Flood risk management research in New Zealand: Where are we, and where are we going?

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Where are we, and where are we going?

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Executive summary

Floods are New Zealand's greatest hazard; both in terms of frequency and continuing losses[1], and in terms of Civil Defence Emergency Management declared events Management. About two-thirds of New Zealand's population lives in areas prone to flooding. But is New Zealand's approach to flood risk management adequate?

The aim of this study was to provide a preliminary analysis of the current state of river flood risk management in New Zealand and identify some current research gaps, which may be important for the guidance of New Zealand's long-term flood research agenda. These issues have been explored by way of literature review, and a brief survey of key informants i.e., researchers and river managers.

This discussion paper first explores existing river flood risk management practices in New Zealand, including the national context for flood risk management such as legislative drivers and key organisations, and looks at regional flood risk management practices. The document then provides a brief overview of research in areas that contribute to the better understanding of flood processes, briefly stepping through climate, flood flows and inundation research and considering complexities of coastal catchments, flood vulnerability studies and research around community awareness of and preparedness for flood hazards. Finally, the document identifies gaps in flood research, and provides ideas for an improved New Zealand flood hazard research agenda.

Intersecting evidence through the report supports the need for further research or development of better tools for the following flood topics/themes (in no particular order):

1. Regional flood frequency estimations – this need has been agreed to by researchers and practitioners for several years but other than updates for some regions previously supported by NIWA's RiskScape funding, it has not progressed any further (i.e., been sustainably funded). It is recommended that a 'maintenance' programme is also established to make sure this work is regularly updated.

2. Geomorphic feedbacks and physics underlying flow and sediment interactions and lags – the complexity of sediment and water interactions during floods requires more basic research and the development of more practical methods to enable prediction of channel changes during floods. Wider geomorphic landscape changes, such as landslides, earthquakes and debris flows, also impact on sediment inputs to channels which can affect flows, and should be better quantified.

3. Joint probabilities – methods for estimating joint probabilities for combined hazards such as the combination of river floods and coastal processes that contribute to coastal and lowland river inundation events need improvement.

4. Vulnerability assessment – improved methods for estimating potential direct flood damage costs are required, such as updating flood-hazard fragility curves for various asset classes. Methods for assessing indirect costs and social costs should be standardised. The current lack of work in this area may be one of the reasons why the consequences of floods in New Zealand are underestimated, and hence not properly weighed in cost-benefit analyses required for decision-making.

[1] It is unclear whether this statement is affected by the impact of Christchurch earthquakes in 2010/2011.

5. Post event impacts assessments – a standardised approach to collecting flood damage information following flood events is essential to build a national picture of impacts and contribute to improved flood fragility curves. The MCDEM has (in 2006) provided a hazard event reporting template (http://www.civildefence.govt.nz/memwebsite.nsf/wpg_url/for-the-cdem-sector-cdem-groups-group-resources?opendocument), but there is potential for a considerable amount of variability in its interpretation and use, and it is not clear how widespread the use of this tool is. Developing a centralised database to hold such data may also be useful.

6. Engagement tools – social science research in the area flood hazard awareness and preparedness should be drawn together to provide good practice methodologies for community engagement, to improve the 'personal responsibility' principle of flood risk management. Such work would complement existing MCDEM *Community Engagement* guidance. Similar work has recently been completed in a MSI funded *Coastal Adaptation to Climate Change* project (Rouse & Blackett 2011) which could be adapted to river flood situations. A potential host for such information is the MCDEM website. While engagement processes are often heavy on time and resources, the benefits to such work should result in decreased clean-up costs following future flood events.

7. Widespread provision of LiDAR data – this need has been identified for the coast in the SIGs research priorities document, and for river floods by practitioners and researchers. LiDAR is a best practice approach to gathering accurate topographic information over wide areas, vital for inundation modelling and mapping, and the assessment of flood vulnerabilities. National co-ordination of this data may be helpful; LINZ may be a suitable lead organisation (perhaps through their National Elevation Data Framework project, see http://www.linz.govt.nz/topography/national-imagery-coordination).

8. Database of GIS flood information – another data related tool that may be useful is a centralised repository for flood related information, to enable river managers to access current good practice information. This could be hosted by the Natural Hazards Platform.

9. Improvements in flood forecasting tools – continuing to improve flood forecasting tools (such as EcoConnect) through validating forecasts and improving their accuracy. This includes all stages of weather (rainfall) forecasts, linked rainfall-runoff predictions, forecasts of sea level, and models of inundation, to improve the ability to forecast at very short time scales.

10. Improvement of flood visualisation methods – for flood forecasting, during event flood warnings, and general public awareness and preparedness, better methods of presenting and visualising flood extent, depth, velocities and damage information are required. This includes visualisation of floods under climate change scenarios.

There are many other ideas for research needs identified in this report, but other front-runners for further work include: methods for understanding super-design floods; methods for monitoring the effectiveness of RMA plan rules on flood risk reduction; developing other tools to better assess the effects of floods; testing different tools to aid decision making in regard to flood reduction options (such as how to define acceptable or tolerable ‘residual’ risk for a community); understanding why certain tools (such as the flood risk management Standard or post event effects templates) are not used by councils; exploring minimum floor level requirements; and the development of advice for considering multiple-source scientific uncertainties in flood predictions when making flood risk management decisions.

It is also worth noting that some tools do exist in many of the above areas, but often they are advanced tools requiring high inputs of data and resources (time), or are still under development or very recently produced by research programmes, and so are not in the realm of the manager/practitioner yet. Further work is needed to produce robust tools suitable for managers use – and interactions between researchers and managers is vital to the success of this information and tool transfer process.

During the compilation of this report, while considering steps towards establishing a nationally consistent agenda for flood research, comments regarding the potential for improving the flood risk management framework were also raised. It appears that flood risk management is subject to similar barriers as found with coastal erosion management (e.g., Blackett & Hume 2011) which include:

- Lack of clear national directive
- Poor representation of national or regional interests in local decision making
- Absence of long term planning
- Power issues in matters of development vs community, and
- Resourcing and information gaps in councils.

Potential steps that might improve flood risk management in New Zealand include:

1. While the RMA allows for the provision of national tools such as National Policy Statements (NPS) and National Environmental Standards (NES), as implemented to date this strategic level of direction is missing for flood risk management in New Zealand. **National direction** using the available RMA tools (NPS and NES as appropriate) would help provide a mandate for issues such as long-term strategic planning for community resilience, and a precautionary approach. However an NPS must allow for regional variability to allow for differences in flood hazard risk issues.

2. In the absence of such direction, **national guidance** should be developed from existing best practice sources (Opus 2001, Tonkin & Taylor 2006, MfE 2010a) and compiled into a single approved guidance (probably requiring endorsement by MfE). This could include development of a ‘toolbox’ of methods for different aspects of flood risk management, building on the MfE *Tools for Estimating the Effects of Climate Change on Flood Flow* guidance (2010a). This may benefit from a 4 R’s approach, and should include work on flood vulnerability and flood awareness and preparedness. A recent move by river managers to develop a New Zealand equivalent of the Australian Rainfall Runoff (ARR) manual could be part of this work. Envirolink ‘Tools’ funding may be appropriate to support some of this work. Guidance should aim to ensure the

mainstreaming of flood (including climate change) risk management into normal planning processes. Such guidance would sit underneath the umbrella principles provided by the current flood risk Standard *Managing flood risk - a process standard NZS 9401:2008*.

3. The concept of **integrated catchment management**, such as how to integrate 'all hazards' thinking with flood risk management, or how to incorporate flood risk management with other aspects of water management (water allocation and harvesting issues, water quality) needs to be explored. Joint probabilities research may help for coastal areas.

4. **Information transfer** between researchers and councils, and between regional and local government, should be improved. One potential avenue is the development of a river flood risk website (the Hazards Platform or the joint NIWA/GNS Natural Hazards Centre would be an obvious hosts). A website could host flood impacts data, guidance materials, LiDAR metadata, and other GIS data identified in the research and tools list above. Funding would be needed to maintain this website. Other methods for information transfer include workshops and training opportunities as discussed in point 5 below.

5. Methods to address the acknowledged **variability in capability (skills) and capacity (resources) at regional level** need exploration. Accessing knowledge from experienced river flood managers and researchers through professional development opportunities is one method to share capability. This may include memberships of group such as the Rivers Group (a Joint Technical Group of IPENZ and WaterNZ; see http://www.ipenz.org.nz/riversgroup/), attending workshops and conferences, and training provided by research institutes or other developers of guidance and tools. Some capacity gaps may be addressed by using Envirolink funding to share advice with eligible councils.

1 Introduction

Floods are New Zealand's greatest hazard (MfE 2008a); both in terms of frequency and continuing losses, and in terms of Civil Defence Emergency Management declared events (see Get Ready Get Thru website http://www.getthru.govt.nz/web/GetThru.nsf/web/BOWN-7GYTNW?OpenDocument). About two-thirds of New Zealand's population lives in areas prone to flooding (Waugh et al. 1997). But is New Zealand's approach to flood risk management adequate?

The aim of this study is to provide a preliminary analysis of the current state of flood risk management in New Zealand and identify some current research gaps, which may be important for the guidance of New Zealand's long-term flood research agenda.

The key question being used to explore this issue is:

• What are the problems and gaps in flood risk management and existing research agendas?

A number of supplementary questions have been developed to further examine this key question:

- What is the flood risk management standard in New Zealand?
- What guidance documents are available?
- What is the current practice at regional and local government level?
- How much do councils draw on the existing national standards and guidelines?
- How do councils source and use scientific research on floods?
- Are there regional differences? Why is this?
- Is there sufficient public awareness? (and preparedness?) about flood risk?
- What research (physical and social) is being carried out that directly contributes to the improvement of flood management?

These issues have been explored by way of literature review, and a brief survey of key informants i.e., researchers and river managers.

This discussion paper first explores existing flood[2] risk management practices in New Zealand, including the national context for flood risk management such as legislative drivers and key organisations, and looks at regional flood risk management practices. The document then provides a brief overview of research in areas that contribute to the better understanding of flood processes, briefly stepping through climate, flood flows and inundation research and considering complexities of coastal catchments, flood vulnerability studies and research around community awareness of and preparedness for coping with flood hazards. Finally, the document identifies gaps in flood research, and provides ideas for an improved New Zealand flood research agenda. An annotated literature review is

[2] For the purposes of this report, floods have been limited in scope to river flooding, not including urban stormwater flooding or coastal inundation due to tsunami or storm-tides.

contained in Appendix A, and the questions asked of researchers, central government managers and regional government river managers are listed in Appendices B and C.

2 Flood risk management in New Zealand

As an island nation, the source of New Zealand's freshwaters is precipitation in the form of rain and snow (Salinger et al. 2004). This precipitation, like all components of our weather, varies markedly in space and time because of our highly varied topographic terrain and our position in the mid-latitudes where we are subject to prevailing westerlies and occasionally to the effects of tropical weather systems (Salinger et al. 2004). This variability in space and time means we can sometimes end up with too much water in one place at one time.

A flood is a discharge in a river or stream that exceeds the capacity of the channel and inundates neighbouring areas of normally dry land (Pearson 1992). We call this natural process a 'hazard' when it has an impact on human lives or property. Floods can have economic, social, and cultural effects on the communities living in floodplain areas adjoining rivers and streams (Smart & McKerchar 2010), as well as environmental effects such as soil and channel erosion and modification of instream habitat (Day 2005a). Since humans were first impacted by floods, they have sought to manage floods to protect lives and property (e.g., Pearson 1992).

Readers are referred to Day (2005a) and Opus (2001) for a summary of the evolution of flood risk management in New Zealand, and Ericksen (1986) for a view from the late 1980's and updated in 2005 (Ericksen 2005a,b). The following section briefly discusses how flood risk is managed in New Zealand today, starting with the legislative context and organisations involved in flood risk management.

2.1 Organisations and legislative context

In New Zealand, the responsibility for identifying and managing the effects of natural hazards including floods is referred to in a number of pieces of legislation (MfE 2008a; MfE 2010b; Opus 2001; Tonkin & Taylor 2006; Glavovich et al. 2010). Four key pieces of legislation are:

2.1.1 The Resource Management Act

The purpose of the Resource Management Act 1991 (the RMA) is to promote sustainable management of natural and physical resources, and the RMA is the principal legislative framework for water management (e.g., Rouse & Norton 2010; Peart 2007). The RMA provides a hierarchical system for resource management, under which central government provides a national overview with tools such as National Policy Statements (NPS) and National Environmental Standards (NES) at its disposal. The RMA devolves authority for water management decision to sixteen regional councils or unitary authorities (in some areas) (Memon 1997; Pyle et al. 2001). The RMA confers certain functions on regional and unitary authorities, such as:

- Section 30 c (iv) to control land for the avoidance or mitigation of natural hazards;
- Section 30 d (v) to control the coastal marine areas (CMA) for the avoidance or mitigation of natural hazards;
- Section 30 g (iv) to control the bed of a water body for the avoidance or mitigation of natural hazards; and

- Section 35 (5) j - duty to gather information, monitor and keep records of natural hazards.

The RMA also confers functions on territorial authorities (TAs, such as district and city councils) via section 31, to control the effects of the use, development, or protection of land for the avoidance or mitigation of natural hazards. This means that TAs have responsibilities for flood risk management (unless powers have been transferred back to their regional council) i.e., they have the responsibility to implement measures to prevent or mitigate flood impacts on development. Section 106 also allows for consent authorities to refuse subdivision consents if they consider that the land is subject to inundation from any source, or if any subsequent use of the land might accelerate or worsen such inundation.

2.1.2 The Civil Defence and Emergency Management Act

Another significant piece of legislation with regard to natural hazards is the Civil Defence and Emergency Management Act 2002 (the CDEM Act). The main purpose of the CDEM Act is to improve and promote sustainable management of hazards, by establishing groups to plan and prepare for emergencies in a co-ordinated way, to achieve a level of risk acceptable to local communities.

The CDEM Act requires local authorities to set up and become members of Regional Civil Defence and Emergency Management Groups, and write Civil Defence and Emergency Management Plans, to enable the purpose of the CDEM Act to be achieved.

The CDEM Act refers explicitly to the need for local authorities to co-ordinate planning, programmes, and activities related to civil defence emergency management across the areas of *reduction, readiness, response, and recovery*:

- **R**eduction of the risk of emergency occurring
- **R**eadiness for emergencies should they occur
- **R**esponse to emergencies when they occur, and
- **R**ecovery from emergencies once they have occurred.

These 4 R's provide a useful continuum for thinking about risk management, and are used below to help structure some of the discussion in this paper. As the 4 R's lie on a continuum, there may be overlap where some activities that councils undertake fall under more than one R. For example, planning activities can help to reduce flood risks, and proactively consider recovery needs (pre-event recovery planning; see Becker et al. 2008).

2.1.3 The Local Government Act

The Local Government Act (LGA) was amended in 2002, and replaced an earlier 1974 version. The purpose of the LGA (LGA 2002 section 3 or 's3') is to provide for democratic and effective local government that recognises the diversity of New Zealand communities. It encourages local authorities in promoting the social, economic, environmental, and cultural well-being (these are known as 'the four well-beings') of their communities, taking a sustainable development approach. The LGA provides a framework and powers for local authorities to decide which activities they undertake and the manner in which they will undertake them. An example of this is the setting of bylaws; if councils choose they can pass bylaws to allow flood works to be carried out on land they own or control e.g., drainage districts.

The LGA requires councils to identify community outcomes and actions to achieve these outcomes through a 10 year work programme, by developing a Long-Term Plan (LTP). In addition to LTPs, the LGA requires councils to develop an annual plan (s95) which contains annual budgets for implementing activities outlined in the LTP. Together, the LTP and annual plan documents clearly state what activities the council will undertake, and what is to be achieved. These public documents in effect make an agreement between the council and its communities as to what work will be carried out. Thus if flooding issues are something that are key to the communities' well-being, the council should plan for the management of these through their LTP and fund any flood risk management activities under the LGA annual planning framework.

2.1.4 The Building Act

The Building Act 2004 (BA) focuses on ensuring the safety and integrity of structures through construction and subsequent use is administered by the Department of Building and Housing, through TAs.

In respect to natural hazards, s71 of the BA requires a building consent to be refused if works are proposed on land subjected to natural hazards, and adequate provision cannot be made to protect the land and buildings from natural hazards. Section 72 of the BA allows for a waiver if the building work does not exacerbate the natural hazard and if it is considered reasonable to grant the consents.

Section E1 under the Building Code (Schedule 1 of the Building Regulations) has requirements for how houses or communal buildings should be built with respect to surface water flooding. In particular performance provision E1.3.2 states that 'Surface water, resulting from an event having a 2% probability of occurring annually[3], shall not enter buildings'.

The BA process is complemented by the RMA process and in some instances a land-use consent under the RMA is required along with a building consent under the BA. Where both consents are issued, the consent which has the more stringent controls prevails.

2.1.5 Organisations

As the above has highlighted, New Zealand's legislative framework for flood risk management allows for a hierarchical structure, and there is also a hierarchy to the organisations responsible for flood risk management.

At a national level, the Ministry for the Environment (MfE) and Ministry for Civil Defence and Emergency Management (MCDEM) in particular have a role in setting national policy for flood risk management approaches. For the RMA, MfE's role is mainly one of policy setting and guidance. Under the CDEM Act, there is a much stronger operational role at national level, and MCDEM have a role in the development of a National CDEM strategy and a national CDEM Plan, as well as producing Director's guidelines for regional CDEM groups to follow.

[3] This is a 2% AEP or 50 year return period flood, see section 3.2

At the regional level, regional and unitary authorities have direct responsibility for policy setting (Regional Policy Statements) and planning (RMA regional plans, LGA plans, regional CDEM group plans), as well as operational roles in managing floods and civil defence emergencies (such as flood warning or civil defence response roles).

At a local level, TAs (district and city councils) have responsibilities under the RMA (district planning, land-use consents), the LGA (LTPs, annual plans) the CDEM Act, and the BA (building consents).

How these organisations ‘do’ flood risk management is explored in section 2.4 below. First though, the organisations involved in flood hazard research and science advice are discussed briefly in the following section.

2.2 Research funding and organisations

2.2.1 Crown Research Institutes and other national agencies

In the reforms of the late 1980s and early 1990s, both the organisations responsible for flood management were changed as regional councils were established, and those carrying out research into floods changed (Day 2005a). Crown Research Institutes (CRIs) were established, and the main CRIs with responsibility for research around natural hazards are the Institute of Geological and Nuclear Sciences (GNS Science) and the National Institute of Water and Atmospheric Research (NIWA). These two CRIs are the main organisations involved in hazard research in New Zealand today, with NIWA the primary agency for research on hydrological and flood modelling and forecasting, and GNS Science on landslides, debris flows and social/planning aspects. Additional research is carried out by tertiary education institutions; particularly the universities of Canterbury, Auckland, Victoria University of Wellington, Waikato, and Massey. A number of resource management or engineering consultancies also undertake research and consultancy work regarding river floods.

One of the main sources of funding for floods research is via central government through the Ministry of Science and Innovation (MSI; formerly the Foundation for Research, Science and Technology or FRST). ‘Hazards and infrastructure’ was one of six priorities under the FRST funding structure and natural hazards are likely to remain a high priority.

According to the FRST website (live until the MSI website is launched in late 2011), the objective of the ‘Hazards and infrastructure research scheme’ is to increase New Zealand’s resilience to hazards; support sustainable urban development, building and infrastructure; and help communities to manage growth and change, mitigate risks and maximise infrastructure efficiency. Measurements of success of this funding will include:

- the effective management of the major hazards faced by New Zealand communities through improved hazard prediction and alert, management and recovery systems and practices, better urban design and development and resilient infrastructure;
- the effective capture and use of data, including human responses, during and after events; and

- improved planning and service delivery by central, regional and local government, private sector organisations, and the community.

The hazards part of the funding is aimed to support research to improve the management of hazards (for example, fire, flooding and earthquake) through hazard prediction and reduction, improving readiness, and emergency response and recovery. Any research funded should support understanding of the physical causes of hazards, the social, economic and cultural factors influencing development of disaster-resilient communities, and the scientific underpinning for risk assessments/simulation models.

This funding is provided through a Natural Hazards Research Platform, a relatively new way of providing long-term funding which is aimed to provide further long-term certainty for scientists, and reduce the transaction costs involved in applying for research funding every two or three years. The Platform encourages a cooperative approach. It is hosted by GNS Science, and includes expertise from New Zealand's leading hazards research organisations.

In 2002, NIWA and GNS Science established The Natural Hazards Centre. Its role is to provide New Zealanders with a single point of contact for the latest natural hazard research, resources, and scientific expertise (see http://www.naturalhazards.net.nz/). Its strength lies in multidisciplinary skills, all-hazard coverage, and resources for delivering world-class research to emergency and resource managers, the science community, planners and policy makers.

The research and services provided by the Natural Hazards Centre cover the major natural hazards in New Zealand, including:

- Coastal erosion and inundation
- Droughts
- Earthquakes
- Flooding
- Landslides
- Snowfall
- Storms
- Tsunami
- Volcanic activity.

One of the key outputs of the Centre, and now the Platform, is the annual Natural Hazards publication. While the Centre's website still exists and has a section to provide links to tools, there are no flood management tools available there at this time. The Natural Hazards Centre has been largely superseded by the Natural Hazards Platform (http://www.naturalhazards.org.nz/). More information from both organisations is found via their own websites:

- NIWA - http://www.niwa.co.nz/our-science/natural-hazards
- GNS Science - http://gns.cri.nz/Home/Our-Science/Natural-Hazards

Recent changes to CRI governance and funding means that each CRI now has a Statement of Core Purpose which outlines why the Government owns CRIs and what it expects from them. In particular, it defines the areas of operation in which each CRI is the lead agency, and those in which it will collaborate with others to achieve the required outcomes. NIWA has one of its core purposes to "increase the resilience of New Zealand and South-west Pacific islands to tsunamis and weather and climate hazards including drought, floods and sea-level change" and for GNS Science to "increase New Zealand's resilience to natural hazards and reduce risk from … landslides and tsunamis". Each CRI also has a Statement of Corporate Intent, which defines their purpose, expected outcomes, scope of operation, and operating principles. This Statement of Corporate Intent sets out the CRI's strategy for delivering against its core purpose over a five year period, but is reviewable annually. These documents are available on CRI websites.

2.2.2 Regional agencies

In addition to this central government research funding, some of the larger regional councils are able to fund their own research, using their own staff or otherwise through focussed projects which are contracted to consultants from CRIs or other private consultancies.

Councils' funding is obtained by a mixture of means, but a major source of funding for most are rates payable by regional residents and property owners.

Another source of funding available to some of the less well funded regional/unitary councils is Envirolink Advice Grant funding or Envirolink Tools funding for all regional/unitary councils (http://www.envirolink.govt.nz/). Envirolink is a regional council driven funding scheme, with funds administered by MSI. Investment funding is available to Regional or Unitary Councils to contract government-funded research organisations to transfer environmental research knowledge, particularly adapting management tools to local needs, and translating environmental science knowledge into practical advice.

The Envirolink scheme's objectives are to:

- improve science input to the environmental management activities of regional councils,
- increase the engagement of regional councils with the environmental RS&T sector, and
- contribute to greater collective engagement between councils and the science system generally.

One of the outcomes of the scheme, through the regional/unitary councils working with a Regional Council Research Co-ordinator, is the development of a Regional Council Research, Science & Technology Strategy (2011) *Research for the Environment*. (This document is used in section 4 of this report as a source of suggested research gaps in flood hazards and risk management).

The Scope of the RS&T Strategy includes:

(a) Research, science and technology that is necessary to support and inform environmental and sustainable management,

(b) Environmental research and relevant hazard research, and also social, cultural, and economic aspects where they relate to the roles and functions of Regional and Unitary Councils,

(c) The recognition and promotion of sciences that go beyond just the physical to incorporate values and societal effects and values and perspectives, and

(d) Science to enable policy issues to be addressed.

2.3 Standards and Guidance

The section provides a brief outline of current standards and guidance in New Zealand for flood risk management.

2.3.1 National level RMA tools

At the time of writing, there is no NPS or NES for river flooding under the RMA. A draft NPS was drafted in around 2007 and a board of inquiry was established, but the NPS process stalled around matters of cost-benefit and the NPS has not been notified (See http://www.mfe.govt.nz/issues/land/natural-hazard-mgmt/board-of-inquiry-flood-management.html).

We note that the recently released New Zealand Coastal Policy Statement (2010) covers the coastal environment, which includes estuaries and intertidal zones. Policy 24 (1) (d) requires, when identifying hazards in the coastal environment, consideration of ‘the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent’. By extension this could include flooding in estuaries and intertidal zones, which includes a consideration of low-land river or creek flooding in those areas (see section 3.5).

2.3.2 Managing flood risk – a process standard NZS 9401:2008

This flood risk management standard was developed by a committee including representatives from central, regional and local government, and published in 2008. The purpose of the Standard is “to provide an agreed best practice approach for local and central government, professionals (planners, engineers, hydrologists, scientists, risk managers, lawyers and so on), developers, utility suppliers, property owners, and communities to ensure that proper consideration is given to all aspects of flood risk when making decisions, so that over the longer term, the risk of flood damage decreases.” The Standard is a voluntary tool that provides a set of principles to help decision making and promote good practice in flood risk management.

The Standard is based on international and New Zealand best practice, and takes a risk-based approach (with reference to the Australia/New Zealand standard for risk management (AS/NZS 4360:2004, which has since been updated). The Standard recommends a decision making process and is not technical, prescriptive or performance based.

The framework underlying the Standard is based on contains five elements:

1. Catchment-based management to provide a natural framework within which to manage the flood risk;

2. Sustainable management to bring natural and social systems together over the longer term to provide a context for flood risk management decisions;
3. Adaptive management to ensure that changes in natural processes, hazards, exposed values, and their vulnerability are identified by monitoring and addressed in a timely manner;
4. Risk management to encourage a wider assessment of strategies and options, anticipation of change, and awareness of residual risks; and
5. Comprehensive risk treatment strategies including reduction, readiness, response and recovery.

There are also six implementation principles:

1. Engaging communities and stakeholders
2. Understanding natural systems and catchment processes
3. Understanding the interaction of natural and social systems, in a catchment-based management context
4. Decision making at the local level
5. All possible forms and levels of management, and
6. Residual risk.

The process for flood risk management from this Standard is shown in Figure 2.1.

It is worth noting that the Standard originates from the draft New Zealand Protocol on Managing Flood Risk published in 2005 (Day 2005b). The Protocol was developed by local government, with help from the Institute of Professional Engineers New Zealand and central government. The Protocol was the local government contribution to a flood review carried out by MfE at the same time (*Meeting the challenges of future flooding in New Zealand,* MfE 2008a).

In original information developed at the same time as the Protocol, an ‘Implementation Planning’ document showed that the Protocol was intended to be an overarching document under which to structure flood research and management. Underneath that umbrella, it was intended to develop implementation guides and modules for a number of flood topics (e.g., catchment management, risk communication etc) intended to provide more ‘nuts and bolts’ guidance on these areas. Funding for the continuation of this work was not forthcoming (T. Day, pers. com.) and the work halted.

2.3.3 Tools for Estimating the Effects of Climate Change on Flood Flow

A key guidance document for local government in regards to flood management in a changing climate is the *Tools for Estimating the Effects of Climate Change on Flood Flow: A Guidance Manual for Local Government in New Zealand.* (MfE 2010a) and its summary publication *Preparing for Future Flooding* (MfE 2010b).

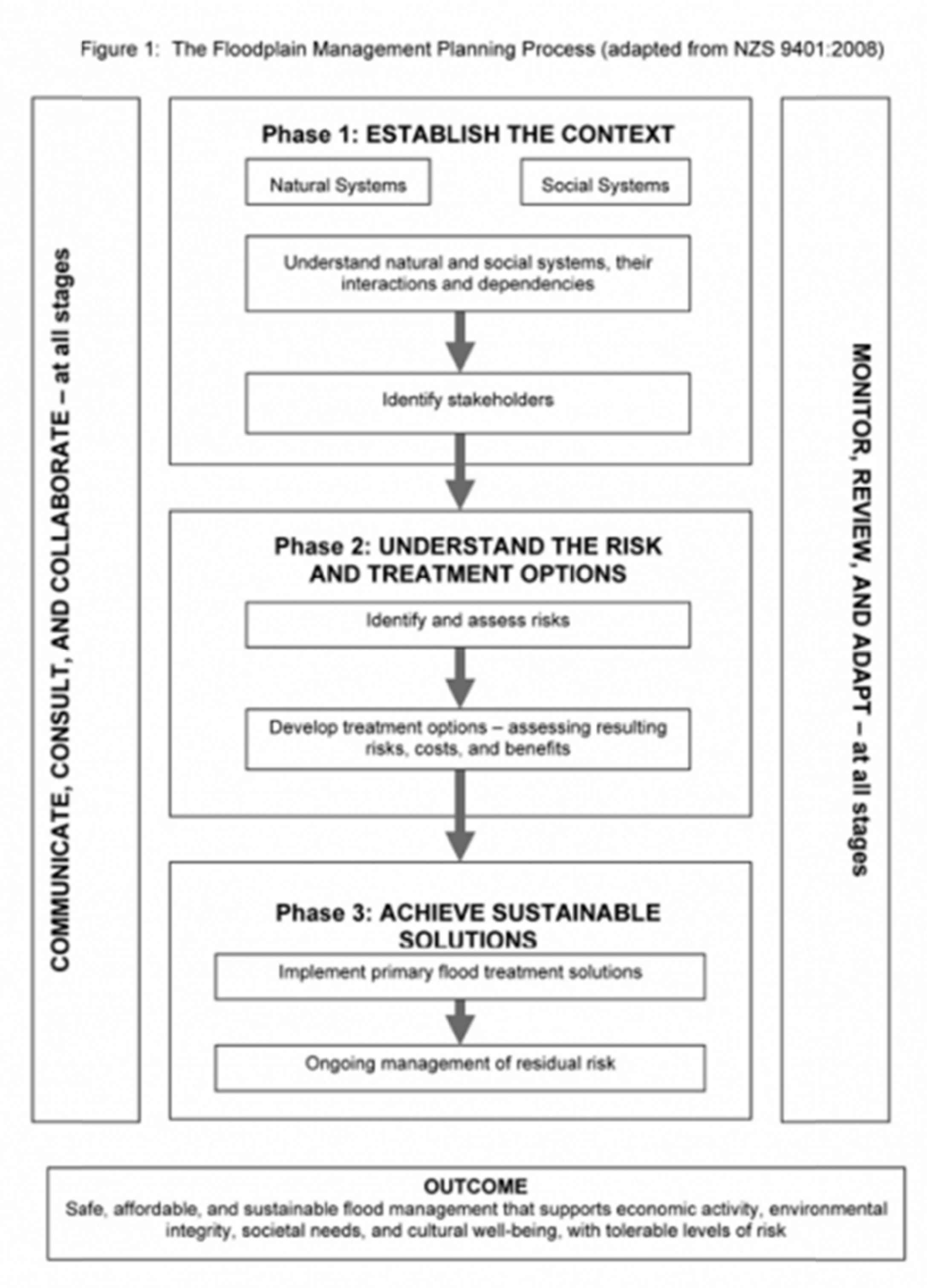


Figure 2-1: Flood risk management process. (Source: www.gw.govt.nz/Floodplain-management-planning/).

The main aim of the *Tools* guidance manual is to help local authority staff – including river managers, engineering staff and asset managers – to manage and minimise the risks posed by increased flood risk due to climate change. More specifically, the *Tools* manual provides good practice guidance for incorporating climate change impacts into flow estimation. While the *Tools* guidance has a focus on climate change, the methods described in the manual are those that are used in flood prediction more generally.

The *Tools* manual first provides information on the key effects of climate change on flood risk. It then describes both screening and advanced methods for:

- estimating changes in the frequency and/or magnitude of rainfall
- converting changes in rainfall to changes in flow rate, and then
- converting changes in flow rate to changes in inundation

The *Tools* guidance manual then provides some case studies to illustrate these methods, and a short discussion of some issues pertinent to engineering design, such as the appropriate use of historical records, clear reporting flow estimates, dealing with uncertainties in estimates, using professional judgement and appropriate scenario choice.

The summary publication *Preparing for future flooding* is structured in four parts. Part 1 provides an overview of the expected impacts of climate change on flooding such as changes in rainfall, temperature, sea-level, storminess and sediment transport processes. Part 2 includes a summary of the methods for estimating changes in rainfall, river flows and inundation from the *Tools* manual. Part 3 contains an overview of how to use a risk management approach to flood hazard management under climate change, with reference to both the Standard AS/NZS ISO 31000:2009 *Risk Management – Principles and Guidelines* and the New Zealand flood risk Standard described above. Part 4 provides an overview of the legislative context (RMA and CDEM Act) and requirements for planning for flood risk management.

2.3.4 Other New Zealand guidance materials

There is some general information concerning floods available on the MfE website (www.mfe.govt.nz/issues/land/natural-hazard-mgmt/flood-protection.html), and on the MCDEM website (www.civildefence.govt.nz/) in particular with regard to community preparedness via the ‘Get Ready, Get Thru’ campaign (www.getthru.govt.nz/web/GetThru.nsf/web/BOWN-7GYTNW?OpenDocument). Flood-specific preparedness and response messages are promoted through the *Consistent Messages* guideline (http://www.civildefence.govt.nz/memwebsite.nsf/Files/Consistent-messages-feedback/$file/Part%20B%20floods%20final.pdf). An older document, *Managing the flood hazard*, was produced by the then Ministry for Emergency Management in 2000, prior to the enactment of the CDEM Act.

Another source of guidance materials for resource management practitioners is MfE’s Quality Planning (QP) website (www.qualityplanning.org.nz/). The QP site has a guidance note on Natural Hazards Management that includes information on managing flood hazards through RMA plans. A *Natural Hazard Management* research report (Tonkin & Taylor 2006) commissioned by the Ministry is also available from the QP website. This report provides an overview of hazard management in New Zealand, covering hazard identification, how to estimate hazard magnitude-frequency and consequences, how to assess and prioritise risks, potential treatment of risk (using the 4 R's), and an overview of the planning and legal framework, including case law and best practice examples.

Other sources of guidance include the Opus (2001) *Floodplain Management Planning Guidelines,* which provide a floodplain management planning framework with a risk management basis. This requires identification of the flood hazard, technical investigations to assess the flood hazard risk, identification of mitigation options including structural and non-structural methods, and final selection of options. The framework involves ongoing communication and consultation, and monitoring and review during this process. The *Guidelines* give case study examples at all stages of this process. The *Guidelines* also comment on consultation and decision-making, and provide information regarding legislative roles and responsibilities. Finally they provide catchment specific case studies from a number of regions.

Another source of guidance is the *River Manager's Guide* DVD (Smart & Diettrich 2010), produced through Envirolink tools funding for the River Managers Group[4]. The *Guide* is "a compilation of current river management advice, practices and examples that have been contributed by practitioners for the benefit of others." The topics on the DVD include statutes and principles, operations and maintenance, agencies and stakeholders, sediment management, flood management, water quality, human interface, and natural environment management. These topic areas provide a number of clickable links to sub-topics, and include case studies of work done by various councils.

2.4 Regional practice

2.4.1 Brief overview

As the above legislative framework shows, the operational management of flood risk is devolved to regional government, with the intent that decision making occurs at the level at which people are affected by the potential risk (Day 2005b; NZS9401:2008; MfE 2008a).

Under the RMA, councils can use different planning tools to manage flood risk. Councils may use tools such as rainfall-runoff and flood inundation models (see section 3 for more detail on these) or analyses of previous floods to develop flood hazard maps showing inundation extents and/or depths. There is no standard for what tools are used (Opus 2001) but it is likely that 1-D models are the most common form of flood model used by regional authorities and TAs as they are cheaper and easier to run and can be applied without the use of detailed topographical data. 2-D models are more likely to be used by larger (better resourced) councils, or in areas with a large potential flood risk (although this depends on the river and floodplain being modelled, and the data available).

The flood hazard maps are used to designate flood hazard zones, and the RMA process then allows for councils to limit land-use within those zones, for example using plan rules (see Tonkin & Taylor 2006 for best practice examples). Ideally regional and territorial councils work together to identify hazard zones and implement land-use rules in district plans consistently across a region. Building code regulations, such as minimum floor levels, may then be applied to buildings within such zones.

[4] The River Managers Group (RMG) is one of the regional councils' Special Interest groups or SIGs.

Councils may also manage flood risks by providing flood warning systems, forecasting floods, undertaking river protection (flood) works, and undertaking CDEM Group activities (including community awareness and preparedness activities). The RMA also requires regional councils to keep information about natural hazards (s35 (5)(j)) which is often in the form of a hazards register. For example, Otago Regional Council is developing a GIS hazards database which draws together historic information, to make such information more accessible (Poland 2011).

Another place where councils (district or city councils) keep information regarding hazards is on a land information memorandum or LIM[5]. A LIM gives information on the council's files on land and buildings, and this can include information on hazards such as flooding (Tonkin & Taylor 2006).

Councils have been managing flood risks for their communities since the RMA was introduced, and prior to that catchment boards were doing the same job under the Soil Conservation and Rivers Control Act 1941. National guidance on the subject is relatively sparse (as discussed above), and most of the written information that exists has been developed relatively recently. As such, the 16 councils have had time to evolve flood management practices with regional differences resulting from their different geographical locations, flood hazard experiences and resources available to address the flood hazard. Their approach to addressing natural hazards in their Regional Policy Statements is varied (Tonkin & Taylor 2006).

In a review of flood management in New Zealand in 2008 (section 2.3.2 above), MfE looked at some case studies to understand how councils manage flood risk. With regard to regional variability, MfE (2008a) found that there is no one standard approach to managing flood risk (Note that while the review was completed prior to the New Zealand flood risk management Standard being released, that Standard still allows for regional variability in flood risk management). The review noted that this makes comparison across the country difficult. Tools used to manage floods can vary – which MfE noted is both a weakness and a strength. Some councils are better resourced and have better information and more robust flood risk management practices than others.

Local Government New Zealand (LGNZ) have recently stated (LGNZ 2011) that they believe that there is a case for central government to provide stronger national direction by producing a National Policy Statement for Flood Risk. LGNZ argues that New Zealand as a whole, and central government, will equally benefit from the provision of an NPS on flood risk management through opportunities to reduce the externalised costs of flood events and the costs of litigation.

2.4.2 Information from river managers

In terms of this review, the aim was to better understand the current flood risk management practice at regional and local government level. In particular:

- How much do councils draw on the existing national standards and guidelines?
- How do councils source and use scientific research on floods?

[5] A LIM abides by the Local Government Official Information and Meetings Act 1987, Section 44A

- Are there regional differences? Why is this?

To look at this issue, a number of questions were asked of a few regional river managers (see Appendix B). The following section summarises the responses to some of these questions.

The following sections state the questions asked and then provide a compiled bullet list of responses from river managers in no particular order. Please note that the tools listed under the first question will be explained further in the following section of this report.

Q1: What tools do you currently use to help you to manage flood risks?

- regular river cross-section monitoring programme
- longitudinal crest level surveys of stopbanks
- flow monitoring
- rainfall monitoring
- modelling of rainfall and runoff
- High Intensity Rainfall System (HIRDS) for model design rainfall
- frequency of high intensity rainfall (TP19 & TP108 methods)
- Regional Frequency Estimation
- flood hazard mapping
- flood forecasting - varying degrees of automation and user interfaces (e.g. Horizons use WaterRIDE, see http://www.waterride.net/)
- flood hazard map library to link to flood (flow) forecasting systems to enable forecast of inundation extents
- dam break [modelling]
- planning tools such as regional rules regarding flood plain development, also LTP and CDEM Group plans
- flood protection asset management through service delivery contracts, and targeted gravel extraction
- Data inputs such as LiDAR for topography, soil classification to understand infiltration rates, impervious surface database
- GIS framework for data layers and mapping outputs
- Climate change projections via MfE guidance.

Q2: Do you integrate current scientific (physical or social) research into your flood management activities?

- *If Yes, where do you normally source this research?*

- whatever resources provide the most credible information, e.g., MfE for climate change
- via consultants for floodplain mapping
- some journal articles (e.g., *Journal of Hydrology (NZ)*, *Journal of Flood Risk Management*, *Natural Hazards*)
- conferences and workshops, including:
- New Zealand Water & Wastes Association (now Water NZ)
- DHI Workshops
- River Managers Group
- ESRI (Arc View) website or workshops
- Other continuous professional development opportunities.

▪ *If No, what are the main barriers to this?*

- Access to peer-reviewed literature, knowing where to look
- Management and political barriers about incorporating information about hazards where this is perceived to lead to for example lowered property prices.

Q3: How useful do you find national regulation and guidance, such as:

▪ *The New Zealand Standard for managing flood risk (NZS 9401:2008 Managing flood risk - a process Standard)*

- of some value
- limited use and it's not a document that we refer to often
- useful for submissions on TA plan changes and resource consents
- not used.

▪ *MfE Guidance documents (e.g. Tools manual or Preparing for future flooding)*

- very useful; used as the basis for climate change design. (These sorts of documents are clear, give a good understanding and provide back-up for decisions made)
- very useful
- useful in context of reference for consultants preparing assessments of environmental effects to support consent applications
- useful.

▪ *Others?*

- NSW Flood Plain Development Manual[6] – very useful [authors note – not a New Zealand document]
- Opus 2001 Floodplain Management Planning guidelines.

[6] http://www.environment.nsw.gov.au/floodplains/manual.htm

3 Flood research

As introduced in section 2, under the CDEM Act there is a requirement to look at hazard planning, programmes, and activities across the areas of *reduction, readiness, response, and recovery*:

- Reduction of the risk of floods occurring – this includes planning (under the CDEM Act, RMA or LGA) such as developing hazard zones, physical works, public awareness of hazards
- Readiness for floods should they occur – this includes flood detection, warning systems, evacuation planning, and public awareness and preparedness
- Response to floods when they occur – this is the actual response by flood managers to an event, where the plans and systems developed earlier are put into operation, and
- Recovery from floods after they have occurred.

The research that we discuss in this section provides the basic information to help address issues around the 4 Rs. For example, flood inundation mapping can be used to develop hazard zones, rainfall and flood forecasting can be used to provide flood warning systems, and better understanding of human perception of floods can help with the design of better community awareness and preparedness materials.

This section is structured to first step through physical flood processes and flood vulnerability, and then to look at social research particularly regarding community awareness and preparedness. For each topic, a general overview is given and then recent research and tools are briefly described. The information is sourced from recent key papers or reports, and from questions asked of a few key flood researchers in New Zealand (Appendix C), central government managers (Appendix C) and river managers (Appendix B).

3.1 Rainfall and climate

3.1.1 Overview

For most river floods (i.e., excluding dam-break floods), the key drivers for flooding are the antecedent conditions of the catchment and the precipitation that reaches the channel. Understanding variations in precipitation in time and space will therefore provide useful information to flood managers.

Climate may be subject to natural variability at a range of temporal scales: diurnal (daily, which is basically ‘weather’), seasonal, annual, decadal or even longer-term. In the short term (days), extreme daily precipitation is driven by three main types of weather systems: a) prevailing westerly winds (zonal type) mainly affecting southwest of South Island; b) trough systems mainly affecting the east coast of South Island and central New Zealand; and c) blocking low or high systems affecting the north and east costs of North island (Griffiths 2011). New Zealand experiences weather formed in the boundary between cool sub-Antarctic air and warmer, moist air from the tropics. The prevailing westerlies and the topography, such as the Southern Alps, influence where the precipitation is distributed around the country. Wide spatial variations occur in precipitation duration and intensity.

Heavy rainfall is produced by certain types of weather systems, such as extra-tropical low pressure systems, blocking systems or fronts (e.g., Mosley & Pearson 1997; Griffiths 2011).

Seasonal precipitation (rain and snow) varies depending on the proximity to certain circulation patterns (tropical vs polar influences).

Longer term climate variability may be due to larger scale patterns such as the El Niño-Southern Oscillation (ENSO), which can lead to inter annual (between 3 and 5 years) variability. ENSO is a tropical Pacific-wide oscillation that affects pressure, winds and sea surface temperatures (Salinger et al. 2004). In an El Niño phase, New Zealand experiences more southwesterly flow than normal, so that the south-west is wetter and the north-east is drier. Roughly the opposite happens during a La Niña phase. Decadal variability in climate may be due to phenomena such as decadal variability in ENSO and the Interdecadal Pacific Oscillation (IPO), the positive and negative phases of which can influence the ENSO so that in positive phases New Zealand may experience more frequent and stronger El Niño events and more La Niña events during negative phases. However these oscillations account for only modest portions of the year-to-year variance of climate in some regions. The majority of the variance of seasonal and annual climate data is not explained by any known phenomena and must be regarded as 'chaotic' weather processes at present.

Consideration of long-term climatic variability also requires an understanding of future climate trends, such as global climate change. Changes to the RMA in 2004 mean that decision makers must have 'particular regard to' the effects of climate change (RMA section 7(i)) on natural and physical resources. Work by the Intergovernmental Panel on Climate Change (IPCC) has modelled a range of potential scenarios for climate change, which can be 'scaled down' from global climate models into models which predict the effects of this for New Zealand. The most recent round (AR4) of IPCC reports in 2007 has provided improved understanding of potential effects, and these have been downscaled for the New Zealand context by NIWA through climate change guidance for local government published by MfE discussed below. Climate change effects need to be considered at each step of understanding rainfall, runoff, inundation and geomorphology as discussed in the following sections.

3.1.2 Recent research and tools

Of interest for flood estimation and management are research and tools that provide more information on extreme rainfall events.

One such tool is the High Intensity Rainfall System V3 (or HIRDS; see hirds.niwa.co.nz). HIRDS is a web-based utility that can estimate rainfall frequency at any point in New Zealand. It can be used to estimate rainfall depths for hydrological design purposes, and to assess the rarity of observed storm events. HIRDS offers planners and engineers more certainty about the frequency of high-intensity rainfalls, enabling them to better design stormwater drainage systems and other structures. New to version 3 of HIRDS is the option to generate tables of high intensity rainfall for given climate change scenarios.

HIRDS has been compared with other techniques for predicting high intensity rainfall, such as extreme value frequency analysis of data sets (e.g., McKerchar 2008).

An example of a simple tool that is available for estimating rainfall where no rainfall data exists is the Water Resources Explorer New Zealand (WRENZ, see http://wrenz.niwa.co.nz/webmodel/). WRENZ is a GIS based web application that allows the user to display selected layers of water resource related spatial information on a map of New Zealand. One of these layers uses a point and click function to identify catchments and then uses Tait and Turner's (2005) rainfall surfaces to produce a map of mean annual rainfall depth contours for that catchment.

Tools for understanding temperature and rainfall variations due to climate change are provided by MfE, who has provided some guidance for local authorities on how globally projected climate changes may affect each region of New Zealand:

- MfE (2008b). *Climate Change Effects and Impact Assessment: A Guidance Manual for Local Government in New Zealand.* This guidance is a comprehensive technical report based on the Fourth Assessment Report of the IPCC.
- MfE (2008c). *Preparing for Climate Change: A Guide for Local Government in New Zealand.* (Red book). This is a summary of the MfE (2008b) guidance.
- MfE (2008d). *Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand.* This guidance is a comprehensive technical report which is updated after each IPCC assessment.
- MfE (2009). *Preparing for Coastal Change: A Guide for Local Government in New Zealand.* (Blue book). This is a summary of the MfE (2008c) guidance, with easy to read fact sheets.
- MfE (2010a). *Tools for estimating the effects of climate change on flood flow: A guidance manual for local government in New Zealand.* This guidance is a comprehensive technical report.
- MfE (2010b). *Preparing for future flooding: A guide for local government in New Zealand.* (Green book). This is a summary of the MfE (2010a) guidance.

These documents provide information regarding climate change in New Zealand, predicted between 1980-1999 and 2030-2049 (50 year projection) or 1980-1999 and 2080-2099 (100 year projection) for a mid-range IPCC climate change scenario. Projections of likely: annual mean temperature change; annual mean precipitation; and seasonal mean rainfall are given, along with comments on likely changes to extreme weather events. Tables are given that list the predicted changes in seasonal and annual mean temperatures and rainfall, broken down into regions of New Zealand (e.g., MfE 2008b, Table 2.2).

In the MfE (2008b) guidance, the hard work of running global climate models (GCMs) and downscaling the results to New Zealand has been carried out. While for now the MfE guidance documents provide our best information on temperature and precipitation changes for regions in New Zealand (particularly for screening level studies), in the future more advanced techniques may be available. For instance, a New Zealand regional climate model has been developed, which aims to better quantify climate changes over New Zealand. By improving downscaling and looking at a range of IPCC scenarios, the regional climate model will develop probabilistic scenarios of expected future regional climate changes, aiming to encourage better use of climate change scenario information in strategic planning. (See more at http://www.niwa.co.nz/our-science/climate/research-projects/all/regional-modelling-of-new-zealand-climate#null).

With particular relevance to floods and climate change, the MfE *Tools* guidance (MfE 2010a) includes a table of screening and advanced methods for calculating rainfall, including regional climate modelling. The advanced methods (refer to MfE 2010a for detail) are:

- Weather generators (WGs)
- Empirical adjustments
- Analogue selection from observed data
- Downscaling of global models
- Mesoscale weather models for example RAMS and NIWA's NZ LAM
- Regional climate models (RCMs).

It is worth noting here that some of these advanced methods are currently not widely distributed operational 'tools' that any river manager could use, but require a certain level of expertise to use, as well as often requiring quite specific data inputs. However, recent work under the NIWA-led *Impacts of Climate Change on Urban Infrastructure & the Built Environment* project is providing more tools and case studies to help river managers to use these tools. The *Urban Impacts Toolbox* is designed to "help planners, engineers, asset managers, and hazard analysts in New Zealand urban councils understand and evaluate the potential impacts of climate change in their city." The Toolbox is designed with an overall 5-step evaluation framework represented by the 'trays' in the Toolbox. Within each tray are downloadable reports (or 'tools'), each with a specific purpose. This includes tools on river flood assessment, and useful process diagrams to help select between different methods for rainfall, runoff and inundation assessments. The *Urban Impacts Toolbox* will be available (from December 2011) via the NIWA website www.niwa.co.nz/climate.

To provide flood forecasting services (for flood warning systems), forecasts of rainfall are required as input. Tools for forecasting rainfall (and hence flood flows) are discussed in section 3.2.2 below.

3.2 Flood flows

3.2.1 Overview

Key questions often asked about flood flows are "How severe, frequent and prolonged are they?" and "When will the next one happen?" (Pearson & Henderson 2004).

A key for understanding this is exploring the likelihood, or probability, of a flood of certain size happening in a certain time period. For example, a flood peak discharge with a 1% probability of being exceeded in any one year (Annual Exceedence Probability or AEP) is often described as a flood with a 100-year return period or average recurrence interval (Pearson & Davies 1997). Infrastructure such as flood protection works are often designed to survive a certain return period event, such as a 50 year event (2% AEP).

Some catchments contain flow gauges, and for these catchments historical data can be studied to find out more about flood histories[7]. These flow gauges typically measure the level of water in a river and use an existing relationship between water level, river cross-section and river flows (a rating curve) to predict river flows from the recorded level or stage. These data can then be analysed to determine flow statistics, such as mean annual flow, mean annual flood and so on. A longer time series will provide more robust statistics, and be able to produce more certain estimates of the return period of larger floods. A key assumption in this ability to use historic data to predict future flows is that the data are stationary; although as discussed in the previous section they may be climatic trends that need to be identified and understood first.

In order to estimate what might happen in the future, deterministic models can be used, which use understood physical processes to turn input rainfall into likely flood flows. Tools to estimate this process are known as rainfall-runoff models and some are listed in section 3.2.2 below. Important to such models is an understanding of the antecedent conditions, i.e., how wet or dry the catchment was before the rainfall event, as this influences how much water can enter the channel. Variations in catchment land-use, such as the type and amount of vegetation vs impermeable surfaces, can affect the magnitude and duration of flood flows (e.g. Rowe et al. 1997; Fahey et al. 2004; Parkyn & Wilcock 2004; Suren & Elliott 2004).

If an estimate is for a given specific time period this is usually called a ‘forecast’ (McKerchar et al. 1997), and forecasts for very immediate time periods (how high will the river be tomorrow?) are normally made using real-time or near real-time data or input model forecasts. Uncertainty regarding forecasts may be communicated using error bands on forecast flows.

If the catchment is ungauged and there are no data from the catchment, a method of estimating likely flood flows is required. Lack of data ‘at a site’ leads to need for regional methods of forecasting flood frequencies; such methods work on the basis that estimated flow statistics for ungauged catchments can be provided by extrapolating from data in neighbouring or similar catchments. For example McKerchar and Pearson (1989) produced maps of regional estimates of flood frequency which show contour maps of mean annual flood and 100-year floods.

For structure design especially for dams or large value assets, engineers are often required to provide an estimate of the probable maximum floods (PMF: the largest flood that is physically possible given meteorological and hydrological circumstances). Two ways to estimate the PMF are: 1) to use a predicted probable maximum rainfall as an input to a rainfall-runoff model and hence calculate PMF; or 2) to use an existing flow record to calculate a flood of a certain return period and use a scaling factor to multiply that to a PMF. Examples of this approach include 2 times the 100 year flood (Tomlinson & Thompson 1992), 2.2 times the 100 year flood (McKerchar 1991), 7 times the mean annual flood (Hydrology Centre 1988), the largest flood times three (Hydrology Centre 1988), or 3 times the 200 year flood (Riley Consultants Ltd 2009).

[7] Some information regarding historical weather events is available through the Historic Weather Events Catalogue at http://hwe.niwa.co.nz

3.2.2 Recent research and tools

This summary is based on the *Tools* guidance (MfE 2010a). There are some methods that are suitable for screening studies (i.e., identify hotspots requiring further in depth studies), such as the Rational Method and TM61. According to MfE (2010a), this method is a widely used technique in engineering hydrology, although it is known to produce results which have large uncertainty (see McKerchar & Macky 2001). For a comparison of the New Zealand performance of the Rational Method check with two other methods, see McKerchar and Macky (2001).

Another 'engineering' method is the unit hydrograph approach as outlined in the Auckland Regional Council's Technical Publication 108 (TP108) *Guidelines for stormwater runoff modelling in the Auckland region* (available at http://www.arc.govt.nz/plans/technical-publications/technical-publications/technical-publications-101-150.cfm; which superseded TP 19 *Guidelines for the estimation of flood flows in the Auckland Region 1992*).

McKerchar and Pearson's (1989) contour maps of mean annual flood and 100-year average recurrence floods for New Zealand are widely used, and to date have only been updated in an ad hoc way for certain regions (R. Henderson pers. com.).

Rainfall-runoff models include TopNet (e.g., Clark et al. 2008), RORB (Laurenson et al. 2007; http://civil.eng.monash.edu.au/expertise/water/rorb), and DHI's Mike 11 estimates catchment hydrology using a rainfall-runoff module (http://mikebydhi.com/Products/WaterResources/MIKE11/Hydrology.aspx) (see MfE 2010a). These models can produce modelled daily or even hourly flows, but these detailed model outputs require similarly detailed inputs such as rainfall, evaporation, soil types, soil moisture, vegetation and topography, and of course data to calibrate the models with. Again, some of these tools require a certain level of expertise to operate.

While the *Tools* guidance (MfE 2010a) provides some case studies of examples of estimating flood flows (and inundation) under climate change, recent research is continuing to develop methods for this and provide further case studies of climate change effects on flood predictions. NIWA's *Impacts of climate change on river flows and floods* project has been exploring this issue further (see http://www.niwa.co.nz/our-science/climate/research-projects/all/impacts-of-climate-change-on-river-flows-and-floods ; Poyck et al. 2011). Other case studies are given in the *Urban Impacts Toolbox* discussed in section 3.1.2.

To provide flood forecasting services (for flood warning systems), forecasts of rainfall are required, combined with methods to predict river flows. Weather (rainfall) forecast are available in New Zealand from Met Service (http://www.metservice.com/national/index) and also via NIWA's EcoConnect system (http://ecoconnect.niwa.co.nz/).

The MetService provides weather forecasts and both severe weather and severe thunderstorm notifications at three levels: outlook, watch or warning (http://www.metservice.com/national/warnings/index). Outlook forecasts come with a confidence estimate (high, medium, low) based on likelihood of occurrence. These forecasts and notifications can then be linked to rainfall-runoff models such as TopNet to provide river level forecasts. Forecasts specific enough for use as model inputs are provided on a user-pays basis.

EcoConnect is an environmental forecasting and information service provided by NIWA (on a user pays basis). EcoConnect uses real-time data from NIWA's satellite reception systems and environmental monitoring networks, data from the UK MetOffice's global models as boundary conditions, and sophisticated computer modelling and advanced climate analysis tools to provide continually updated accurate forecasts of rain, snow, wind, temperature, river flow, sea state, storm surge and tides. The EcoConnect website also provides access to measured climate and environmental data. EcoConnect rainfall predictions are linked with rainfall-runoff models such as TopNet to provide river level forecasts, which can be used to predict potential flood events. A key research strand, due to be made operational in late 2011, is the addition of a data assimilation process to the model predictions, whereby measured flow data is assimilated in order to continually update and improve model predictions. Predictions will show error band estimates from model ensembles.

3.3 Inundation

3.3.1 Overview

In section 2 above, we defined a flood as a discharge in a river or stream that exceeds the capacity of the channel and inundates neighbouring areas of normally dry land (Pearson 1992). Floods can also occur when a river defence is breached or undermined, in what otherwise would be a flow contained within the channel e.g., Rangitāiki River flood in Bay of Plenty in July 2004. A key to understanding floods then is knowing what magnitude of flood flow leads to the inundation of surrounding land, what volume of flood water will overspill the channel, where it will flow and to what extent and depth, and how frequently these floods occur.

For different sizes (magnitude, return period) of flood, the area of land that is inundated, and to what depth, can be modelled and mapped. A vital input to this though is an accurate depiction of the topography of the land immediately surrounding the river channel. For uses of these models to understand flood routing through built up (urban) areas, the 'topography' includes the built environment including roads, drains, vegetation and buildings.

3.3.2 Research and tools

The modern best practice for terrain surveying and hence mapping is the Light Detection And Ranging or LiDAR system, which is a method of airborne laser scanning that provides very detailed and accurate digital topography information (see for example www.nzam.com/article.asp?id=lidar; or http://www.envirolink.govt.nz/PageFiles/94/29-tsdc24session1.pdf). Ground-based surveys using survey equipment such as RTK-GPS (Real-Time Kinematic Global Positioning System) can also provide similar information over a smaller area. This information is used to create digital terrain models (DTMs) of the channel and surrounding areas, over which flood flows are routed to model inundation extents.

The following summary is mainly taken from (MfE 2010a). The models used to create the inundation maps can vary in complexity but are all based on fluid hydraulics. The main variation is in how many dimensions the model represents reality: 1-dimensional models approximate river flow to occur along a single line, while 3-dimensional models consider flow complexities both across a channel and with depth (MfE 2010a). The pros and cons of 1-D, 2-D and 3-D models are discussed in MfE (2010a), but in summary:

- With 1-D models, the river and its floodplains are represented by cross-section slices spaced closely enough to capture the main features of the topography. Flow circulation patterns cannot be resolved. Predicted cross-section flood levels can be interpolated to give a map showing inundation extent. Examples of 1-D models include AULOS, DHI MIKE-11, and HEC-RAS.
- With 2-D models, a river and its floodplains are described by 3-dimensional digital representations of the ground surface roughness and elevation. Water levels and velocities can vary in all horizontal directions but are depth averaged. Flow paths are determined by the ground topography and roughness. The model results indicate local flood depths and velocities at each node of the DTM. Some models use 1-D equations for the river channel and 2-D equations for the floodplains. Examples of 2-D models include RiCOM, Hydro-2de, River2d, Delft 2D-FLOW, TUFLOW and DHI MIKE21[8].
- With 3-D models, a river and its floodplains are described digitally as for a 2-D model. Calculated water velocities may vary in all 3 dimensions, with vertical velocities calculated for specified layers. Secondary currents can be reproduced. These models are more commonly used for specific, detailed investigations such as flow around structures. Large or complex models require a supercomputer to reduce the run time. Examples of 3-D models include FLUENT, CFX, FLOW-3D, Delft 3D-FLOW, TUFLOW and DHI MIKE3.

The resulting maps show flood extents (1-D), depths and velocities (2-D and 3-D) which can then be used to help establish flood hazard zones, and other model outputs can be used to better understand flood vulnerabilities (see section 3.6).

These models have high resource (time) requirements in terms of set-up, creating model grids with accurate topography and roughness estimates, and a certain level of expertise is required to run them. Data are also required in order to calibrate and validate the models. Some case studies are discussed in the *Urban Impacts Toolbox* discussed in section 3.1.2. As discussed further below, model parameterisation becomes even more complex when looking at built-up areas.

3.4 River geomorphology

3.4.1 Overview

The above sections have identified tools for looking at rainfall, runoff and flood inundation. However the impacts of floods aren't limited to water-logging of areas that are inundated, as flood waters are often sediment laden and leave mud behind when floodwaters recede (Hicks & Davies 1997). The form (shape) of a river changes in order for it to perform its function, which is to transport both water and sediment to the coast (Davies & McSaveney 2011). Understanding the dynamic interactions between flood flows, sediment transport and river geomorphology (river bed and banks) is necessary to better understand some of the consequences of floods.

It is also important to understand wider catchment geomorphic processes such as landslides and debris flows, which provide sediment inputs to the river system. The importance of these

[8] DHI provide software called MikeFlood which combines a Mike11 river model with 2-D floodplain modelling (URS 2006)

sediment additions to river channels and their capacity to carry floods is not always well understood (Davies & McSaveney 2011).

A useful review of floods and sediment transport is contained in Hicks & Davies (1997). They list some of the possible effects of changes in river channels due to floods as:

- Bed degradation e.g. leading to local scour at bridge piers and general scour at bridge constrictions or below dams
- Bed aggradation (build up) leading to reduced capacity of the channel to carry flood flows
- Lateral erosion of banks
- Large scale lateral movements (avulsion) on alluvial fans or rivers with meandering sinuous channels
- Sediment deposition on floodplains or in reservoirs.

Understanding relationships between floods of different sizes and geomorphic processes in the river is important. For instance, certain sized floods are required to: flush fine sediment or periphyton from bed sediments (flushing flows), maintain 'average' channel form and function (channel maintenance flows), or keep river mouths open to the coast to allow for flood egress and fish passage. The first two examples involve flood flows of a size that is maintained in a river channel so do not necessarily constitute flood hazard, whereas the latter may.

Within a river system, patterns of aggradation and degradation vary in both time and space, making such changes in channel position and level, and thus changes to floodplain inundation, very hard to predict (MfE 2010a). The physics of interactions and inertial lags between flow and the shape of the channel while sediment is moving under turbulent flows is not well-understood (G.Smart pers. com.). This applies to dynamic changes that can occur within the period of the flood and also the net change in geomorphology before and after the flood. Good time series data as a result of frequent post-flood monitoring are rare, although more river monitoring to enable an adaptive approach to river management is advocated (Williman 2010). As a result, numerical morphodynamic modelling is likely to be required to quantify site specific changes to sediment transport and channel morphology.

3.4.2 Research and tools

Because the interactions between flow and sediment transport are complex and monitoring river bed levels during floods is difficult, numerical (computer) modelling is the best tool to make predictions[9] of sediment transport during floods. As for inundation models, sediment transport models have been developed that consider the problems in different dimensions. 1-D models simulate flow and sediment transport along a long-profile using averaged cross-sections (Wu 2008). They evolve the bed longitudinal profile and changes to bed substrate over time. These models are useful for looking at long-term problems or issues along a long reach of river. There are a number of such models widely available for use including MIKE 11 (http://mikebydhi.com/Products/WaterResources/MIKE11.aspx), HEC-RAS (http://www.hec.usace.army.mil/software/hec-ras/), CCHE1D-3.0 sediment transport model (Wu and Vieira 2002; Wu et al. 2004), or GRATE (M. Hicks pers. com.).

[9] As with all models, results are most useful if they are able to be validated using actual data from flood events.

2-D models with depth-averaged formulations, are a useful tool for looking at smaller stretches of river where local bed level and textural changes over event timescales are considered important, for instance at river meander bends (Wu 2008). They are computationally more complex and time consuming than 1-D models. Examples include MIKE 21C (http://www.dhigroup.com/Software/WaterResources /MIKE21C.aspx) and Delft 2D-FLOW (morphology module).

In reality, flows and sediment transport, particularly suspended sediment, occur in three dimensions, and 3-D models are best equipped to model real flow situations in complex situations. The numerical solutions for the models are very complex and hence more computationally expensive than 2-D models, and so are often used just in very small locations such as scour around structures (Wu 2008). Examples include Delft 3D-FLOW (morphology module).

However as noted above, such models are advanced tools that require expertise to use, and also require detailed set-up and data inputs. Correctly parameterising these models takes expert opinion and trial and error. As such these are not yet distributed and used at river manager desktops, but are more likely to be operated by consultants.

Davies and McSaveney (2011) note a need for more work to develop operational procedures (tools) for flood assessment including geomorphic interactions.

3.5 Rivers at the coast

3.5.1 Overview

Many of New Zealand's large cities lie not only in floodplains but also close to the coast. This section will make some brief comments pertinent to managing floods in areas where the river flood is subject to potential interaction with coastal waters by way of compounding processes such as tides, storm surge, swell and wave run-up and seiche (long waves); it is not intended to discuss coastal inundation via tsunami (see instead Saunders et al. 2011).

Rivers tend to flatten out in gradient as the river approaches its base-level or near the coast. High tides twice a day (approx. 12.4 hour intervals) lead to twice daily small increases in this base-level. In the river mouth area, where tidal range is sufficient that tidal waters intrude into the river from the coast, there are movements of water out to sea on the ebb tide down to low water, and then movements of water upstream into the river on a flood (incoming) tide, culminating at local high water.

When river floods coincide with these tidal variations, on an ebb tide, river flood flows can escape more directly to the coast, whereas on an incoming tide - especially at high water - flood waters are held back and the addition of tidal water level onto the flood level can increase the potential for inundation. A 100 year return period flood in the river, on top of high tide, will give a greater than 100 year return period inundation event for coastal lowlands. Work to understand the joint probability of a 100 year flood happening at the same time as a very high tide - or as a 100 year storm with associated low pressure giving storm surge and wave run-up effects – is more complex. Regional correlations between weather systems producing river floods and generating coastal inundation events are not well developed (G. Smart pers. com.).

In addition to tides, the effects of storm surge, seiche and wave processes on increased sea-levels as well as changes in mean sea level from climate cycles e.g., seasonal and ENSO, are important to understanding coastal inundation. These can be looked at using extreme sea-level analysis based on joint-probability approaches, the aim of which is to determine the height and likelihood of occurrence of unusually high (or low) sea-levels (Goring et al. 2011).

MfE (2010a) note that coastal and estuarine riverine systems require specific hydraulic investigations because:

- A flatter river gradient reduces the velocity of floodwater escape, encourages silting and aggradation during low-flow periods and further restricts river conveyance; and
- Localised aggradation and degradation of the channel require site-specific studies to understand potential changes in inundation.

With regard to climate change, MfE (2010a) also states that coastal riverine communities are subject to further risk because:

- An increase in flood frequency increases the chance of floods occurring during adverse tidal conditions;
- Storm surges will increase if low-pressure systems become more intense and/or winds increase – wind changes may also affect wave and swell heights; and
- Sea-level rise has a double adverse effect by raising the exit water level and flattening the gradient of the coastal river reaches.

3.5.2 Research and tools

Many of the numerical models listed in section 3.3 and 3.4 above can be used in coastal river situations. For example studies can use information regarding high tide levels and potential sea-level rise scenarios to estimate one or more downstream or base levels in the model (e.g. URS 2006). A number of scenarios can be tested in this way. Site specific investigations are more likely to be undertaken due to the risks from combined river and tidal floods.

Again, such models require expertise to use, and detailed set-up and data inputs. Correctly parameterising these models takes expert opinion and trial and error. As such these are not yet distributed and used at river manager desktops, but are more likely to be operated by consultants.

The *Urban Impacts Toolbox* discussed in section 3.1.2 includes tools for better understanding extreme sea-level analysis. For example it includes a tool on extreme sea-level analysis which will help users to understand the differences between different approaches to analysing extreme sea-levels. These include direct (Annual Maxima Method or AMM, r-largest method or RLM, and peaks-over-threshold method or POT) and indirect (revised joint probability method or RJPM and empirical simulation technique or EST developed by Goring et al. 2011). The *Urban Impacts Toolbox* also gives a case study of the combination of sea-level rise and extreme sea-level scenarios on coastal inundation.

3.6 Flood vulnerability

3.6.1 Overview

The above sections have highlighted some of the research and tools that help to understand the potential magnitude and frequency of the flood hazard, but the next step in order to manage the flood risk is to understand the consequences of that hazard.

The technical field of risk management provides a series of tools to ensure that decision making is transparent and based on a sound, independent evaluation of risks (ERMA 2002). In New Zealand, the generic application of risk management is guided by a Standards Australia and Standards New Zealand document (AS/NZS ISO 31000:2009). Guidance on risk management and risk assessment techniques is provided by an international standard (IEC/ISO 31010:2009) and a Standards Australia guide on communicating and consulting about risk (AS HB 327:2010) has been developed as a companion to AS/NZS ISO 31000:2009. Good practice can be guided by the processes outlined in these standards and guidance; following these steps allows for a transparent process with agreed and well communicated criteria for defining and managing risk (or uncertainty; Rouse & Norton 2010). The legislation (e.g. CDEM Act s17), national flood risk management Standard, and MfE *Tools* (2010a) and Opus (2001) *Guidelines* discussed in section 2 all follow a risk-management approach.

A recently advocated approach to hazards planning, rather than depending on a certain design event, is to encourage councils to plan for hazards using a risk-based approach, assessing consequences of potential events of certain sizes before determining the likelihood of those events (J.Beban pers. com.).

Section 17 (1) (a) (iii) of the CDEM Act requires the implementation of cost-effective risk reduction measures, which means costs-benefits need to be assessed prior presenting risk reduction initiatives to the decision makers. This is similar to the consideration of alternatives, benefits, and costs required by the RMA under s32. To choose suitable methods to reduce the flood hazard risk, the costs of likely impacts of the flood and the costs and benefits of alternative options for reducing that risk need to be understood.

One way of understanding potential impacts of flood events is to measure actual impacts arising from flood events. With regards to post-event impact assessments, councils may undertake a rapid assessment of buildings using (sometimes) the MCDEM building safety guidelines framework (http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Building-Safety-Guidelines). However assessments of flood impacts never or rarely go beyond the superficial assessment on the day of whether a building can be inhabited (R. Paulik pers. com.). Furthermore, councils only tend to assess impacts to their assets and land. This means that little information regarding flood impacts is collected following an event, which may hinder councils/CDEM from effectively meeting a number of statutory hazard management requirements. A lack of a national standardised method for impact assessment and monitoring has previously exacerbated this issue (Ericksen 1986; Walton et al. 2004a).

There are some exceptions; the large Manawatu floods in 2004 received a full review (Reid et al. 2004) to identify lessons learned for New Zealand's emergency management arrangements. Reid et al. (2004) estimated the overall economic impact of the floods at $400 million. (The review also found though the CDEM framework worked in general, there was a lack of public understanding regarding community roles in being prepared for hazards. Communication breakdowns were identified, particularly with some flood warning systems. A total of 39 recommendations were made, in regard to CDEM arrangements. These ranged from increased public awareness, to early involvement of scientific input to provide predictions and advice, to improved computer systems for mapping residential dwellings and infrastructure). The social impacts of these floods were studied by Smith et al. (2011), who found that the vulnerability of the rural communities affected had been increased by the 'hollowing out' of the rural community, with changing populations and loss of community foci, and changes in communication methods adding to an increased sense of isolation during events. Other examples of post event reviews include an NZIER review of the 2002 Waikato weather bomb event (Walton et al. 2004b), and a MAF report on the resilience and response of farm households after the 2006 Canterbury snow storm (Smith 2007).

In order to predict potential impacts, depth-damage functions, also known as stage-damage curves or fragility curves are used (Ericksen 1986; Walton et al. 2004a; Reese & Ramsay 2010). These are the most common method to estimate potential direct damage costs. Fragility curves usually relate an aspect of the flood such as depth or velocity of flow to percentage damage (relative to replacement cost) of the item such as a building (Reese & Ramsay 2010). In parallel, good records of infrastructure in the flood hazard zone are required (Walton et al. 2004a).

While the use of 2-D modelling of flood extents has recently increased in New Zealand, the subsequent development of flood fragility functions to determine risk within floodplains has not widely followed suit. The aforementioned lack of impact data collected after flood events and a recognition of the need and usefulness of a national standardised method for impact assessment and monitoring have been hindrances to developing flood fragility curves for risk assessment.

3.6.2 Research and tools

The tools used to assess flood vulnerability are mentioned briefly above. Building an understanding of flood vulnerability by studying actual events requires post-event surveys of businesses and communities, and physical damage assessments where possible. Prediction of potential impacts is possible using fragility curves.

The Ministry of Civil Defence and Emergency Management has (in 2006) provided a hazard event reporting template (http://www.civildefence.govt.nz/memwebsite.nsf/wpg_url/for-the-cdem-sector-cdem-groups-group-resources?opendocument) to encourage consistent post event reporting. However, it is a high level document and there is potential for a considerable amount of variability in its interpretation and use. It is not clear how widespread the use of this tool is.

Recent research in this area includes the RiskScape project, a joint venture between GNS Science and NIWA. RiskScape is an easy-to-use multi-hazard impact and risk assessment tool available online at http://www.riskscape.org.nz/. RiskScape uses a mixture of empirical and synthetic flood fragility functions (Reese & Ramsay 2010) for buildings, contents, injuries, fatalities, displacement, vehicles, road network, business disruption, loss of income, water supply network, sewerage network and stormwater network.

There are a few examples of flood vulnerability assessments in New Zealand such as the Whangarei CBD flood damage assessment (URS 2006) which used 1 and 2-D models to produce flood hazard maps for a 100 year Average Recurrence Interval (ARI) flood, and then used flood depths and extents to estimate likely flood damages on different types of buildings in the CBD using flood damage (fragility) curves. A similar piece of work for Waikato Regional Council (formerly Environment Waikato) and Thames-Coromandel District Council developed models to look at financial risk and 'lives' risk of flooding for Coromandel communities (URS 2003).

The *Urban Impacts Toolbox* discussed in section 3.1.2 includes tools for carrying our 'rapid' cost-benefit evaluation (rCBE), and individual house mitigation option assessments, as well as discussing the use of RiskScape.

Ensuring that up-to-date, accurate topographic information is available to input into the inundation models is a challenge in the rapidly changing urban environment. Accurate roughness information is also required, as well as data on building floor levels.

3.7 Community awareness and preparedness

3.7.1 Overview

In the context of the 4 R's, social science aspects of the flood hazard are important to improving flood reduction and readiness.

Raising community awareness

A first step in helping people to be prepared for floods is in increasing general awareness of the flood hazard. Previous civil defence oriented approaches (e.g., Griffiths & Ross 1997) talk about preparing 'a good communications strategy', which implies a one-way or passive information flow. Printed media such as leaflets, websites, or other media such as radio or TV adverts may provide useful information about flood hazards. However it is not always clear whether this one-way information flow results in increased awareness or not – even to the point that the council appears to have the flood hazard under control.

More recent developments encourage the use of other more participatory approaches to encourage a higher level of interaction between specific groups and flood managers so that levels of awareness are raised, for example by asking questions to help people reflect on their own understanding and preparedness. This increased engagement also promotes community agreement with decisions regarding flood hazard tolerance and its management including the residual risk (MfE 2008a).

Increasing community preparedness

MCDEM (2007) have defined preparedness in New Zealand as:

Individuals having a plan and emergency survival items - both of which are regularly checked and updated and being able to look after themselves for three days or more in a disaster.

Benchmark research that MCDEM commissioned in 2006 indicates that only 7 per cent of New Zealanders are prepared at home and at work, while 21 per cent are prepared at home only, when considering this definition.

Making sure that people prepare for flood hazards requires not just a greater level of awareness but also incentive to change behaviour and undertake actions. Understanding why people do or do not prepare for the hazards is an important stage in thinking when planning for activities to increase community preparedness. Providing people with information about the risk is not sufficient to change their behaviour, which depends on how people perceive (interpret) that information and the risk.

Perception is the filter through which the external environment is given meaning by a person (Ericksen 1986). Factors such as personal experience of hazards, future expectations and 'gambler's fallacy' effects related to misunderstanding of flood statistics and terms (such as return periods – people think if there has been a 100 year flood there won't be another one in their lifetime) and increased sense of security from damage caused by flood defence structures (Ericksen 1986), can affect people's perception of the risk of floods. People may expect that, if their own house has never been flooded and they themselves have never experienced a flood, they will never experience flooding. This presumption of immunity can affect decisions made by the community which would reduce flood risks.

On a personal level, people first may consider 'is it possible to prepare?' (i.e., will preparation help? [10]). A relevant concept here, relating to perception of risk, is that of outcome expectancy. People with a negative outcome expectancy might tend to think the hazard is too big, and so they won't do anything to prepare as there is no point. If someone has positive outcome expectancy, they think they can do something to make themselves safer.

Believing you can prepare is not the same as knowing what to do, and so helping people understand what to do is the next step. If people don't know from their own experience how best to prepare, they have to trust in the information they receive. People are more likely to prefer (trust) sources of information regarding preparedness such as friends and communities of people they work or worship with. A useful information source is to use people who have prepared for previous events to say what they did and if it worked.

Once people see the point in acting, and know what to do, the final step is to take action. However there are still barriers that prevent people acting:

- Optimistic bias – accidents happen to other people – people assume hazard information is intended for others either more at risk or less prepared than themselves (e.g., Reese et al. 2011)
- Risk homeostasis – people defer responsibility to other agencies to look after them, which happens for instance when there is a warning system in place, or hard defences such as flood walls or stopbanks (e.g., Reese et al. 2011)
- Overestimation - people often overestimate how prepared they are, so they don't take in information about how to be more prepared.

[10] Much of this information is summarised from a video on risk communication with regard to bushfires featuring Professor Douglas Paton, available at: http://www.youtube.com/watch?v=KjoDH-zhfdQ&feature=related

Communicating risk

Whether raising awareness or seeking action to improve preparedness, it is also important to consider how the flood hazard and its risks are communicated. Factors to help ensure success include:

- breaking the information down into chunks – one topic at a time
- make communication more active – ask questions to encourage engagement over the issues on a personal level
- use terms that are meaningful and focussed on consequences (MfE 2008a), and
- using images and information from previous floods.

In summary, 3 steps to communicate preparedness are:

1. convincing someone there is a point in doing something
2. letting people develop these ideas in community contexts
3. improving engagement mechanisms.

Further generic guidance on communicating risk is provided by Standards Australia guide on communicating and consulting about risk (AS HB 327:2010).

3.7.2 Research and tools

Work in this area of community awareness and preparedness is carried out in New Zealand in particular by the Joint Centre for Disaster Research (a joint venture between Massey University and GNS Science within the School of Psychology). The Joint centre undertakes multi-disciplinary applied teaching and research aimed at understanding the impacts of disasters on communities, improving risk management and enhancing community preparedness, response and recovery from various hazard events (see http://disasters.massey.ac.nz/index.htm).

Surveys are a key tool to understanding community hazard perception and preparedness (e.g., Reese et al. 2011). The literature, and thus tools, for considering how to engage with communities in a way that goes beyond passive information sharing are diverse. As an example here we show the IAP2 (2011) spectrum of public participation (Table 3.1).

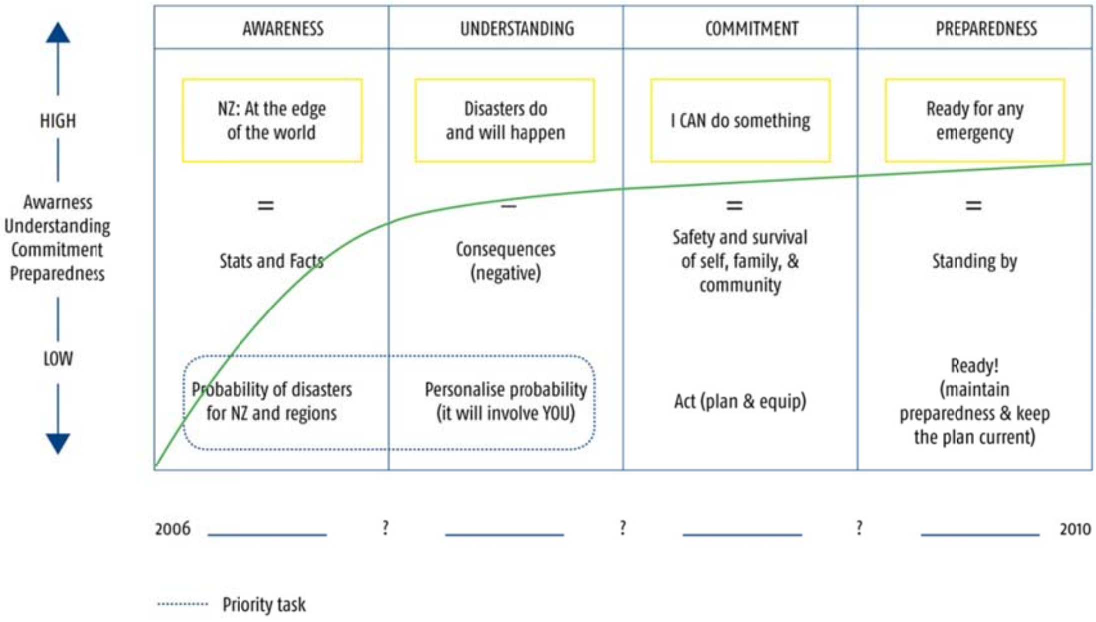
MCDEM provides national leadership in this area. MCDEM has recently developed guidance for local government in how best to engage with their communities in a meaningful way about disaster preparedness and resilience building (http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-Community-Engagement?OpenDocument). The guideline describes best practice for the process through which communities can be engaged and be involved in civil defence emergency management in their area. It is not a prescriptive document but it shows the process that should be used, indicates important considerations that need to be taken into account and gives examples of some tools that can be used. It assumes that those leading the engagement process have the appropriate character and competencies required to lead and facilitate the engagement. Additionally, the MCDEM national CDEM public education strategy document (MCDEM 2007) provides some background information regarding awareness and preparedness including the kinds of barriers and communication approaches described above (Figure 3.1).

Table 3-1: The IAP2 (2011) spectrum of public participation.

Inform	Consult	Involve	Collaborate	Empower
Goal: To provide the public with balanced and objective information to assist them in understanding the problem, alternatives opportunities and solutions	Goal: To obtain public feedback on analysis alternatives or decisions	Goal: To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered	Goal: To partner with the public in each aspect of the decision including the development of alternative and the identification of the preferred solution	Goal: To place final decision making in the hands of the public
Promise to the public: we will keep you informed	Promise to the public: We will keep you informed, listen and acknowledge concerns and provide feedback on how public input influenced the decision	Promise to the public: We will work with you to ensure your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision	Promise to the public: We will look to you for direct advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible	Promise to the public: We will implement what you decide.
Common techniques: fact sheets, web pages, open houses	Common techniques: public comment, focus groups, surveys, public meetings	Common techniques: workshops, deliberative polling	Common techniques: citizen advisory, committees, consensus building, participatory decision making	Common techniques: citizen juries, ballots, delegated decisions

Specific tools to help communities include Dairy New Zealand's *Dairy Floods Checklist: preparing and responding to floods* (undated) which is a checklist approach to helping dairy farmers consider whether they are prepared for floods, how to respond in an event, and plan for long term farm recovery. Other tools include MCDEM's 'Get Ready Get Thru' checklists for floods and the *Consistent Messages* guidance (see section 2.3.4).

Figure 3-1: From awareness to preparedness (MCDEM 2007).



4 Discussion and recommendations

The previous sections of this discussion paper have looked at existing flood management practices and flood research activities with particular regard to the development of tools that can be used to better understand and manage floods. Based on this overview, and using evidence from the literature review and survey of key researchers and river managers, this final section identifies gaps in research from practitioners and researchers, and then consolidates these into a draft improved research agenda for New Zealand flood management.

4.1 Gaps in research – practitioners view

The following summary is based on information gathered from central government managers and regional council river managers, the MfE (2008a) review, and the regional council *Research for the environment* strategy (2011) and related documents available at the Envirolink website (http://www.envirolink.govt.nz/).

4.1.1 Existing documents

The MfE (2008a) review *Meeting the challenges of future flooding in New Zealand* asked some specific questions around flood research, tools and communication, as summarised here:

How to improve flood forecasting and warnings?(review question 9 discussion)

- Greater collaboration between organisations - MetService and NIWA for forecasting in particular, as well as others for river-level monitoring
- Increased weather radar data
- Increased rainfall and river-level monitoring – i.e. more sites, or second gauges at some sites
- Greater capacity for flood forecasting - within councils, and through access to forecast information to improve capability
- Increase community involvement in warning and response plans – so that they know what to do when they receive a warning.

Are practitioner's science needs being met? Practitioners said they need:

- Best practice guidance
- Hydrological modelling
- Predicted rainfall including regional flood frequency estimates
- Guidance on the environmental and economic effects of flooding, and in addition
- Any work needs to be relevant to both regional and territorial authorities.

How good is the communication between science and practitioners?

- Barriers – 1) top down funding decisions, and 2) effort required to understand needs from many practitioners
- Information dissemination is poor – issues around Intellectual property (IP) and the simple lack of $$ at the end of programmes to disseminate the information
- Hard for councils to know what useful research has been funded.

The regional council's *Research for the environment* (2011) strategy identifies hazard risk assessment as one of six high-level research priorities. It states:

> "There is an overall need for better tools to assist with the analysis of, and effective responses to, hazards and consequent societal risks. More research is needed to provide a more robust and defensible position to address hazard risk more effectively, and to give decision makers confidence. The key issue is risk management – how to deal with risk, identifying effective risk reduction measures and balancing risk reduction with acceptable cost. This includes residual risk, which is seen as a critical planning issue around questions of where development is appropriate in relation to our understanding of the various risks."

During 2009 and 2010 the regional councils' Special Interest Groups (or SIGs) were encouraged to develop their own list of research needs, and a list of these is available on Envirolink website. The *SIG Research Priorities 2011 plus 2009 Critical Issues and Research Needs* document includes topics of relevance to flood risk management research (Table 4.1).

4.1.2 Answers from central government managers and regional council river managers

The following research gaps were ascertained by asking river managers:

- *What other research do you think is required to help you better understand flood risk for your region/area?*
- *What other tools would help you to better manage flood risks?*

The gaps identified are listed in bullet form, with short descriptors, and in no particular order. In an attempt to be inclusive, all bullets with very similar issues have been retained so there is some duplication, and similar topics are grouped together where this was possible.

- Widespread LiDAR coverage needed to develop robust DTMs to underly flood inundation modelling, national co-ordination of this
- Better understanding of how to take next step from flood zone to potential consequences and use cost-benefit approach to change decisions made about where to locate infrastructure etc
- Better tools to assist with the analysis of, and effective responses to, hazards and consequent societal risks

Table 4-1: Flood relevant research priorities from SIG groups.

SIG	Critical issue	Research need	Important because
River Managers group	The nation's economic performance and community functioning remains at risk from flooding of our major river systems. Events with a return period on par with the March 2010 earthquake may cause damage and disruption on the scale of that event.	The development and implementation of updated (state of the art) techniques for modelling and mapping to determine the economic risk of river flood hazards that are applied consistently regionally and nationally. The application of flood modelling to identify areas of greatest economic risk from flooding combining economic value with flood-risk areas and recommended approaches to mitigate that risk.	This is critical to be able understand and categorise consistently around the country as to which areas are at greatest risk from flooding for strategic local and national planning and decision making. (Note that current best practice for Flood Risk Assessment such as NSZ 9401:2008 Managing Flood Risk – A process Standard; and MFE Preparing for Future Flooding – A Guide for Local Government in New Zealand, May 2010, could form the basis for flood risk assessment from the flood hazard mapping. Riskscape has the potential to assist with this process, however it does not at this time.
	Climate change and future development effects on the economic sustainability of river schemes.	Understanding how the effects of climate change and future development will impact on river systems is critical to their economic sustainability. This includes: Understanding impacts of changes in extreme, annual and seasonal rainfall, sea level rise and storm intensity, on the costs to schemes such as the need for higher standards of protection, more pumping, reduced levels of service or managed realignment of flood defences. Changes to the natural geomorphological (sediment transport and erosion) behaviour of our major river systems. Managing gravel resources and planning for use of this resource in an environment altered by climate change through differences in accretion and degradation. Changes to landform, vegetation and soil characteristics of the catchment and how interventions in these areas can assist in the mitigation of flood risk. Gaining a better understanding socio-economic profiles, energy use and transport choices into the future – including how many people and what assets are at flood risk currently and into the future.	The effect of climate change on extreme rainfall duration and intensity, as well as annual and seasonal changes in rainfall has potentially significant implications for our river systems and flood management.

SIG	Critical issue	Research need	Important because
Local Authority Environmental Monitoring	Regional flood estimation is based on the application of a tool that hasn't been revised nationally since 1989. This is a tool that is utilised throughout NZ for both engineering and flood management purposes. Councils and other engineering agencies need to be able to calculate river flow and flood frequency for the design of structures, however, New Zealand's primary tool for flood analyses is now significantly dated.	The Regional Flood Estimation (McKerchar AI, Pearson CP. 1989. Flood Frequency in New Zealand. Publication No 20 of the Hydrology Centre. Christchurch: DSIR) to be revised and updated. This tool needs to be updated based on the longer flow record and more comprehensive data that is now available throughout the country.	This tool provides a robust methodology that is widely used within New Zealand to enable flood magnitude and frequency to be determined, particularly within ungauged catchments. This document is now 22 years old. Considerably more and better quality data is now available to enable this methodology to be updated. Much improved spatial coverage is now available as well as considerably longer flow records. It is important that the tool be updated to improve flood design information for river works, bridges and culverts. The design of structures that will withstand significant flood events is of critical importance to the New Zealand economy. All Regional Councils and many other engineering agencies reference this methodology when undertaking the design of structures in and adjacent to our nation's waterways. It is important that this design work is undertaken using the best methodology and information available to ensure that efficient use of financial resources occurs in construction.
Regional Policy Managers	There is a need for more and better tools to assist in the analysis of and responses to natural hazard risks.	In this is quite a large portfolio of research need to be considered, including managed retreat, insurance as a tool for managing risk and the 4R's – emergency management. In the past most hazard responses are captured by engineers and this approach has not really given us the tool to manage the residual risk component. Specific criteria against which risk is assessed would be very helpful as would an idea of what's acceptable risk? It is noted that there are some international standards and work in this area, however the criteria aren't specific enough to measure against. What's the spectrum of intervention options?	Generally there is a lack of coverage of the natural hazards area in the original CI&RN document (March 2009). There is an overall need for better tools to assist with the analysis of, and responses to, hazard risks. There are some standards available, but more research is needed to provide a more robust and defensible position to address hazard risk more effectively, and to give decision makers confidence. The key issue is risk management - how to deal with risk. This includes residual risk, which is seen as a critical planning issue around questions of where development is appropriate in relation to our understanding of the

SIG	Critical issue	Research need	Important because
			various risks.
Natural Hazards Group	Councils need to have a better appreciation as to what level natural hazard risk becomes acceptable to be able to use this knowledge in land use planning.	Further research is needed to provide guidance to Councils on how to include natural hazard risk into land use plans and how to determine what an acceptable level of risk is.	There is a need to know at what levels (social, economic, environmental, cultural, and health and safety criteria (LG, RM, CDEM Acts)) natural hazard risk becomes acceptable (CDEM Act, s 3(b)), tolerable (AS/NZS ISO 31000:2009, clause 5.3.5, 6th bullet) and intolerable (SAA/SNZ HB 436:2004, ch 7). There is also a need to provide guidance on how to include hazard risk into land use plans i.e., better tools to assist with the analysis of, and responses to, hazard risks.
	Councils need to be able to predict river flood and flow frequency, however, New Zealand's national flood risk maps are out of date and need to be revised to provide more accurate information.	There is a need for the report 'McKerchar AI, Pearson CP. 1989. Flood Frequency in New Zealand. Publication No 20 of the Hydrology Centre. Christchurch: DSIR' to be revised and updated.	All Regional Councils reference this report for flood flow & frequency but at 21 years old, a review is overdue. NIWA has been aiming for this revision with proposals to FRST & commenced work under other projects, such as Riskscape. But there have been constraints and there is limited progress to date.
Surface Water Integrated Management	Uptake of existing science	An age-old problem of transferability of science into the community and the consequent application; often this is more a time constraint issue of the recipients than science providers. A critical issue and probably a social science research need. Demystifying science to enable informed water resource debates	A lot of science within NZ that has a significant applied component does not get into the community (whether local government, industry or domestic), this has led to duplication of effort and slow uptake, resulting in unnecessary delays in addressing social, economic, cultural and environmental issues. Improving the uptake and articulating the message to multi-sector audiences will improve NZ's environmental performance.

- Vulnerability assessment – post-event data collection
- Cost-benefit analysis when deciding what policies to use, and when designing and building flood works
- Development of best practice flood mitigation planning measures
- Research into ‘typical’ design rainfall hyetographs/profiles
- Appropriate areal reduction factors (currently use UK values)
- Economics of elevated floor levels – exploring the impacts of higher levels as Building Act default (2% AEP) is generally accepted as being too low
- Research on using hazard categories (i.e., high or low) to introduce flood hazard planning measures
- Uncertainty analysis – combining uncertainties from different forecast models to understand any general rules for estimating freeboard etc
- National guidelines for ‘how to’ for hydrologic and hydraulic modelling
- Public education methods for flood hazards
- Methods to monitor RMA plan provisions
- Regional Flood Estimation procedures for small catchments
- Research on retaining water in the landscape, options and limitations on a regional scale
- Managing super design flood events
- Rainfall-runoff research for NZ at a regional level (although large amounts of study have been carried out in this area, runoff determination remains a significant source of error)
- An understanding of the accumulation of post-settlement alluvium on tributary channels and floodplains and how this may affect erosion and deposition in our major river systems
- Better tools and methods for assessing long term sediment erosion/deposition in a river system that are applicable at a regional level
- New Zealand equivalent of Australian Rainfall and Runoff guidance (ARR, currently being revised see http://www.engineersaustralia.org.au/ieaust/index.cfm?44EFEEF4-D50A-BC6D-258F-1DC32BF04011)
- Technical research on sediment transport.

Central government managers were asked: *What gaps do you perceive in flood research in New Zealand?*

Their answers in bullet form are:

- Integrated catchment approaches – applied more consistently and comprehensively
- Integrated climate-land-water- coast system modelling
- Cost-benefit analysis of risk reduction/mitigation measures – understanding of the pricing of risk
- Social and economic impacts of flood losses on communities and industry/sectors
- Transfer of science information between scientists and councils, and between regional and territorial authorities
- Why is the flood risk management Standard not being applied widely by regional councils? Ditto other tools, such as the MCDEM template for post-event effects
- Understanding of consequences
- How much current flooding can be attributed to climate change effects?
- How will rainfall intensities around the country change under climate change?

4.2 Gaps in research – researchers view

4.2.1 Research articles

Recent papers have made suggestions for flood research needs:

- Davies & McSaveney (2011) – state that geomorphic changes in rivers during floods are significant, and need to be properly investigated. Detailed guidelines need to be developed that fit beneath the existing flood risk standard. Climate change effects may be negligible in comparison to the effects on floods caused by inputs of sediment into channel from other geomorphic processes such as landslides and debris flows.
- Smart & McKerchar (2010) – state that flood statistics show do not show an increase in floods through time, that increased flood losses are due to increased development in flood prone areas, and that flood risk management requires better land-use planning to avoid the hazard risk.
- Glavovich et al. (2010) – state there is a need for further understanding of social dimension of hazard risk, including likely social impacts and how to build community resilience with an eye to climate change. They also discussed making research both policy relevant and written in a way understandable to planners and decision-makers, and raising hazard awareness amongst decision-makers.

4.2.2 Answers from researchers

The following summary is based on information gathered from researchers mainly at NIWA and GNS Science, in answer to the question: *What gaps do you perceive in flood research in New Zealand?*

The gaps identified are listed in bullet form, with short descriptors, and in no particular order. In an attempt to be inclusive, all bullets with very similar issues have been retained so there is some duplication, and similar topics are grouped together where this was possible.

- Re-doing regional flood frequency analysis of McKerchar & Pearson (1989) as data and method now 30 years old, and develop a revolving maintenance programme so that key analyses like this get updated regularly (every 5-10 years)
- Improve national and regional flood fragility curves
- Other tools to standardise assessment of consequences
- Widespread LiDAR coverage and national database
- Improved (co-ordinated) catchment land-use information
- Improved observation networks
- Physics of sediment transport flow interactions to better model active channels during floods
- Consequences of provision of hazard information on LIMs (do people understand it, does it change their perception or lead to different property investment behaviour)
- Flood impacts database (see also Walton et al. 2004a)
- Socio-economic scenarios for future population growth, building densities etc for long-term planning (including climate change)
- Improved understanding of floods related to thunderstorms using new high-resolution weather forecasts
- Impacts of land-use changes on extreme floods (100yr +; super-design floods)
- Flood estimation for extreme floods e.g., PMF – how to estimate for dam design
- Rainfall in alpine areas
- Integrated flood management planning, i.e., all hazards in one catchment, issues and consequences for total catchment bundled
- Case studies of climate change and flood estimation
- Regional climate modelling – use that to drive a detailed weather model and runoff model and inundations – what do floods look like in 2070?

- Continue to improve flood forecasting tools (e.g., EcoConnect) through validating forecasts and improving their accuracy
- Provide error estimates from multiple uncertainty sources, and help with decision-making under uncertainty
- Exploiting future opportunities of developing and assimilating remote sensing products for near real-time assimilation for forecasting and/or post event analysis
- Understanding and communicating risk (what risk is acceptable in making development decisions) and comparing across hazards
- What lessons can we learn from Chch earthquake that are relevant to floods?
- Research needs to be more integrated: flood modelling, forecasting etc. are always done separately
- Need to look into how this can help warning people, how do we get the message across, etc.
- A big question is, given all we know about floods physically, why are poor decisions relating to flooding still occurring?

4.3 Barriers

4.3.1 Barriers that prevent research being taken up by managers

The following summary is based on information gathered from researchers and central government managers, in answer to the question *What barriers do you think there are that stop research being taken up by managers?*

Researchers:

- Funding and data ownership issues – when work is for regional councils, findings may not be nationally available (see also Lawrence 2006)
- Research often stops with delivering results / report -> no follow up to disseminate information i.e., implementation of research into practice is often not funded
- Lack of communication between researcher and councils
- Lack of single repository for flood hazard information
- Research reports are too long and technical – need lay summaries (see also Glavovich et al. 2010)
- Lack of strategies within CRIs as to how to disseminate research results to practitioners
- Science vs policy worlds (Mars vs Venus; see Rouse & Norton 2008): use different jargon, have different timescales in mind

- Science needs to demonstrate benefit of tools
- Science needs to acknowledge and demonstrate that managers are the decision makers
- Operational needs – floods happen at weekends when researchers aren't there
- Tools need to be robust and available to make decisions NOW
- Managers don't always know what questions to ask or what is possible in terms of new approaches to forecasting or analysis tools
- Regional fragmentation of management and research (regional investigations happen on an ad hoc basis, i.e., relevant to region but not necessarily nationally)
- Lag time between research being done and published and widespread uptake
- No national guidance to help managers select methods & tools (e.g., no equivalent of ARR)
- No agreed mechanism for making unofficial guidelines or tool 'the accepted' way of doing things – councils may not use 'new' tools until they become more established and widely used
- Answer from the new research or tool is 'too difficult' to manage so the tool is rejected.

Managers:

- Capacity & capability in local government – variable across country
- Regionalised approaches and systems
- Lack of awareness or lack of incentives to seek out research
- Limited incentive to share data across networks
- Limited understanding of flood hazard in communities inhibiting informed dialogue about acceptable risk
- Lack of resources ($$)
- Lack of best practice examples.

4.3.2 Barriers to management

River managers were specifically asked: *What are the barriers that hinder you from managing flood hazards for your communities?*

- National guidance on setting flood protection standards aligned to assets and infrastructure at risk would be useful. (Currently there are large communities with flood protection designed to a standard set 40 to 50 years ago. A national standard would give direction and consistency to flood protection. This should include avoidance of the flood hazard)

- Lack of a National Policy Statement
- Lack of legal framework for assessment and management of residual risk
- The focus of the Building Act is for a 50 year building life. There is no risk based approach in the Building Act (i.e., uses the same approach for 1 house in floodable area or 100 houses)
- More prescriptive regulations to prevent building in flood prone areas would also lessen the flood risk
- Lack of money for protection works (more always useful)
- Lack of ability to acquire river corridors so that rivers can be controlled and works upgraded through time without arguing with land/property owners
- Lack of money to do more work, which may demonstrate that floods are low priority for community and thus council, perhaps due to limited understanding of risk, especially consequences of floods
- Lack of awareness of risk, especially in periods when no floods are happening
- Other priorities for resources.

In addition, the questions regarding gaps and barriers which researchers and central government managers were asked (sections 4.1, 4.2) often resulted in responses which were more relevant to identifying problems with the current flood management framework rather than flood research or tools. These barriers to management include:

- Policy gap – an NPS needed but this needs to cater for regional variation
- Longer timeframes needed for planning (NPS should require this, and a precautionary approach)
- Poor relationships between key legislation e.g. RMA and BA timeframes (50 year for BA floor levels is too short)
- Where consequences of floods are not properly understood, it is easier for development needs to outweigh precautionary approaches in consent decisions. Also, if consequences are not properly explored, the cost part of cost-benefits analysis may be underestimated
- Lack of community understanding and agreement on what level of risk is acceptable (requires full understanding of flood consequences)
- Hazard information not available in planning documents (flood risks not obvious to developers)
- Staff turnover in councils leading to lack institutional knowledge – better systems required to aid retention of knowledge and good practice
- Low level of flood hazard perception, or false sense of security due to warning systems or flood protection works

- More research identifies more uncertainty and more research needs – but while this loop repeats, managers need to use the best available information to make a timely decision
- RMA as implemented now (with no national tools like NPS and NES) is not strategic.

4.4 Lessons from overseas

Major floods in the UK in 2007 resulted in the country's largest peacetime emergency since World War II. This triggered a governmental review to see what lessons could be learned from the experience. The resulting report (the Pitt review 2008) gave a total of 92 recommendations across a range of topics from science (developing models), warning systems (improving forecasting), organisational responsibilities, public awareness, hazard planning, and flood response activities.

Although the UK legislation and frameworks for flood management are different to the New Zealand ones, a few of the key recommendations with regard to science needs may be useful for our own flood research thinking. In particular the Pitt review gave recommendations that there is a need to:

- Continue to improve forecasting and predicting methods to a level which meets the needs of emergency responders (real-time, easy to communicate)
- Further develop tools and techniques for predicting and modelling river flooding, taking account of extreme and multiple events and depths and velocity of water
- Urgently take forward work to develop tools and techniques to model surface water flooding
- Improve technical capability to forecast, model and warn against all sources of flooding
- Progressively develop and bring into use flood visualisation tools that are designed to meet the needs of flood-risk managers, emergency planners and responders.

The Pitt review also made recommendations regarding the organisations involved in flood management. For instance the review recommended that the UK Met Office and the Environment Agency (science providers and response emergency managers) work closer together on forecasting and flood warning. The Pitt review also recommended that greater effort should be made raising community awareness and preparedness for floods (such as preparing a 'flood kit' of key survival equipment and key documents).

4.5 First thoughts for an improved New Zealand flood research agenda

Given the preceding information, this section provides a summary of key themes or topics that will benefit from further research or development of tools, and pulls together suggestions that are aimed more at improving the strategic framework for managing floods. These two areas have clear synergies, and it is sensible that while taking steps towards establishing a nationally consistent research agenda for flood hazard research, comments regarding the potential for improving the flood management framework are also made.

4.5.1 Topics and themes for research and tool development

Intersecting evidence from the above section supports the need for further research or development of better tools for the following topics/themes[11] (in no particular order):

1. Regional flood frequency estimations – this need has been agreed to by researchers and practitioners for several years but other than updates for some regions previously supported by NIWA's RiskScape funding, it has not progressed any further (i.e., been sustainably funded). It is recommended that a 'maintenance' programme is also established to make sure this work is regularly updated.

2. Geomorphic feedbacks and physics underlying flow and sediment interactions and lags – the complexity of sediment and water interactions during floods requires more basic research and the development of more practical methods to enable prediction of channel changes during floods. Wider geomorphic landscape changes, such as landslides, earthquakes and debris flows, also impact on sediment inputs to channels which can affect flows, and should be better quantified.

3. Joint probabilities – methods for estimating joint probabilities for combined hazards such as the combination of river floods and coastal processes that contribute to coastal and lowland river inundation events need improvement.

4. Vulnerability assessment – improved methods for estimating potential direct flood damage costs are required, such as updating flood-hazard fragility curves for various asset classes. Methods for assessing indirect costs and social costs should be standardised. The current lack of work in this area may be one of the reasons why the consequences of floods in New Zealand are underestimated, and hence not properly weighed in cost-benefit analyses required for decision-making.

5. Post event impacts assessments – a standardised approach to collecting flood damage information following flood events is essential to build a national picture of impacts and contribute to improved flood fragility curves. The MCDEM has (in 2006) provided a hazard event reporting template (http://www.civildefence.govt.nz/memwebsite.nsf/wpg_url/for-the-cdem-sector-cdem-groups-group-resources?opendocument), but there is potential for a considerable amount of variability in its interpretation and use, and it is not clear how widespread the use of this tool is. Developing a centralised database to hold such data may also be useful – see point 8.

6. Engagement tools – social science research in the area flood hazard awareness and preparedness should be drawn together to provide good practice methodologies for community engagement, to improve the 'personal responsibility' principle of flood risk management. Such work would complement existing MCDEM *Community Engagement* guidance. Similar work has recently been completed in a MSI funded *Coastal Adaptation to Climate Change* project (Rouse & Blackett 2011) which could be adapted to river flood situations. A potential host for such information is the MCDEM

[11] This summary list developed from the full lists given in early parts of section 4, and is not extensive.

website (or see point 4 in section 4.5.2 below). While engagement processes are often heavy on time and resources, the benefits to such work should result in decreased clean-up costs following future flood events.

7. Widespread provision of LiDAR data – this need has been identified for the coast in the SIGs research priorities document, and for river floods by practitioners and researchers. LiDAR is a best practice approach to gathering accurate topographic information over wide areas, vital for inundation modelling and mapping, and the assessment of flood vulnerabilities. National co-ordination of this data may be helpful; LINZ may be a suitable lead organisation (perhaps through their National Elevation Data Framework project, see http://www.linz.govt.nz/topography/national-imagery-coordination).

8. Database of GIS flood information – another data related tool that may be useful is a centralised repository for flood related information, to enable river managers to access current good practice information. This could be hosted by the Natural Hazards Platform.

9. Improvements in flood forecasting tools – continuing to improve flood forecasting tools (such as EcoConnect) through validating forecasts and improving their accuracy. This includes all stages of weather (rainfall) forecasts, linked rainfall-runoff predictions, forecasts of sea level, and models of inundation, to improve the ability to forecast at very short time scales.

10. Improvement of flood visualisation methods – for flood forecasting, during event flood warnings, and general public awareness and preparedness, better methods of presenting and visualising flood extent, depth, velocities and damage information are required. This includes visualisation of floods under climate change scenarios.

There are many other ideas for research needs identified in this report, but other front-runners for further work include: methods for understanding super-design floods; methods for monitoring the effectiveness of RMA plan rules on flood risk reduction; developing other tools to better assess the effects of floods; testing different tools to aid decision making in regard to flood reduction options (such as how to define acceptable or tolerable 'residual' risk for a community); understanding why certain tools (such as the flood risk management Standard or post event effects templates) are not used by councils; exploring minimum floor level requirements; and the development of advice for considering multiple-source scientific uncertainties in flood predictions when making flood risk management decisions.

It is also worth noting that some tools do exist in many of the above areas, but often they are advanced tools requiring high inputs of data and resources (time), or are still under development or very recently produced by research programmes, and so are not in the realm of the manager/practitioner yet. Further work is needed to produce robust tools suitable for managers use – and interactions between researchers and managers is vital to the success of this information and tool transfer process.

4.5.2 Suggestions for an improved flood risk management framework

It appears that flood management is subject to similar barriers as found with coastal erosion management (e.g., Blackett & Hume 2011) which include:

- Lack of clear national directive
- Poor representation of national or regional interests in local decision making
- Absence of long term planning
- Power issues in matters of development vs community, and
- Resourcing and information gaps in councils.

Potential steps that might improve flood management in New Zealand include:

1. While the RMA allows for the provision of national tools such as NPSs and NESs, as implemented to date this strategic level of direction is missing for flood risk management in New Zealand. **National direction** using the available RMA tools (NPS and NES as appropriate) would help provide a mandate for issues such as long-term strategic planning for community resilience, and a precautionary approach. However an NPS must allow for regional variability to allow for differences in flood hazard risk issues.
2. In the absence of such direction, **national guidance** should be developed from existing best practice sources (Opus 2001, Tonkin & Taylor 2006, MfE 2010a) and compiled into a single approved guidance (probably requiring endorsement by MfE). This could include development of a 'toolbox' of methods for different aspects of flood risk management, building on the MfE climate change flood 'Tools' guidance. This may benefit from a 4 R's approach, and should include work on flood vulnerability and flood awareness and preparedness. A recent move by river managers to develop a New Zealand equivalent of the Australian Rainfall Runoff (ARR) manual could be part of this work. Envirolink 'Tools' funding may be appropriate to support some of this work. Guidance should aim to ensure the mainstreaming of flood (including climate change) risk management into normal planning processes.
3. The concept of **integrated catchment management**, such as how to integrate 'all hazards' thinking with flood risk management, or how to incorporate flood risk management with other aspects of water management (water allocation and harvesting issues, water quality) needs to be explored. Joint probabilities research may help in this area, particularly in coastal areas.
4. **Information transfer** between researchers and councils, and between regional and local government, should be improved. One potential avenue is the development of a river flood risk website (the Hazards Platform or the joint NIWA/GNS Natural Hazards Centre would be an obvious hosts). A website could host flood impacts data, guidance materials, LiDAR data, and other GIS data identified in the research and tools list above. Funding would be needed to maintain this website. Other methods for information transfer include workshops and training opportunities as discussed in point 5 below.
5. Methods to address the acknowledged **variability in capability (skills) and capacity (resources) at regional level** need exploration. Accessing knowledge from experienced river flood managers and researchers through professional development

opportunities is one method to share capability. This may include memberships of group such as the Rivers Group (a Joint Technical Group of IPENZ and WaterNZ; see http://www.ipenz.org.nz/riversgroup/), attending workshops and conferences, and training provided by research institutes or other developers of guidance and tools. Some capacity gaps may be addressed by using Envirolink funding to share advice with eligible councils.

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Appendix A Annotated Bibliography of key documents

Reference	Summary comments
NZS 9401:2008 Managing flood risk - A process Standard	Provides an agreed best practice approach for local and central government, professionals (planners, engineers, hydrologists, scientists, risk managers, lawyers and so on), developers, utility suppliers, property owners, and communities to ensure that proper consideration is given to all aspects of flood risk when making decisions, so that over the longer term, the risk of flood damage decreases. Intent – informed decisions based on a fuller understanding of cause, effect and likelihood of flooding
MfE (2008a). Meeting the Challenges of Future Flooding in New Zealand. Ministry for the Environment and The Flood Risk Management and River Control Review Steering Group, ME 900, August 2008.	This review was carried out following some large floods in New Zealand in 2004, and covers 3 key topics: the roles of central government, local government and communities in flood management; funding and affordability; and an assessment of current flood risk management practices. The review contains the Steering Group's vision and a set of principles to guide future flood risk management. With regard to the role of science there are a number of key findings from the review in the Appendices to the document, where 36 questions were used to explore 7 key areas of flood risk management. In particular Q10 looks at whether the science needs of flood management practitioners are being met by current science programmes. The review found that the need for primary data collection such as rainfall and river flow was being met, although access to this data was constrained in areas, a matter exacerbated by underfunding of databases. On the other hand more applied needs were not being met, and a specific example of the need to updated national flood estimates was given as a high priority example. Other gaps included: updating of high-intensity rainfall database, and more information on the social, economic and environmental effects of flooding. Barriers to communication between scientists, practitioners and decision makers were also looked at (Q11), and opportunities to improve information transfer can be determined from these barriers. National guidance is needed in a number of areas, including for understanding the effects of climate change on floods (Q19). Better ways to communicate information about flood risks was also needed (Q30).
Day, T.J. (2005a). Managing flood risk: the case for change. Centre for Advanced Engineering, 2005.	First document in series, from which the *Managing Flood Risk: draft flood management protocol* was developed. The report covers drivers for change to flood management at the time, and calls for a nationally recognised risk management framework and some agreed principles for decision-making regarding floods. The report comments on the division in the 1990s of responsibility for flood research from flood management, citing this as a reason why a focussed research agenda for pure and applied flood research has not emerged.

Day, T.J. (2005b). Managing flood risk: Draft flood management protocol. Centre for Advanced Engineering, December 2005.	Second document in series, follows *Managing Flood Risk: The case for change*. The *Protocol* document aims to provide councils with a decision making framework through which flood risk can be addressed. It has a strong risk management focus, and contains 22 implementation 'principles' under the headings of 7 'elements', which include understanding natural river processes, interaction of natural and social systems, context based decision making, continuing community engagement, appropriate forms and levels of protection, recognition and treatment of residual risks, and adaptive management.
LGNZ (2011). The Local Government case for a National Policy Statement for flood risk. Local Government New Zealand, February 2011.	Focus of this document is the LGNZ case to central government in support of an NPS for flood management, to add weight at the top of the RMA hierarchy for planning in regard to flood risk management. The document outlines national benefits to helping to reduce costs that occur due to flood event recovery and in defending cases through court where councils are taking precautionary or flood risk management approach that is being appealed by other parties. Clarity on the specific issue of RMA s85 (compensation wrt controls on land) i.e. public good vs private land rights are also discussed as a benefit to an NPS.
Ministry for the Environment. (2010a). Tools for estimating the effects of climate change on flood flow: A guidance manual for local government in New Zealand. Woods R, Mullan AB, Smart G, Rouse H, Hollis M, McKerchar A, Ibbitt R, Dean S, and Collins D (NIWA). Prepared for Ministry for the Environment.	Purpose - The main aim of this guidance manual is to help local authority staff – including river managers, engineering staff and asset managers – to manage and minimise the risks posed by increased flood risk due to climate change. More specifically, the manual provides good practice guidance for incorporating climate change impacts into flow estimation. It does this by providing: • information on the key effects of climate change on flood risk • methods for estimating changes in the frequency and/or magnitude of rainfall • methods for converting changes in rainfall to changes in flow rate • methods for converting changes in flow rate to changes in inundation • some case studies to illustrate these methods. The manual offers a list of options but is neither exhaustive nor prescriptive. In other words, it is not a handbook for flood estimation or flood risk management. The document describes screening and advanced tools for: estimating changes in rainfall, estimating changes in river flows, and estimating changes in inundation. It also provides some case study examples, and discussion of some issues relevant to flood engineering.
Ministry for the Environment. (2010b). Preparing for future flooding: a guide for local government in New Zealand. ME1012	*Preparing for Future Flooding* is a 30 page summary of the Ministry's technical report *Tools for Estimating the effects of climate change on flood flow*. It provides an overview of the expected impacts of climate change on flooding such as changes in rainfall, temperature, sea-level, storminess and sediment transport processes. It

	provides good practice information and guidance to help local authorities incorporate climate change impacts into flood risk management planning through providing examples of approaches local government has taken.
Tonkin & Taylor Ltd (2006). Natural Hazard Management research report, prepared for the Ministry for the Environment.	This report provides an overview of hazard management in New Zealand, covering hazard identification, how to estimate hazard magnitude-frequency and consequences, how to assess and prioritise risks, potential treatment of risk (using the 4 R's), and an overview of the planning and legal framework, including case law and best practice examples. While most of the document takes an 'all hazards' approach, the best practice section includes a flooding hazards section. A selection of objectives, policies and methods from different regional and district plans are given, as well as some other mechanisms for flood management.
Opus (2001). Floodplain Management Planning Guidelines: current thinking and practice in New Zealand. SMF project (with regional and central government partners & supporters)	These guidelines provide a background to floodplain management planning, one aspect of which is a shift from more structural approaches to river control. They provide a floodplain management planning framework which has a risk management basis, requiring identification of the flood hazard, technical investigations to assess the flood hazard risk, identification of mitigation options including structural and non-structural methods, and final selection of options. The framework involves ongoing communication and consultation, and monitoring and review during this process. The guidelines give case study examples at all stages of this process. The guidelines also comment on consultation and decision-making, and provide information regarding legislative roles and responsibilities. Finally they provide catchment specific case studies from a number of regions.
Smart, G.M.; McKerchar, A.I. (2010). More flood disasters in New Zealand. Journal of Hydrology (NZ) 49(2):69-78	Smart & McKerchar's key findings are that: ▪ There is an increase in reported flood damage in New Zealand ▪ There is no evidence that floods are increasing in size or frequency ▪ Risk has increased due to increased development in flood plains ▪ Location of floods is affected by climatic conditions eg El Nino (NB El Milfo index for Milford Sound!) ▪ There are tools available to accurately evaluate flood risk, such as LiDAR to develop DTMs, rainfall-runoff models, and inundation models ▪ Regulation ie the Building Code allows a high

	level of flood risk ▪ Reduction in flood damage therefore will require better management either through river engineering or improved land-use planning and other regulations
Davies, T.R.H. & McSavemey, M. (2011). Bedload sediment flux and flood risk management in New Zealand. Journal of Hydrology (NZ) 50(1):181-190	Key theme of the paper is that rivers are not just conveyors of water but also sediment, and changes to channel due to bedload and suspended sediment flux can cause large changes to channels. Traditional flood assessment methods have concentrated on water and ignored the complicated feedbacks between channel and sediment movement. In particular active geological landscapes (landslides, earthquakes, debris flows) can contribute large amounts of sediment to the system. They suggest that the New Zealand flood risk standard provides a suitable high level framework that such effects can be considered, but that operational procedures for flood assessment including geomorphic interactions need to be developed. They further suggest that given the potential consequences of geomorphic interactions on floods, they are significant enough to warrant action, and that perhaps climate change effects in floods may be negligible in comparison.
Pitt, M. (2008). Learning lessons from the 2007 floods (The Pitt review). Report to the UK government, ES25.	This report details recommendations as a result of lessons learned from UK floods of 2007. Findings include: ▪ step change in the quality of flood warnings required ▪ closer cooperation between the Environment Agency and Met Office ▪ improved modelling of all forms of flooding ▪ wider brief for the Environment Agency to take an overview ▪ more can be done to protect communities through robust building and planning controls ▪ better planning and higher levels of protection for critical infrastructure are needed ▪ greater involvement of private sector companies in planning to keep people safe in the event of a dam or reservoir failure ▪ need to be more open about risk ▪ people would benefit from better advice on how to protect their families and homes ▪ levels of awareness should be raised through

	education and publicity programmes. A total of 92 recommendations are made across a range of topics from science (developing models), warning systems (improving forecasting), organisational responsibilities, public awareness, hazard planning, response activities.

Appendix B Survey Questions

Purpose of the survey – to find out from councils what tools they use, what are the barriers to progress, if and how they use research and what new research needed, what new tools are needed

1. Please identify the area of council that you work in (e.g. operations/flood engineering, planning, Civil Defence and Emergency Management)

4. What tools do you currently use to help you to manage flood risks? (e.g. monitoring of river cross-sections, river flow monitoring, flood forecasting, modelling of rainfall-runoff or inundation mapping, flood hazard mapping, other regulations)

5. Do you integrate current scientific (physical or social) research into your flood management activities? Yes/No.

   1.1 If Yes, where do you normally source this research (e.g. peer-reviewed journals (which ones?), conferences or workshops (which are best?), websites, inter-council groups (such as the River Managers Group))

   1.2 If No, what are the main barriers to this?

6. How useful do you find national regulation and guidance, such as:

   1.3 The New Zealand Standard for managing flood risk (NZS 9401:2008 Managing flood risk - a process Standard)

   1.4 MfE Guidance documents (e.g. *Tools* manual or *Preparing for future flooding*)

   1.5 Others?

7. What are the barriers that hinder you from managing flood hazards for your communities? (e.g. resources, other priorities for council, lack of community awareness of the flood hazard, lack of political will, lack of national guidance)

8. Overall, do you think your council's management of flood hazards is adequate?

9. What other research do you think is required to help you better understand flood risk for your region/area?

10. What other tools would help you to better manage flood risks?

Many thanks for your consideration of these questions.

Appendix C Questions for discussions with key informants

Questions around their perception of state of flood research in New Zealand, barriers to research uptake, and gaps in research

Researchers

1. What research or tools are you aware of that contribute to the management of flood risk in New Zealand?

2. What research do you think has been done (by you or others) that should be informing flood management but isn't?

3. What gaps do you perceive in flood research in New Zealand?

4. What barriers do you think there are that stop research being taken up by managers?

5. How do you communicate your research findings to flood managers?

6. Who else should I talk to about this?

Central Government Managers

(note – managers from councils are covered under survey questions in Appendix B)

1. What research or tools are you aware of that contribute to the management of flood risk in New Zealand?

2. What research do you think has been done that should be informing flood management but isn't?

3. What gaps do you perceive in flood research in New Zealand?

4. What barriers do you think there are that stop research being taken up by managers?

5. Who else should I talk to about this?

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