only for the Kaeo catchment, but along the East coast of Northland generally. Recent revisions to the NIWA HIRDS database also show marked increases to predicted rainfall depths along the East coast relative to the earlier 1999 version. Although flooding is therefore a known historical risk for Kaeo, the 2007 floods were of overwhelming magnitude and fundamentally shifted the assessed flood risk for this area.

1.4 THE FLOOD RISK

The flood risk in the catchment was assessed by undertaking MIKE FLOOD involving 1-D MIKE11 model for the river system and MIKE21 for the overland flows. The risk was assessed for the 100 year ARI storm event with and without climate change allowances. The flood risks were assessed by generating the following maps:

- Maps showing maximum depth of flooding – these are at the peak but the timing of the peak should be expected to be different at various locations because of the difference in travel time of the subcatchment flow to a downstream location in the river system. The maximum flood depths over the MIKE21 domain (2-D) was obtained from the entire simulation period using post-processing facility of the DHI software packages.
- Maps showing maximum flood elevation - these are at the peak but the timing of the peak should be expected to be different at various points. The maximum elevation over the 2-D model domain was extracted similarly to that of maximum flood depth.

- Maps showing maximum speed – these are the maximums from the entire simulation period. The maximum speed over the 2-D model domain was extracted similarly to that of maximum flood depth.
- Maps showing flood hazard – these are from depth (d) /speed (s) criteria which are based on the following:
  - Low Risk – d x v ≤ 0.5
  - Medium Risk – 0.5< d x v ≤1.0 or 1.0< v ≤2.0
  - High Risk – d x v>1.0 or d>1.0 or v>2.0

The Flood hazard classification risk matrix is shown in Figure 7.

Typical maps of level, depth, speed and hazard are shown in the following Figures 2 through 5 for the 100 year ARI storm event with climate change allowances:

Figure 2 Maximum Flood level - 100 Year ARI with Climate Change allowances

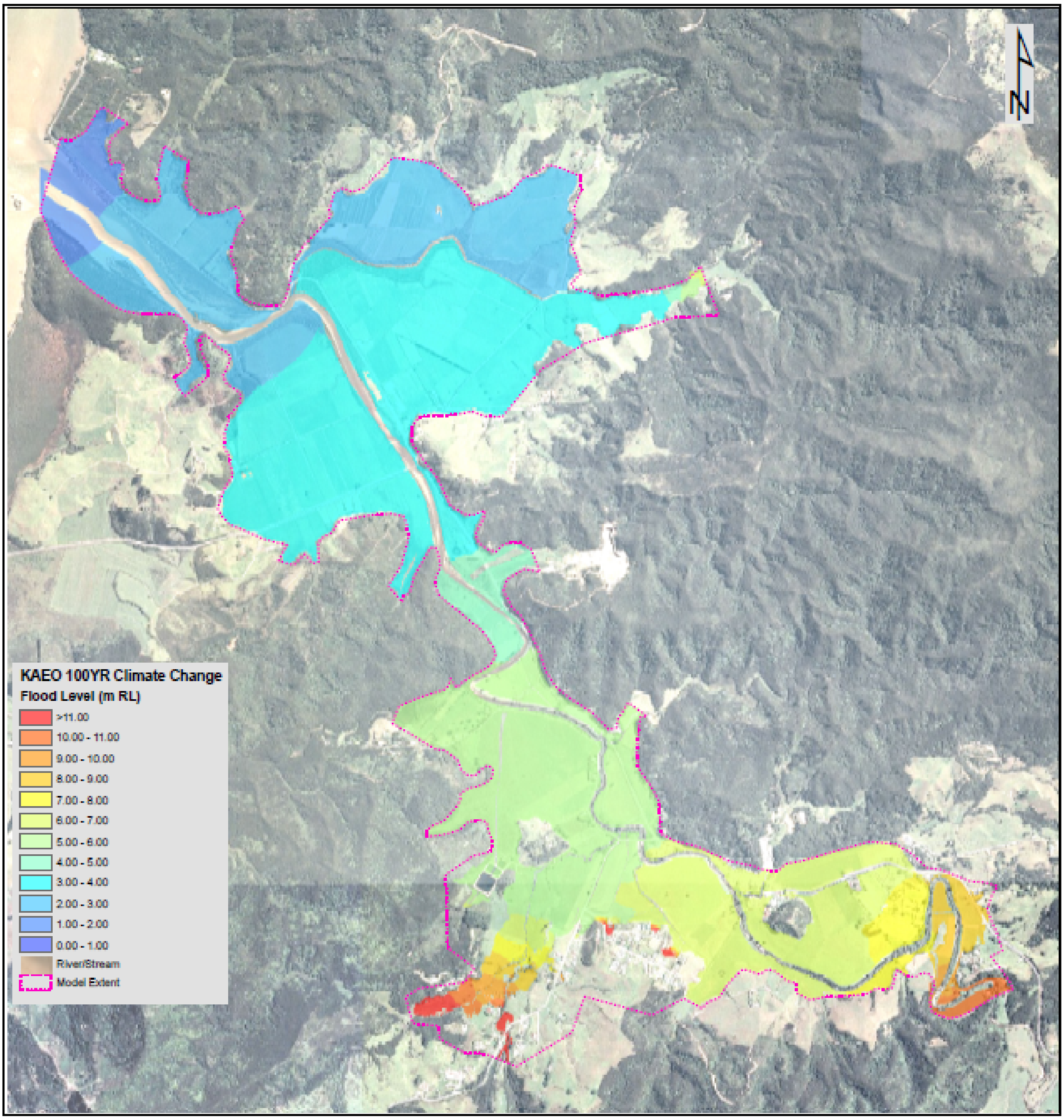


Figure 3 Maximum Flood Depth - 100 Year ARI with Climate Change allowances

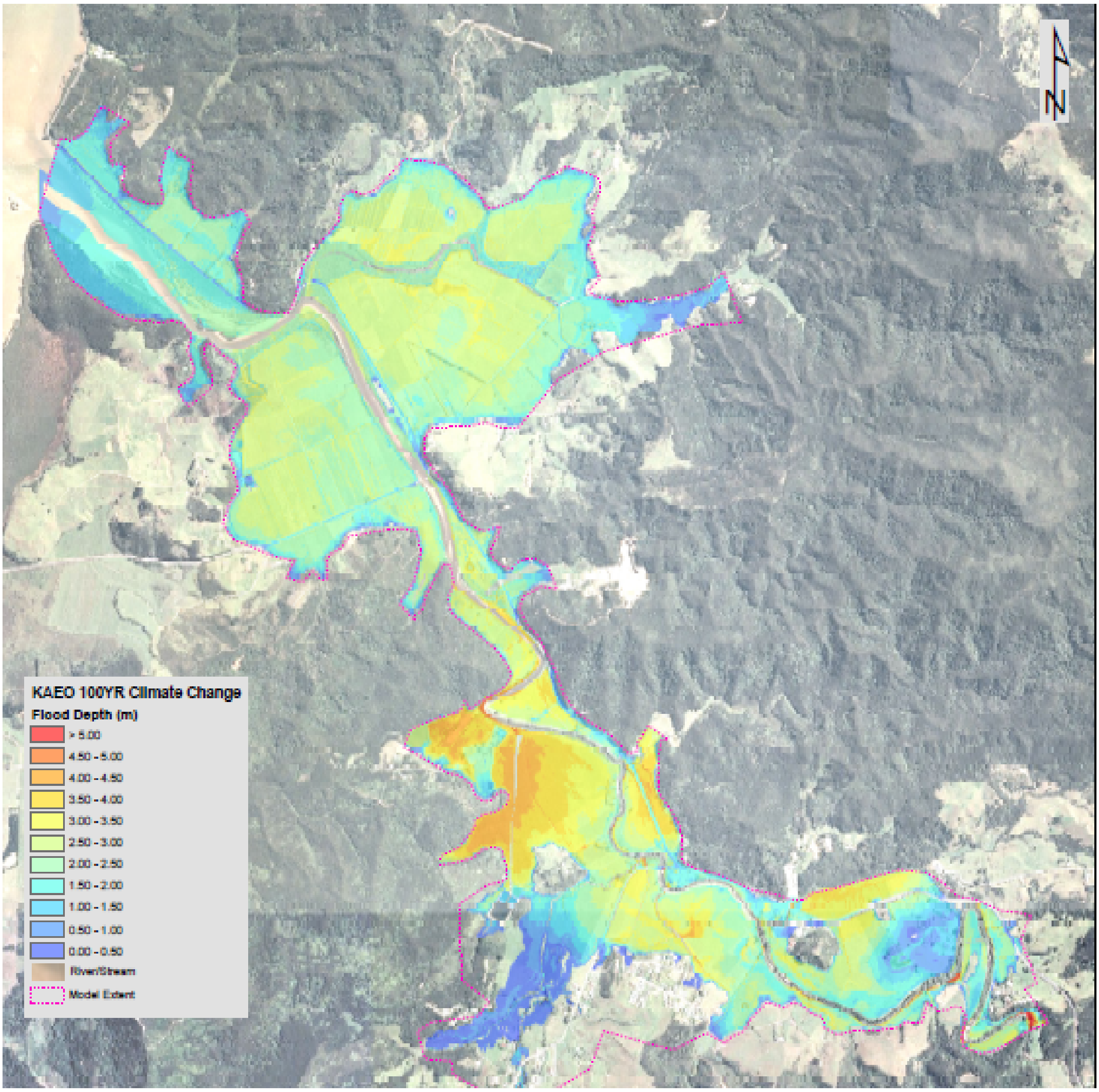


Figure 4 Maximum Speed - 100 Year ARI with Climate Change allowances

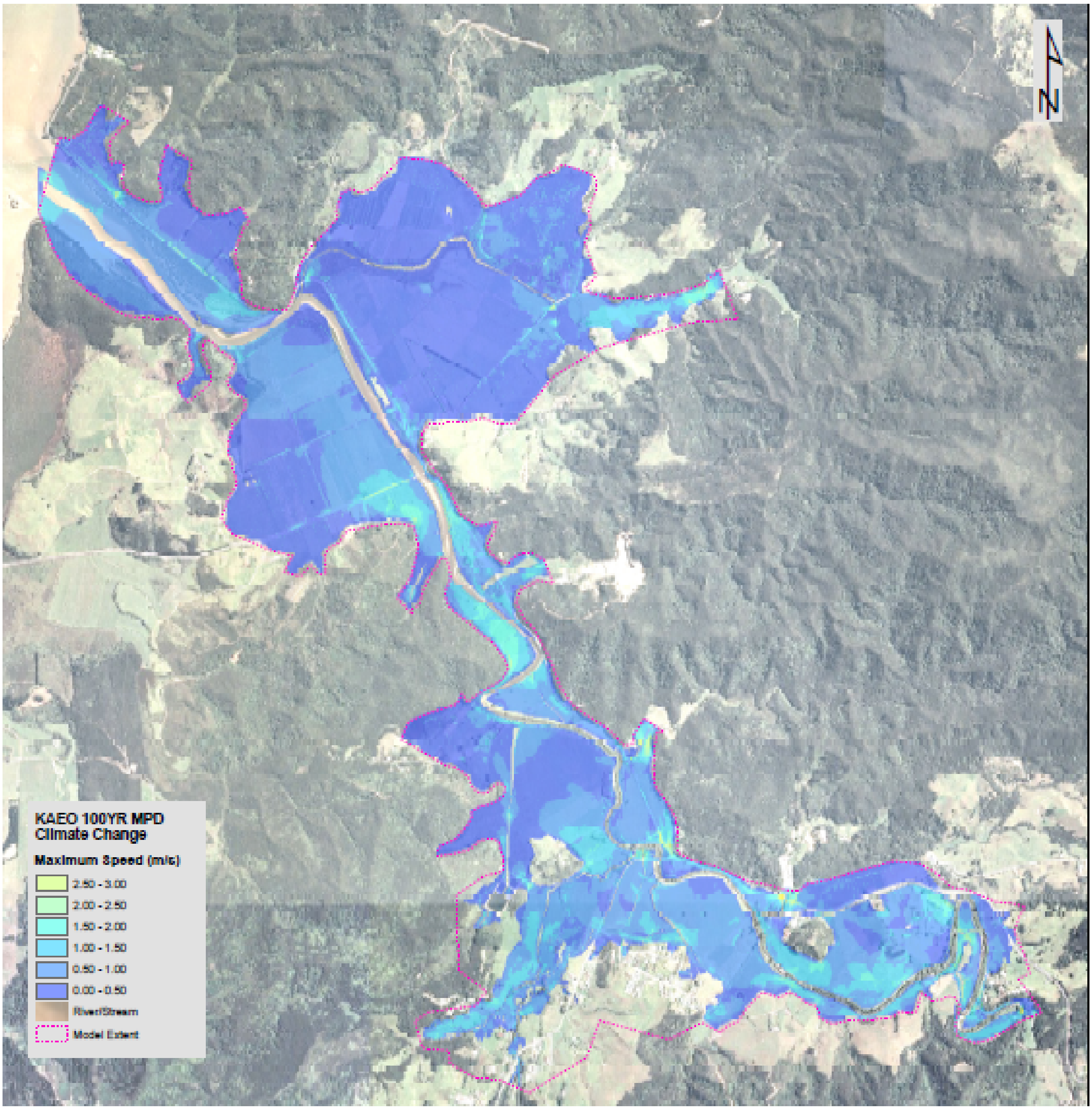
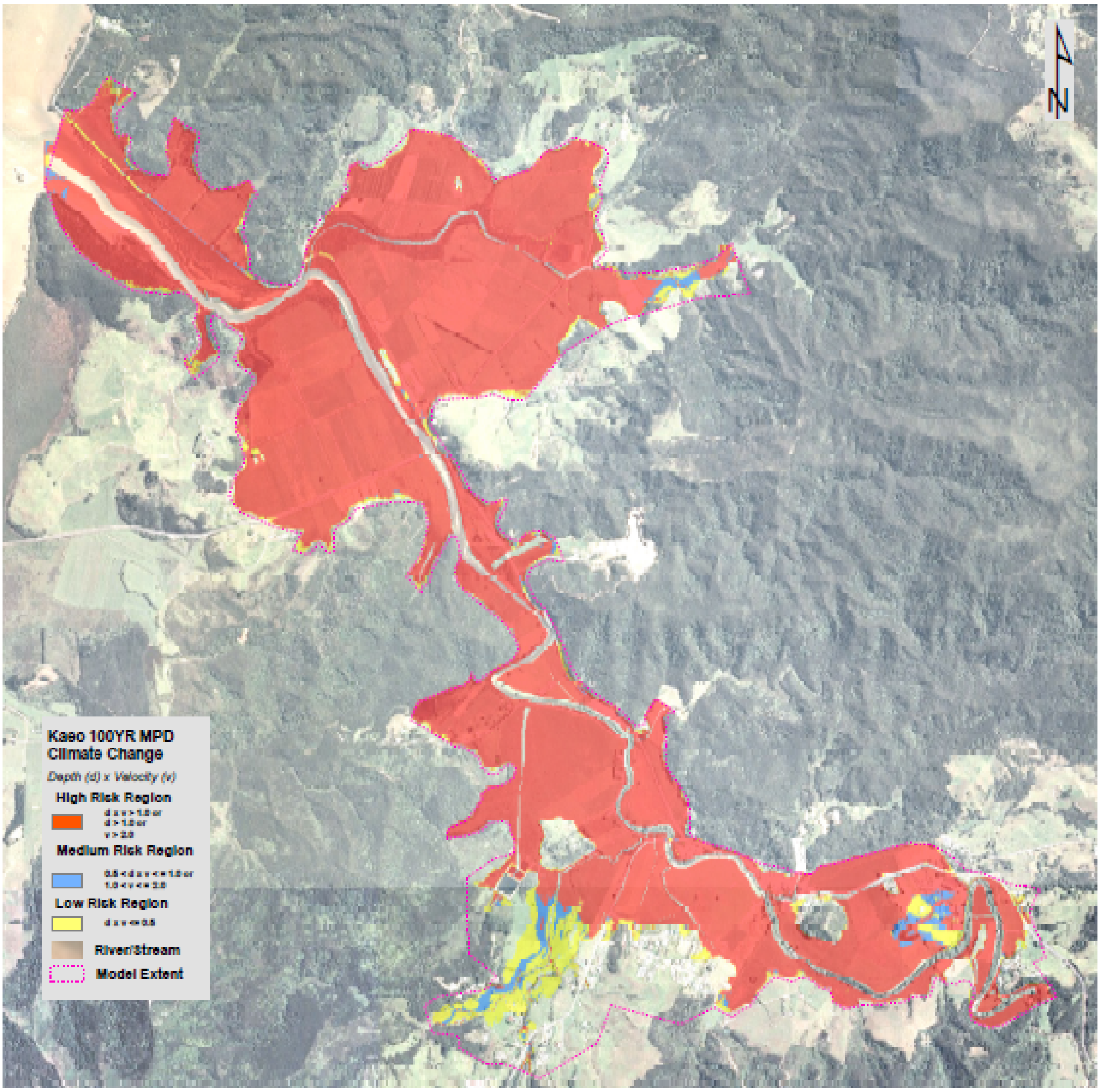


Figure 5 Flood Hazards - 100 Year ARI with Climate Change allowances



It can be seen from **Figure 5** that most of the areas in the lower catchment on both sides of the Kaeo River are at high risk. The lower catchment is quite flat and flood waters from the upper catchment sits here attributing high flood depth as can be seen from **Figure 3**. The high risk in the catchment is attributed either by high flood depth or combination of depth and velocity.

1.5 CENTRAL GOVERNMENT SUPPORT

In November 2008, following the March and July 2007 floods, Central Government offered to provide funding support for the most vulnerable flood affected properties in Kaeo, contingent on the following:

- Assistance for Kaeo would be provided in the context of a strategy being developed for long term flood risk mitigation by the Northland Regional Council.
- The cost of relocating or raising vulnerable houses should be split four ways between the Northland Regional Council, Far North District Council, the home owners and the government.

- The government's one quarter share towards these costs would be capped at $500,000 (GST exclusive).

Prior to this offer of support, the Northland Regional Council had commenced work towards the development of a flood risk reduction strategy for Kaeo. This work included maintenance of the river channel and floodplain and development of a hydrometric network and hydraulic model from which to assess the flood hazard, risk and components of a flood risk reduction strategy.

Utilising the principles of NZS9401:2008 '*Managing Flood Risk - A Process Standard*', a flood risk reduction strategy was developed for Kaeo. Development of the strategy was underpinned by the following key components:

- Community and stakeholder consultation and engagement through the strategy development process.
- Flood hazard assessment, undertaken through hydraulic modeling.
- Flood risk assessment, based on an assessment of the depth and velocity of flood water and the potential for damage to property and loss of life.
- Multi criteria analysis of flood risk reduction options, based on social, environmental, economic, cultural, technical criteria and degree of flood risk reduction, including scenario modeling of options where appropriate.

1.6 NRC OPTIONS CONSIDERED

A range of options to reduce the flood risk were considered during development of the strategy. These included the enhanced status quo (flood warnings and maintenance of the river channel and floodplain), raising buildings on site, flood proofing or relocation of buildings, dredging the river channel, bridge modification and stopbank relocation, flood proofing the township, deflection banks to reduce velocities in the township, development of a flood proofed site for relocation, flood detention in the upper catchment and retreat from high risk areas.

A multi-criteria analysis of the various flood risk reduction options was undertaken to assess benefits in terms of economic cost of works, social impact, cultural impact, environmental effects, technical feasibility and degree of flood mitigation. The analysis was by no means exhaustive, and subject to interpretation, but it enabled a direct comparison of the pros and cons of each of the options and provided an effective way of demonstrating to stakeholders the relative merits of each option during development of the strategy.

1.7 FLOOD RISK REDUCTION STRATEGY DEVELOPMENT

The development of the flood risk reduction strategy, utilising outcomes from the analysis of the flood hazard, risk and flood mitigation options assessment, was based on the principles of:

- Reducing risk caused by flood hazards as low as reasonably practicable in the circumstances that exist.
- Improving the understanding of flood risk (by and to individuals, communities, and local and central government).
- Enabling society to function in the confidence that the risks are well managed.

Six main components were identified for development in the flood risk reduction strategy as shown in Table 1. These components are consistent with the key elements of NZS 9401:2008. The status of these components is varied with some completed, some ongoing and others requiring further refinement and completion during implementation of the flood risk reduction strategy.

Table 1 Key components for development in the flood risk reduction strategy

No	Component	Objective
1.	Community and stakeholder engagement	Improved understanding and management of flood risk
2.	Remedial river works	Reduce risk from smaller floods
3.	Identify and assess risk	Informed decision-making
4.	Flood warning and community response plan	Reduce risk from all floods, manage residual risk
5.	Long term risk reduction	Reduce risk long term
6.	Risk management policy	Avoid creating future/ additional risk

A summary of each of the components developed in the flood risk reduction strategy is provided in the following.

1.7.1 COMMUNITY AND STAKEHOLDER ENGAGEMENT

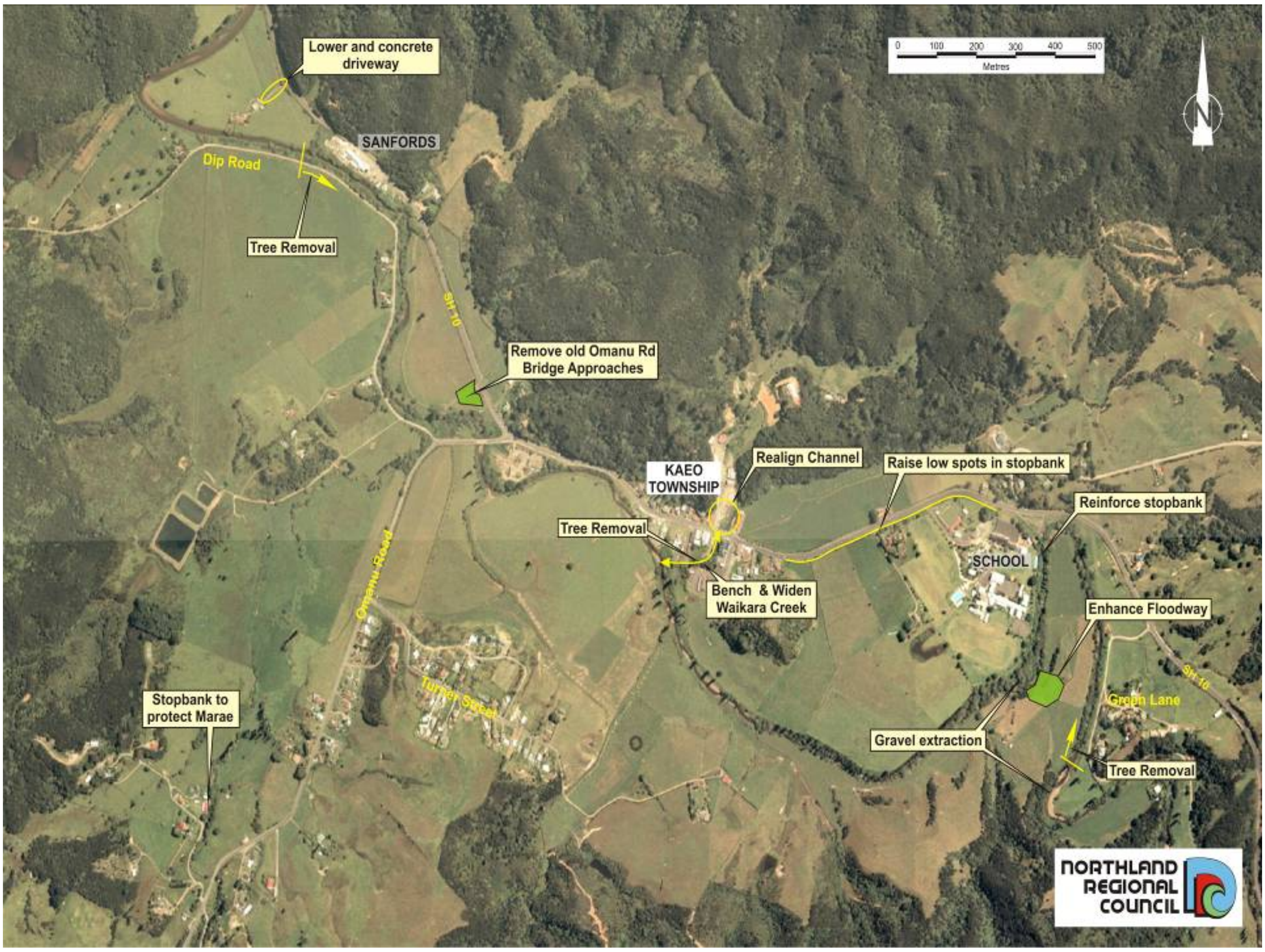
In 2008 the Kaeo River - Whangaroa Catchment Management Liaison Committee was established to provide a forum for community and stakeholder engagement. Ongoing engagement has been undertaken with the Committee to assist in the development and implementation of the flood risk reduction strategy. The establishment of the Committee has facilitated wider stakeholder engagement and has improved the communities understanding of the flood risk and management.

1.7.2 REMEDIAL RIVER WORKS

Significant physical works have been undertaken in the past and in recent years to reduce flood risk from the smaller more frequent floods. The cost of these physical works has amounted to more than $540,000 during 2007 to 2009. These works are ongoing.

These works have focused on maintaining the efficiency of the floodplain and river channel to convey floodwaters, and primarily involve the removal of accumulated sediment from the river channel and removal of flow obstructions from the floodplain (See **Figure 6**). Other works include the maintenance of the school stopbank, which requires frequent remedial work due to erosion, and other miscellaneous works.

Figure 6 Locations of Remedial Works undertaken by NRC in the Kaeo Catchment

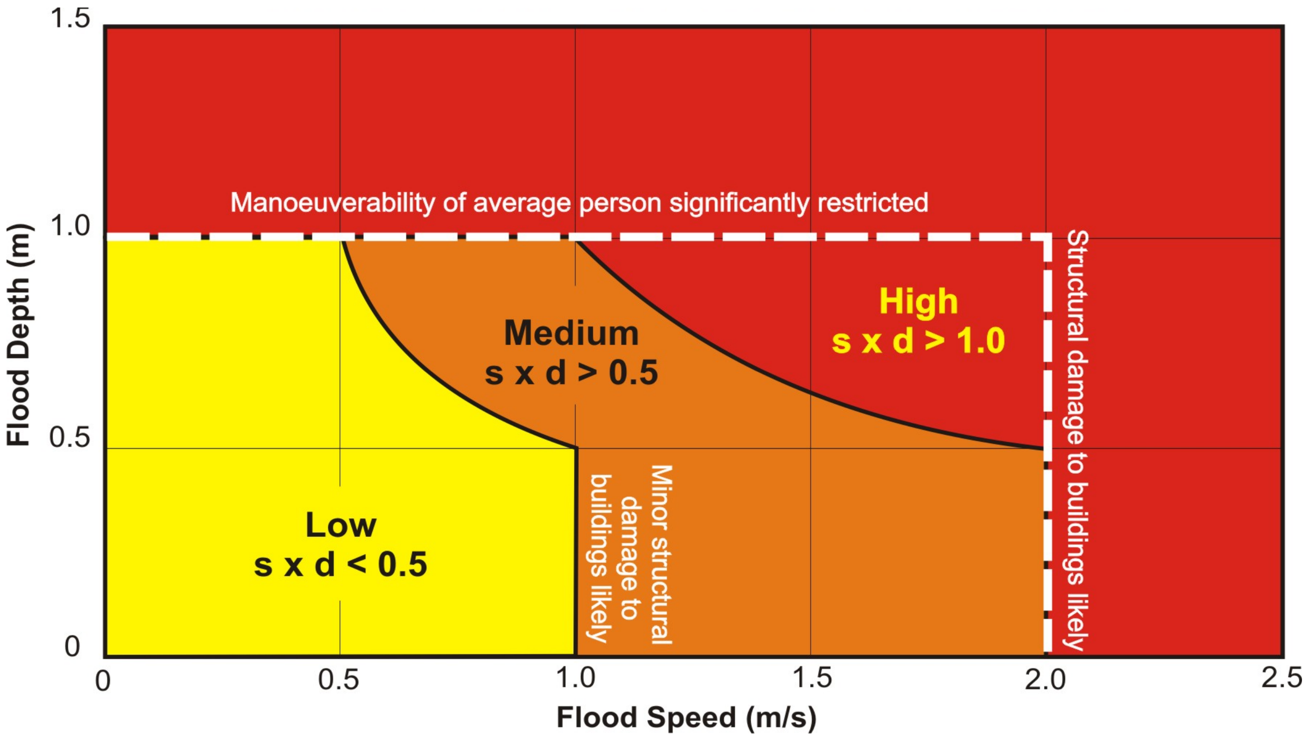


1.7.3 IDENTIFY AND ASSESS RISK

The risk from flooding was assessed based on the depth and speed of flood waters, utilizing a flood hazard classification matrix (See **Figure 7**) which was applied to hydraulic modeling results to produce flood hazard maps.

The flood hazard has been shown to be high for the majority of the Kaeo River floodplain, due to the depth and/or speed of flood waters. The risk to the dwellings and businesses occupying the floodplain is also high, with 47 residential, commercial, community or infrastructural assets identified as being located in high to medium hazard zones.

Figure 7 Flood Hazard Classification Matrix



1.7.4 COMMUNITY RESPONSE PLAN AND FLOOD WARNING SYSTEM

A community response plan has been developed with the community by the Far North District Council. The plan aims to enable the community to respond to emergencies and if required, remain self reliant, from identified hazards including flooding.

A flood warning system has been developed utilising the Kaeo hydrometric network to provide a warning to emergency service providers and residents of rising river levels that could lead to flooding. The network also includes a video camera that provides web-based updates of flooding, enabling near real-time observation of flood levels at the river and floodplain, including SH10, immediately downstream of the Kaeo Township.

1.7.5 LONG TERM RISK REDUCTION

Options identified in the strategy for long term flood risk reduction, include:

- Managed retreat or protection works for highest risk dwellings located on the flood plain.
- Flood scheme works, namely stopbanks and deflection banks to reduce flood velocity through the township and to protect the schools from flooding, along with providing a flood proof site that enables for future development/relocation of dwellings and businesses.

The flood scheme works proposed for Kaeo are designed to reduce the depth and velocity of flood waters in the Kaeo Township, protect the schools, improve access to Kaeo during flood events and provides a defended site that enables for future development/relocation of dwellings and businesses.

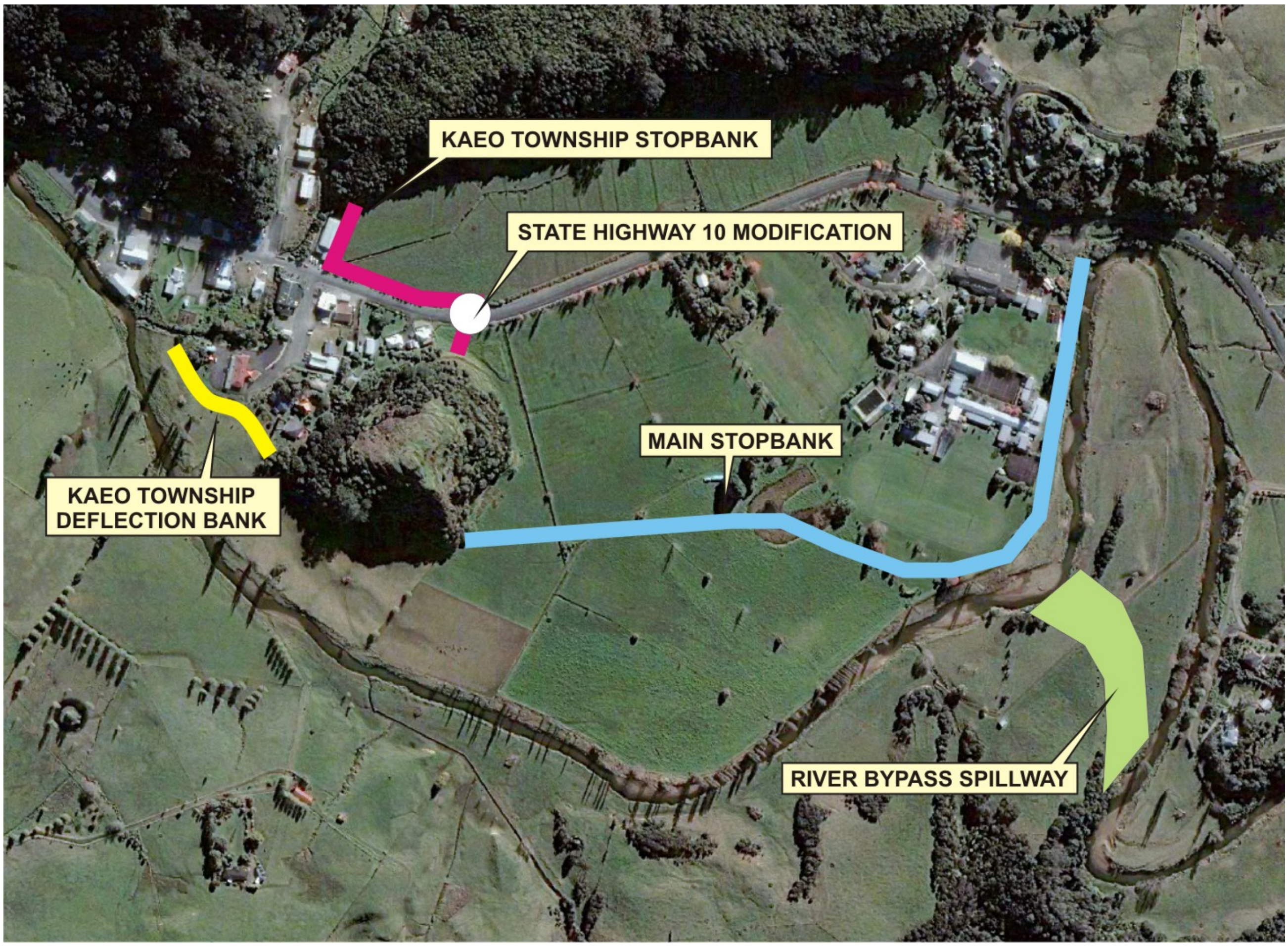
Figure 8 shows the elements of the proposed Kaeo flood scheme works, which are described in the following:

- A stop bank will be constructed immediately east of Kaeo township. This stop bank is designed to reduce the velocity and depth of flood water in the Kaeo Township by preventing Kaeo River flood water from flowing directly through the township and preventing flood waters back flowing into the area defended by the main stop bank.
- A section of State Highway 10, located immediately east of the Kaeo police station, will be raised in height to merge with the proposed township stop bank crest levels.
- A deflection bank will be constructed at a location from near the Kaeo cemetery extending towards the confluence of the Kaeo River and Waikara Creek. This deflection bank is designed to reduce the velocity of Kaeo River flood waters in the Kaeo Township by deflecting flood flow away from the township.
- A river bypass spillway will be constructed to bypass high flows from the river meander adjacent to the school stop bank. This will work to reduce the depth and velocity of flood water adjacent to the existing school stop bank.
- Stop banks and/or a flood wall will be constructed to protect the Whangaroa College and Kaeo Primary School and the eastern approach to the Kaeo Township via SH10. This will involve increasing the height of the existing school stop bank. In conjunction with this, a new stopbank will be constructed from the southwest extent of the school stop bank extending to the base of Pohue Pa. This will form a continuous stop bank that provides an area protected from river flood waters.

The benefits of the proposed Kaeo flood scheme have been assessed through scenario modelling. The benefits of the proposed scheme include:

- Reduction in the depth and velocity of flood waters in the Kaeo Township by up to 0.25 m and an average of 0.5 m/s - 1.0 m/s respectively, by diverting flood water from the township. The works also act to reduce the depth and velocity of flood waters adjacent to the existing school stop bank.
- Whangaroa College and Kaeo Primary School are defended from river flood waters to a 1% AEP CC design standard. Flood modelling indicates that the proposed works reduce flood depth behind the enclosed stop bank area by up to 3.5 m.
- The land between the township and the schools is defended from river flood waters to a 1% AEP CC design standard, which enables an area of protected land that could be developed in the future to enable relocation of assets from the floodplain.
- The works enhance security of access to the Kaeo Township from south via State Highway 10, with only localised overflow across the highway, in the area immediately south of Kaeo, to a depth of less than 0.5 m during the 1% AEP CC flood.

Figure 8	Elements of the proposed Kaeo Flood Scheme



1.7.6 RISK MANAGEMENT POLICY

Future development within identified flood prone areas of the Kaeo floodplain, that increases risk to life or property, is proposed to be controlled with appropriate planning rules and restrictions based on the flood hazard information.

Clearer policy and provisions for controlling development in flood plains are currently being assessed in the review of the Northland Regional Council's Regional Policy Statement.

2 MODELLING OF THE CATCHMENT

Being a high profile project, high confidence in modelling results was required in this study. The key components of this study were survey of sufficient river cross-sections, use of LiDAR data to generate DTM for 2D model input, sufficient raingauge and flood level information, model calibration and flood hazard mapping. The following sections briefly describe the processes undertaken in the modelling of the catchment.

The hydrology of the catchment has been modelled using the MIKE11 Urban Runoff Module. The hydrological component of the MIKE11 Runoff Model is represented as 186 subcatchments connected to nodes within the river network of the MIKE11 model. Catchments were delineated with consideration of:

- The stormwater network configuration
- Catchment contours – LiDAR and available 5m contours in the area beyond LiDAR extent

- Catchment characteristics
- Property boundaries
- The soil types
- Landuse

The subcatchment size varies from 0.2 hectares to about 440 hectares with only 27 catchments larger than 100 hectares. The larger subcatchments are mainly located at the headwaters in the hilly region of the catchment.

2.1 HYDROLOGICAL MODEL

The catchment runoff was modelled using the MIKE11 Urban Runoff Module. The key features are:

- Runoff rate and volume calculated with the MIKE11 Urban Model B Module
- A separate catchment analysis of pervious and impervious components
- Estimate of areas of different landuse categories
- Subcatchment slope calculated using the Equal Area Method

2.2 HYDRAULIC MODEL

1-D Model: The hydraulic model used was the MIKE11 Hydrodynamic (HD) Module. The key features of the model are:

- Approximately 93 cross-sections were surveyed for model input
- Approximately 460 cross-sections were generated from LiDAR data
- 10 bridges and 2 culverts
- 43 river branches

2-D Model: LiDAR data was utilized to generate grid for the MIKE21 model. To facilitate accurate flood prediction with a reasonable model simulation time considering the desktop computer capacity, grid cell size of 5 m x 5 m were generated for input into MIKE21 model. The 2-D model domain is mainly lower catchment extending from Kaeo School in the south to Whangaroa Harbour in the north.

2.3 MODEL CALIBRATION

No gauge data was available during the development of the model. However, a large number of flood levels were available for the July 2007 storm event. A reasonable match between the observed flood level and predicted flood levels was achieved. The calibrated model was used for flood hazard mapping using design storms.

2.4 FLOOD HAZARD MAPPING

As stated earlier that flood hazard mapping was undertaken for the 100 year ARI storm event for both, with and without climate change allowances. Typical flood hazard maps are shown in **Figure 2** through to **Figure 5**.

2.4.1 SIGNIFICANT FLOODPLAIN AREAS

Significant flooding for the simulated events was found for a vast area mainly in the lower catchment extending from Kaeo School up to the outfall in the Harbour. These areas are quite flat and act as a basin for the runoff arriving from the upper catchment.

2.5 PEER REVIEW OF THE MODEL

Given the potential investment required to achieve a significant increase in protection over the existing scheme design standard, NRC undertook a peer review of the model and from this will be developing a model improvement plan which will have a priority focus on calibration against future flood events and improving the quality of hydrometric data applied to the model. The council has installed five flow gauges at various locations in the catchment as to ensure greater confidence in application of the model for determining effectiveness of scheme upgrade options and design standards in future.

2.6 OPTION MODELLING

Several flood mitigation options were modelled and the key features of the options are briefly described below:

2.6.1 OPTION 1

- Stop bank from SH10 on the east along the Kaeo River bank pass the school and then joining the hill south of SH10 (see Main Stopbank in **Figure 8**).
- Stop Bank from hill pass SH10 and straight to the hill on the northern side.
- Stop bank (Kaeo Township deflection bank as shown in **Figure 8**) from the western side of the hill to the south of SH10 and meeting the high ground

2.6.2 OPTION 2

- The main stopbank as shown in **Figure 8** moved further south along the Kaeo River bank.
- Stop Bank from hill pass SH10 and straight to the hill on the northern side.
- Stop bank (Kaeo Township deflection bank as shown in **Figure 8**).
- River bypass spillway as shown in **Figure 8**.

2.6.3 OPTION 3

- Stop bank as in Option 2 and modification of the Kaeo River along the stopbank.
- Kaeo Township stopbank as shown in **Figure 8**.
- Kaeo Township deflection bank removed.
- River bypass spillway as in Option 2 removed.

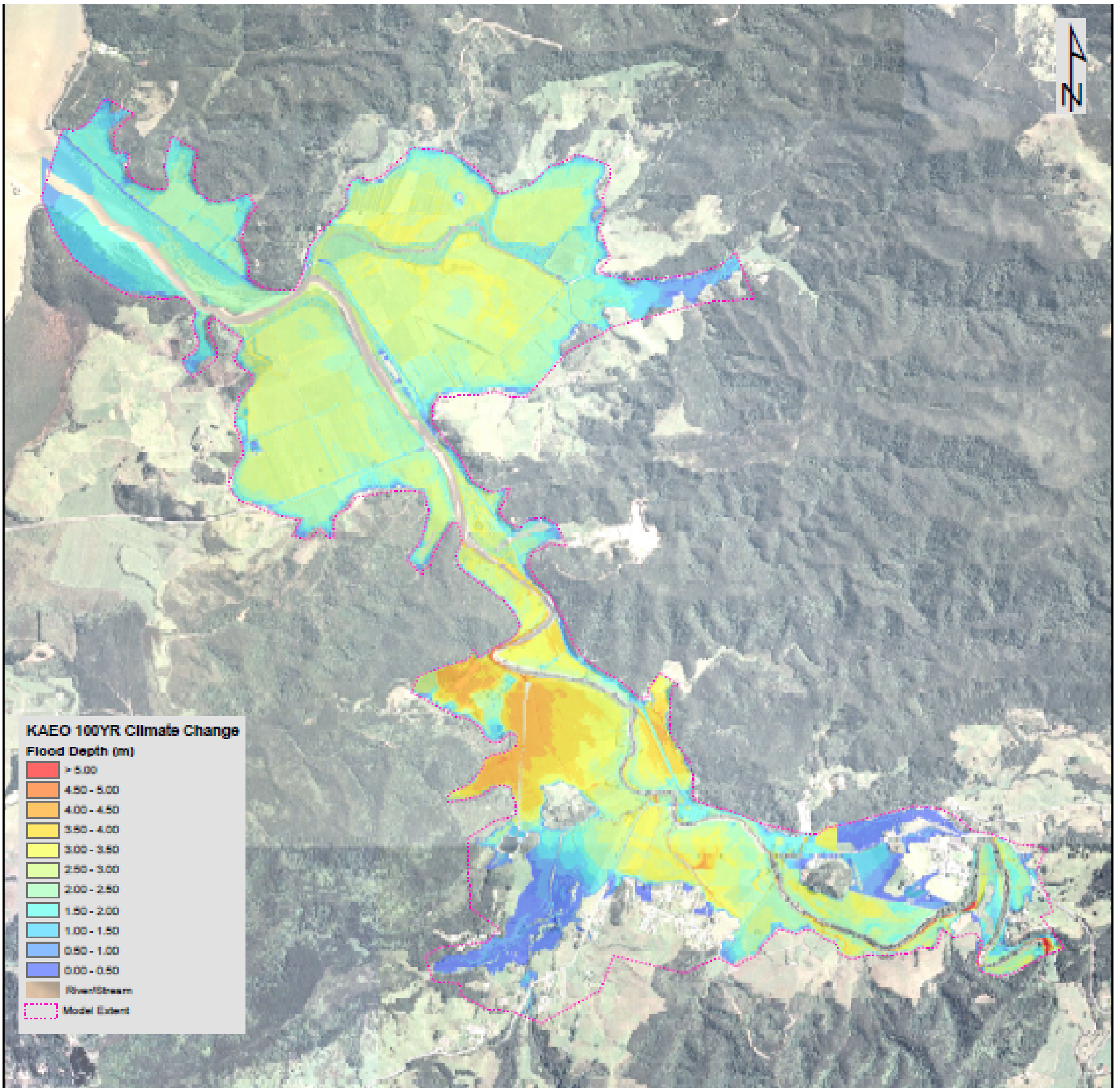
2.6.4 OPTION 4

All the elements as shown in **Figure 8** except the main stopbank along Kaeo River.

2.6.5 RECOMMENDED OPTION

The proposed flood protection scheme mainly consists of Option 2 and some elements from Option 1 and is shown in Figure 8**.** A typical flood depth map for the recommended option is shown in Figure 9 below. When comparing this map with that in **Figure 3,** it can be seen that there is reduced flooding in and around Kaeo Township (**Figure 8** shows location of Kaeo Township).

Figure 9 Maximum Flood Depth for Selected Option – 100 Year ARI with Climate Change



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