BEFORE THE HEARINGS PANEL

IN THE MATTER	**of hearings on submissions concerning the proposed One Plan notified by the Manawatu-Wanganui Regional Council**

SECTION 42A REPORT OF PETER BLACKWOOD ON BEHALF OF HORIZONS REGIONAL COUNCIL

INTRODUCTION

My qualifications/experience

1. My full name is Peter Lindsay Blackwood. I am currently employed as the Manager Investigations and Design, Horizons Regional Council. I have held this position since 30 October 2006. During the period from September 1996 to October 2006 I was employed as the Manager Technical Services for the Bay of Plenty Regional Council.

2. I am qualified with a Bachelor of Engineering (Hons) and gained my Engineer's Registration in 1982. I have 33 years experience in civil engineering, including project management, flood control and drainage (policy, asset management, design and supervision), river management and protection works, coastal hazards (storm surge and wave run-up), environmental engineering, water resources (particularly flood frequency), global warming policy and design, civil design (including bridging), financial analysis, irrigation and power station construction.

3. I have authored or supervised the production of numerous designs and reports on river hydrology and hydraulics, floodplain management, global warming impacts, river alignments and erosion protection works.

4. I have managed or supervised detailed floodplain management studies on the Whakatane-Waimana, Waioeka-Otara, Waikanae and Otaki River Schemes.

5. I provided the bulk of the key flood hazard and environmental assessment technical input into the Environment Bay of Plenty Hydrological & Hydraulic Guidelines and Regional Water & Land Plan. I also provide expert peer review of hydrological and flood hazard papers for both the NZ Journal of Hydrology and Tephra (a publication of the Ministry of Civil Defence Emergency Management).

6. I have presented papers, on global warming impacts and flood hazard policy responses, to an International Workshop on Climate Change, hosted by the New Zealand Climate Change Office in October 2004 and a New Zealand Workshop, hosted by Marlborough District Council in April 2008.

7. I confirm that I have read the Code of Conduct for Expert Witnesses and that I agree to comply with it, with my duty being to the Hearing Panel.

My role in One Plan

8. In my role as Manager Investigations and Design, Horizons Regional Council, I have provided professional advice on One Plan policies and rules pertaining to natural hazards. This is with particular regard to assessment of flood risks and their avoidance or mitigation. Furthermore, I have advised on the impact of climate change upon these risks and their avoidance or mitigation.

Scope of evidence

9. My evidence focuses on two central themes:
   a. Flood hazard definition; and
   b. Flood avoidance and mitigation.

10. Flood hazard will be defined in terms of:
    - How flooding occurs;
    - Characteristics of flooding;
    - Flood probability;
    - Climate change impacts;
    - Existing flood hazard information;
    - Freeboard; and
    - Impact of development in floodprone areas and scheme areas.

11. Flood avoidance and mitigation will cover:
    - Methods for avoiding flood hazards;
    - Methods for mitigation;
    - Horizons flood management schemes;
    - Why 0.5% Annual Exceedance Probability (AEP) has been selected as the hazard level;
    - Why avoidance is preferable to mitigation;
    - Approach to further development within existing urban areas that are floodprone;
    - Approach to rezoning and urban expansion into floodprone areas;
    - Approach to infrastructure and other development that must locate in floodable areas; and
    - The relationship with Territorial Authorities on transfer of information on natural hazards.

EXECUTIVE SUMMARY OF EVIDENCE

12. Flood Hazard Definition

a. How Flooding Occurs

Flooding occurs when the flood size exceeds the channel capacity. The extent of flooding is determined by both the volume of water spilling out of the channel and the topography of the adjacent ground. Flooding may be confined to the margins of a steeply flowing river, or it may cover extensive areas of flat floodplains.

b. Characteristics of Flooding

Magnitude: This is usually measured by height above a known datum, depth (as presented on flood maps) or discharge.

Ponding: Ponding areas are those areas of still floodwaters where depths may rise, sometimes rapidly, to considerable depths. Evacuation may be very difficult, there could be danger to life and social disruption may be high. Generally, ponding areas are unsuitable for development, unless adequate avoidance and mitigation provisions are available.

Spillway: A spillway is the hydraulic structure which conveys water diverted from a watercourse into an off-river overflow path, floodway or ponding area. The spillway is generally a lowered section of stopbank and short section of connecting overland flow channel.

Overflow Path: The overflow paths are areas of land leading fast-flowing floodwater from the river corridor, across the floodplain. The depth and speed of floodwaters are such that development could sustain major damage. The rise of floodwaters may be rapid and very unexpected. Evacuation of people and their possessions would be dangerous and difficult. Social disruption and financial loss would normally be high. Overflow paths are generally unsuitable for development, unless adequate flood avoidance and/or mitigation provisions are made.

Floodway: A floodway is an area of land where water enters in major floods. Often this land has a predetermined function – to relieve pressure and flooding on other parts of the flood defences. Often an entire floodway may in fact be an overflow path – for example the Moutoa floodway on the lower Manawatu River operates once a threshold flood level is reached in the Manawatu River. It transports these excess floodwaters through a shorter flow path, returning the floodwaters to the Manawatu River downstream of the State Highway One bridge at Foxton. Conversely, some floodways include ponding basins where floodwater is detained until the flood peak has passed in the main river. One such case is the mapped Taonui Basin, which comprises both overflow paths and ponding areas. This floodway contains three components:

i. Spillways crossing stopbanks at Flygers Line, Kopane, Rangiotu and Hamiltons Line;
ii. Overflow paths transporting the floodwaters through the Taonui Basin;
iii. Ponding areas at the downstream end.

Areal Extent: The areal extent of land occupied by floodwaters tends to increase with distance from the headwaters – from constricted upstream valleys, to wide floodplains. Thus the area flooded is not only a function of the flood magnitude, but also channel and floodplain topography.

Flooding Duration: Water may flow in overflow paths for a period of time similar (but not exactly the same) as the period the hydrograph is above "bankfull". However, water may remain trapped in ponding areas for significantly longer. Prolonged flooding often leads to an increased burden of cleanup (and great chance of total loss) due to higher sediment deposition and general deterioration.

Speed of Onset: The suddenness with which a flood develops is significant for human adjustment on the floodplain. In small catchments flash-floods quickly follow high intensity rainfall, giving little or no useful warning time. In contrast, on bigger river catchments there may be several hours or days warning time. Horizons Regional Council is progressively installing flood forecasting systems in major catchments, with an associated Interactive Voice Response (IVR) automatic communication system. In the Region the Manawatu River has the greatest advance warning time of just over a day to lower-lying areas. Advance warning helps reduce the risk to health and life, but often cannot reduce property losses – bar removal of valuable possessions in a few cases. However, flooding may well occur at night and advance warning cannot reliably be employed to reduce property losses.

c. Flood Probability

The relative magnitude of a flood for many years has been expressed in terms of an average "return period". For example, a 100 year return period flood is the magnitude flood that occurs on average once every 100 years. However, when floods occur in nature is very largely a random event. The so-called "100 year flood" may not occur at all in any given century, and conversely, there may be several "100 year floods" in a given century, possibly only a year or less apart.

To remove confusion about what the return period means, it is now common to express the flood in terms of an "Annual Exceedance Probability" (AEP). This is the inverse of the return period. Thus a 100 year return period equates to a 1% AEP. This flood has a 1 in 100 chance of occurring in any given year. A 200 year flood equates to a 0.5% AEP (1 in 200 chance).

d. Climate Change Impacts

A sound basis for dealing with the impacts of climate change is presented in the publication "*Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand*", May 2004, New Zealand Climate Change Office, Ministry for the Environment. These overview guidance notes contain an effects and impacts assessment. These guidance notes were applied to determine the likely impacts of climate change on flood risks as follows:

- Based on the "mid-IPCC" (International Panel on Climate Change) projections the temperature in the Manawatu-Wanganui Region will rise by close to 2.0 degrees by 2080. This value ranged between 0.3 and 3.8 degrees, depending on the IPCC scenario considered;
- The temperature rise results in an increase in rainfall intensity in the 1% AEP storm of between 11 and 16 percent (dependent upon storm duration);
- The corresponding increase in the size of the 1% AEP flood flows is:

Whanganui River	+15-18%
Manawatu River	+19%
Small catchments	+20-24%

- The current 0.25-0.33% AEP flood (300-400 year) becomes the future 1% AEP flood by 2080;
- For the Manawatu River the current 0.5% AEP flood becomes the future1% AEP flood in 2053.

In May 2008 the Climate Change Guidance Notes were updated for more recent information. The principal changes were:

- The average rise in temperature by 2090 is 2.1 degrees;
- Thus the corresponding increase in the size of the 1% AEP flood flows is now +20-25% for all river systems;
- Thus the impact on the Whanganui and Manawatu Rivers (and other watercourses) will be slightly higher than previously forecast and thus around the current 0.2% AEP flood (500 year) becomes the future 1% AEP flood by 2090;
- A revised detailed analysis of the Manawatu River shows that the 0.5% AEP flood, as assessed based on data available to 2005 (being the design data which current estimates are based upon), becomes the future 1% AEP flood in 2051.

e. Existing Flood Hazard Information

Horizons Regional Council is well advanced on a comprehensive programme of flood hazard mapping on its principal floodplains. These studies are based on state-of-the-art computer models and recorded flood data and are an accurate basis for estimating flood hazards. Details of how these analyses are conducted are presented in the body of the evidence.

A summary of the Lower Whanganui River modelling is presented as an example of the complex procedures followed. For this river-inundation maps were prepared for the 2%, 1%, 0.5% and "Global Warming" (1% in 2080) floods. The 0.5% AEP flood inundation maps are presented in Appendix One.

Flood hazard modelling is completed on the floodplains and rivers of the Lower Manawatu, Taonui Basin, Mangaone, Tutaenui, Whanganui, Mangatainoka/Makakahi and Waikawa/Manakau. Some of these models also focus on design flood levels resultant from potential stopbank breaches (that is a collapse of the stopbank). Detailed computer models have also been constructed for other major rivers including the Rangitikei, Oroua and part of the Ohau. These models can be applied to determine site flood hazards.

Information on historical flooding is also held in various forms. This information cannot usually provide adequate precision on design levels for a specified probability and will no doubt contain no information on some areas that do flood.

f. Freeboard

The information presented in the detailed computer modelling can be regarded as a sound basis for assessing flood hazards. However, it has to be remembered that in modelling allowance has to be included for the many complexities of nature. Thus to these models needs to be added design freeboard.

Horizons Regional Council specialist engineering staff generally recommend a freeboard of 0.5 m; however in the Taonui Basin it is reduced to 0.3m for two reasons. Firstly, increases in heights of floodwaters at the spillways filling the basin are spread over a large area, with lesser increases in basin flood heights and; secondly, because of the tranquil nature of the ponding area.

g. Impact of Development in Floodprone Areas and Scheme Areas

"The *flood hazard* is defined as the interaction between two systems: the physical flood event and human use of the floodplain. Characteristics of the *physical flood event* that are important for analysing impacts on human occupation of the floodplain include in particular: magnitude, frequency of occurrence, speed of onset, and areal extent of flooding. Characteristics of *human use of the floodplain* important for analysing flood impacts include: perception of risk; types, densities and distributions of land uses and social organisation on the floodplain. Clearly, then, the flood event is not in itself the *flood hazard*. Its potential for hazard is not realised until related to people and their works. Thus, flood potential – defined mainly in terms of human casualties, property damages, and social disruption – depends not only on the characteristics of the flood event, but on characteristics of human activity on the floodplain" (*"Creating Flood Disasters"*, 1986, Dr N.J.Ericksen, NWASCA Water & Soil Miscellaneous Publication Number 77).

In floodable areas developments pose two principal types of risks:

- Risks to the inhabitants and the development itself; and
- Risks to other inhabitants and developments and flood protection infrastructure and effectiveness.

The risks to the development itself are direct losses from flooding, including damage to both buildings and their contents. Furthermore, there may well be threats to health and life. Social impacts can be high.

Unless the "residual risk" (risk resulting from floods either larger than the stopbank design, stopbank breaches or other causes) is low, it is unwise to put developments in these areas. Even though a stopbank is constructed, the increased development behind the stopbank increases the potential vulnerability to flood risks – as has been evidenced time and time again in this country.

As an example of the vulnerability to flooding an economic assessment of potential flood damages to Wanganui from the Lower Whanganui River concluded:

- Total potential flood damages to existing developments in Wanganui from Whanganui River flooding total $91 million in the 1% AEP flood and $141 million in the 0.5% AEP flood;
- Potential flood damages are particularly high in the Balgownie industrial area, totalling $60 million in the 1% AEP flood and $95 million in the 0.5% AEP flood; and
- The probability weighted average annual damages would average $2.7million per annum over time.

Estimates of potential flood damages to Palmerston North from the Manawatu River and Mangaone Stream were made for five scenarios in 1994. These scenarios ranged from the then 1% AEP estimate, with breach at Fitzroy Bend, to a flow 70% larger than that flow, with multiple breaches. The Mangaone scenario was the maximum flow of the 10% AEP (the remainder travels down the Flygers Line floodway). The estimated flood damages ranged from $70.5 million to $514 million (1994) with between 1,060 and 6,500 buildings flooded. Estimated annual damages were $681,000.

Since the assessment of these damages the 2004 flood has shown that the Manawatu River at Palmerston North flows at greater flood heights than previously estimated in extreme floods (due to the hydraulic resistance increasing above previous measurements in extreme floods). Thus more water would flow through Palmerston North than previously estimated and the estimated flood damages and number of properties flooded would correspondingly increase. Much of this is now being mitigated by the City Reach project, whereby the flood protection standard for Palmerston North is being raised to 0.2% AEP. However, the damages in the largest scenario will not alter significantly, as it is not practicable to mitigate this risk.

A detailed listing of social and psychological impacts of flooding is presented in Section 8.5 of the reference *"Waikanae River Floodplain Management Plan Phase One Investigations: Summary Report"*, June 1992, Peter Blackwood and Graeme Campbell, Project Engineers, Wellington Regional Council. The detailed listing is as follows:

- Shock and confusion;
- Physical and social isolation;
- Grieving;
- Uncertainty and loss of control;
- Overdependence and difficulty in making decisions;
- Anger and resentment;
- Anxiety; and
- Family Stress.

Therefore, in order to reduce potential flood losses, careful controls are needed in floodable areas.

Risks to others may be created by the development itself – either through infilling overland flow paths and diverting floodwaters onto previously flood-free land; removing valuable flood storage in ponding areas and thus causing an increase in elevation of flood levels; or by other causes.

Similarly, flood risks may well be aggravated by inappropriate development on or near flood mitigation assets (particularly stopbanks). Flood threats may be caused by direct damage to stopbanks (weakening them and possibly creating seepage paths), excavations, mass lowering of the ground profile or unauthorised and/or poorly constructed service pipes (causing seepage paths).

Again, careful controls are required to avoid exacerbating the potential flood losses to others or reducing the effectiveness of the flood protection.

13. Flood Avoidance and Mitigation

a. Methods for Avoiding Flood Hazard

Development on areas vulnerable to flooding, even though seemingly protected to the design standard, will always be vulnerable to flooding from larger floods, or stopbank breaches. Over time these larger floods *will* happen. Therefore, the only feasible way to avoid the flood hazard is to locate development away from floodprone areas.

b. Methods for Mitigation

There is an array of mitigation methods, of varying effectiveness, as follows:

Stopbanks: Stopbanks are usually designed to provide flood protection to a specified design flood standard. They are usually constructed to form a structurally sound earthen barrier. In places where space may be at a premium they may be replaced by designed concrete flood walls, which provide the same barrier to floodwaters.

Detention Dams: Detention dams detain floodwaters, so that peak flows are reduced and floodwater released subsequent to the peak flow – at a significantly reduced flow. The difficulty with detention dams is in sizing the dam to contain flood flows both at the peak of the flood and in the period leading to the peak.

Pumps: Pumps can strategically be used to reduce flood levels, particularly in smaller catchments.

Minimum Floor Levels: Minimum floor levels can be determined to mitigate flood threats to a predetermined design standard. They are less effective in mitigating overdesign floods or stopbank breaches. They can be used in floodprone areas zoned for residential or other uses. Care has to be taken in ensuring that there are safe accesses/egresses from buildings with adequate floor levels. History has sadly shown a prepondency for people to access or leave buildings, which themselves may well be above flood levels.

Filling: Filling is a more effective way of mitigating flood risk and more likely to provide safer access/egress (although it has to be checked that there is a safe connection to higher ground). It does cost more but the flood depths in the vicinity are likely to be less dangerous. The major problem with filling is that it is likely to redistribute floodwaters, so that risks are exacerbated elsewhere – either through cutting off overflow paths or infilling ponding areas. The cumulative effects of several potential filling activities may become significant. Where feasible it is one of the better mitigation options.

Advance Floodwarning: Advance floodwarning can reduce threats to health and life and in bigger catchments the losses to property contents can be reduced – but not the vast bulk of potential flood damages. It is an essential mechanism for developments already built in floodprone locations.

Insurance: Insurance can to a degree mitigate the flood loss potential. However, it does not mitigate risks to health and life. It may also be a most cost ineffective means of mitigation, compared with other options.

c. Horizons Regional Council's Flood Management Schemes

Horizons Regional Council manages nine flood protection schemes throughout the Manawatu-Wanganui Region. Two primary flood protection methods are employed, in five schemes flood control is achieved through peak flow reduction by the storage of water in detention dams. In all other schemes control is achieved through the use of conventional stopbank structures and associated floodways.

Flood protection assets owned and maintained by the schemes are valued at $93 million and include 437 km of stopbanks and 52 detention dams.

The schemes are designed to varying protection standards, with rural standards ranging from 5% AEP to 1% AEP. Large urban areas are typically protected to the 1% AEP standard; however in the case of Palmerston North City, a very high standard of 0.2% AEP has been agreed.

Due to aggradation in some rivers causing loss of flood carrying capacity, it may not prove affordable or possible to retain current protection levels over time and thus considerable care is needed in considering development proposals adjacent to some reaches of these (and other) rivers.

d. Why 0.5% Annual Exceedance Probability (AEP) has been Selected as the Hazard Level

Horizons Regional Council strongly recommends that during a new development's lifetime the flood protection standard be at least to the 1% AEP level. Several studies have been made over time of acceptable/economic flood protection standards and it is generally accepted that new development should be to at least this standard. Whilst a lower standard may be advocated by a developer, they rarely are those who will be vulnerable to the flood risks over the lifetime of the development. Conversely, most in society have the expectation that they will not be flooded and in most cases have little or no preparedness for flooding.

Based on the mid-IPCC climate change projections contained in the 2004 Climate Change Guidance Notes there will be an increase in the frequency of flooding such that

- The current 0.25-0.33% AEP flood (300-400 year) becomes the future 1% AEP flood by 2080;

- For the Manawatu River the current 0.5% AEP flood becomes the future1% AEP flood in 2053.

Based on the foregoing and the "normal" lifetime of a dwelling or industrial/commercial building of 50 years (or longer in many cases) the minimum level of risk tolerable for human habitation was set at 0.5% AEP – being essentially the forecast 1% AEP flood during the building's lifetime.

The May 2008 update to the Climate Change Guidance Notes means that the impact on the Whanganui and Manawatu Rivers (and other watercourses) will be slightly higher than previously forecast. However, it is not recommended that any change be made at this stage to the recommended flood hazard standard of 0.5% AEP.

e. Why Avoidance is Preferable to Mitigation

In the very strong majority of cases mitigation is to a defined flood standard. In almost no cases is it possible to mitigate flooding to the Probable Maximum Flood (PMF) standard. This, as the name implies, is the expected maximum flood flow that could be generated by the most adverse potential storm. Whilst economic and social impact studies may show that mitigation to a much higher standard than say 0.5% AEP is warranted, it is rare to achieve agreements to such mitigation.

This means that development in the land protected is vulnerable to floods higher than the mitigation standard. It is furthermore vulnerable to stopbank breaches.

The inevitable development that occurs behind new stopbanks means that the potential flood losses actually increase, regardless of the mitigation standard. The flood potential that remains is termed the "*residual flood hazard*". This comprises of economic, social impact costs and threats to health and life.

An example of what might happen without avoidance is the case history of the 1984 Invercargill floods. These floods caused at least $55 million in insured property losses. Two-thirds of the built up area in the flooded area was created after the passage of the Town and Country Planning Act 1953. Strong controls are needed to ensure that potential flood risks are not increased.

In response to submissions an attempt has been made to reach a recommendation that does accommodate some mitigation where careful planning has taken place.

In this regard it is recommended that the design flood to be considered for the One Plan should be the 0.2% AEP flood plus forecast climate change to the year 2090 (in terms of the climate change guidelines). This flood has a sufficiently high probability that it is possible to occur within a development's lifespan. The 0.2% AEP design flood standard has been determined as being the optimum protection level in economic terms for mitigation of flooding of Palmerston North from the Manawatu River. This level of flood protection has been favourably received in consultations and adopted by the people of Palmerston North.

In regard to the tolerable risk to health and life, reference is made directly to Figure L1, NSW Floodplain Development Manual – the Management of Flood Liable Land, April 2005. This is presented in Appendix Two.

This graph shows that it is unsafe to wade in floodwaters deeper than 0.8 metre above finished ground level in still (ponded) areas, with the depth linearly reducing to 0.5 metre in waters flowing at 1.0 metres per second. Furthermore, it shows that at velocities in excess of 1.0 metres per second, safety very quickly diminishes with increasing floodwater depth. Whilst there are cases where it may be safe to wade at higher velocities and depths, the variation in velocities and depths due to localised obstructions and debris blockages make it unsafe to contemplate accepting those velocities. Consequently, the residual depth of flooding and velocities acceptable in the 0.2% AEP flood plus climate to 2090 should be based on the criterion stated above.

In addition obviously all development must be protected to the 0.5% AEP flood plus freeboard.

f. Approach to Further Development within Existing Urban Areas that are Floodprone

Further development within floodprone areas must only proceed where future increases in the risks to health, life and property can be avoided or, if that is not possible, mitigated to an acceptable standard. Flood risks within existing areas that are floodprone can be avoided by locating development on areas of higher ground that are not at risk of flooding. However, frequently the undeveloped portion is not on higher ground, meaning that this option is not available.

There are two situations to consider, as follows:

a. Established residential and industrial areas with existing flood protection of greater than or equal to 1% AEP. The 1% AEP standard is considered as several flood protection schemes provide this level of protection; and

b. Established residential and industrial areas with existing flood protection of less than or equal to 1% AEP that are susceptible to inundation.

In my opinion for the first case an allowable increase in the density and additional infrastructure within protected areas should be permitted. This is because there is a reasonable standard of flood protection at present and, as the area is already urban, there is an expectation that development will proceed at some stage. It could be argued that this should be applied only to areas where existing protection is at 0.5% AEP. However, this would apply to fewer areas, as most schemes are to the 1% AEP, and would probably put an unreasonable restriction on those areas.

In my opinion the practice for the second case should be:

- Encourage building in areas not susceptible to greater than or equal to 1% AEP.
- Allow additional and replacement dwellings and infrastructure within designated residential/industrial boundary but only with mitigation that meets requirements of Policy 10-2 (i – iv). In practice this mitigation would mean protection to a 0.5% AEP that doesn't adversely affect neighbours, eg. elevation of building platform to 0.5% AEP standard. (Additional level of freeboard required to establish finished floor level). Furthermore the residual flood risk must be such that floodwaters are unlikely to reach the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual

This situation would apply to towns such as Marton, where the protection scheme provides 4% AEP (1 in 25 year) flood protection – although this standard may now be approaching 2% AEP.

g. Approach to Rezoning and Urban Expansion Into Floodprone Areas

Most non-urban areas are rural and there are three situations within the 0.5% AEP floodable area to consider, as follows:

a. Areas with existing flood protection greater than or equal to 1% AEP and the residual flood risk is such that floodwaters are unlikely to reach the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual;
b. Areas with existing flood protection greater than or equal to 1% AEP and the residual flood risk is such that floodwaters are likely to <u>exceed</u> the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual; and
c. Areas without existing flood protection greater than or equal to 1% AEP that are susceptible to inundation.

In the first situation the development requires suitable mitigation, eg. elevation of building platforms to 0.5% AEP (with additional freeboard to finished floor level). Additional and replacement structures to support farm operation (eg. farm sheds) are allowed. Thus in this situation Horizons Regional Council is clearly recommending avoidance of urban developments on the floodplain.

In the second and third situations the flood risk is somewhat higher and considerable filling of the land and/or other suitable mitigation would be required before there was a prospect of re-zoning and urban expansion.

To summarise, land that could be rezoned or developed for urban use must clearly meet both the following criteria:

- It must be protected to the 0.5% AEP flood standard; and
- The residual risk must be low. That is, in the 0.2% AEP flood plus forecast climate change to the year 2090 (in terms of the climate change guidelines) the depths and velocities must be within those prescribed as safe for wading in Figure L1, NSW Floodplain Development Manual.

h. Approach to Infrastructure and Other Development that Locate in Floodable Areas

This paragraph considers such activities as pipelines, pylons, bridges, dams and the like. Policy 10-4 of the Proposed One Plan states that the placement of new "critical infrastructure" in the 0.5% AEP floodable area (including mapped floodways), or in an area likely to be affected by another type of natural hazard, shall be avoided unless there is no reasonable alternative. The reasoning for this is that these activities are critical to the functioning of the community and must not be unnecessarily threatened with damage and loss of operation. Furthermore, they should not pose a danger to health and life, through requirements to access the infrastructure during floods.

- I agree with submissions that this requirement should not be an impediment to the construction of new bridges. Consequently, it is recommended that the policy be amended to enable bridges to be established in such circumstances. However, it should be emphasised that in assessing resource consents due care needs to be exercised to ensure that any potential adverse effects are mitigated.

In some cases there will be no reasonable alternative and the critical infrastructure will have to be placed in the floodable area.

Typical examples of critical infrastructure, structures and activities that cannot be located elsewhere include manholes for pipelines crossing a wide floodplain, flood mitigation works and possibly even a pump station. The construction of these structures must only occur where there is no reasonable alternative and must be subject to careful assessment to ensure that any potential adverse effects are avoided or mitigated. Conditions that are required to ensure this include:

Avoidance or mitigation in the 0.5% AEP flood of:

- Any restriction to flows and consequent increases in both upstream flood levels and local velocities; furthermore total avoidance of any potential to cause a change in course of flood flows;
- Mitigation of the likelihood of entrapping debris on the structure;
- Mitigation of induced erosion;
- Location of all new pipelines below the depth of scour in the waterway expected in a 0.5% AEP flood;
- Avoidance of structural failure of the structure resulting in adverse effects in the immediate vicinity, or somewhere downstream where structural parts may cause or add to a debris blockage; and
- A clear emergency action plan to cover alternative functioning or repair in the event of flood damage. It has to be stressed in this plan that emergency access can only be allowed under conditions of absolute safety (and that may well mean the structure's function becomes inoperative for a period).

i. The relationship with Territorial Authorities on transfer of information on natural hazards

The information presented in the detailed flood hazard mapping studies can be regarded as a sound basis for assessing flood hazards. Details of the floodplain hazard maps completed and in train, and information transfer, are given in the body of this evidence.

Where the floodplain mapping has not been completed, then Horizons Regional Council may provide the best available advice it holds on the flood risks to that area – with appropriate qualifications as to accuracy and whether further detailed studies are required. Information provided by the Horizons Coordinator District Advice includes site specific information required for Building Consents subdivision appraisals, Plan change appraisals and responses to general enquiries by both general public and Territorial Authorities.

FLOOD HAZARD DEFINITION

14. Flood Hazard Definition

a. How Flooding Occurs

Flood size or discharge is measured as the quantity of water flowing past a point when a flood is at its peak. The unit of flow is cubic metres per second, otherwise known as cumecs (1 cumec = 1000 litres per second).

Flooding occurs when the flood size exceeds the channel capacity (also called the "bankfull capacity") of the river, stream or waterway. On average in most natural channels significant flooding of the surrounding land occurs once the flood size reaches close to the two-year return period flood (50% AEP) – although flooding may occur at smaller flows on aggraded rivers, where the river channel has risen due to deposition of sediment, or braided rivers. In more incised channels it may take a larger flood size to cause flooding.

The extent of the flooding that results is determined by both the volume of water spilling out of the channel and the topography of the adjacent ground. In the steep headwater catchments the flooding may often be contained to a narrow strip of river flats adjoining the channel. However, once the tributaries combine into the rivers crossing the much flatter floodplains, then very extensive areas of land may be flooded. In severe cases a river may avulse (change course) onto a new course, flooding land hitherto considered relatively flood free. This is a particular problem for land located on alluvial fans.

b. Characteristics of Flooding

Magnitude: The size or magnitude of a flood can be measured in several ways, the most common being stage, depth or discharge. The stage (or elevation) is the height of water above a known datum or given point on a river – most commonly at a water level recording station. The elevation also implies a directly proportional depth at that point. However, depth is more commonly a key parameter presented on flood maps. The flood discharge is normally directly computable from the stage, based on physical measurements to form a rating curve.

Ponding: Ponding areas are those areas where floodwaters would pond either during or after a major flood event. Water speed is slow in ponds. However, water levels could rise rapidly to considerable depths. Evacuation of people and their possessions may be difficult, especially on foot, and may need to be by boat or helicopter. There could be danger to life and social disruption may be high. Generally, ponding areas are unsuitable for development, unless adequate avoidance and mitigation provisions are available. Removal of ponding areas may result in adverse effects elsewhere on the floodplain.

Spillway: The engineering definition of a spillway is the hydraulic structure which conveys water diverted from a watercourse into an off-river overflow path, floodway or ponding area. The spillway is generally a lowered section of stopbank and short section of connecting (to the overflow path, floodway or ponding area) overland flow channel, which is reinforced when warranted to convey higher velocity overflows.

Overflow Path: The overflow paths are areas of land leading fast flowing floodwater from the river corridor, across the floodplain. The depth and speed of floodwaters are such that development could sustain major damage. The rise of floodwaters may be rapid and very unexpected. Evacuation of people and their possessions would be dangerous and difficult. Social disruption and financial loss would normally be high. If an overflow path were blocked this could potentially cause a significant redistribution of floodwaters to other areas of the floodplain. Overflow paths are generally unsuitable for development, unless adequate flood avoidance and/or mitigation provisions are made. Considerable care has to be taken in the vicinity of overflow paths to recognise that the floodable area may increase due to other uncontrollable activities, eg. roading, fencing and even buildings.

Floodway: A floodway is an area of land where water enters in major floods. It is often land that has a predetermined function as a floodway – to relieve pressure and flooding on other parts of the flood defences. The upstream end of a floodway usually has the same flooding characteristics as an overflow path – areas of fast-flowing floodwater. Often an entire floodway may in fact be an overflow path – for example the Moutoa floodway on the lower Manawatu River operates once a threshold flood level is reached in the Manawatu River. It transports these excess floodwaters through a shorter flow path, returning the floodwaters to the Manawatu River downstream of the State Highway One bridge at Foxton. Conversely, some floodways include ponding basins, where floodwater is detained until the flood peak has passed in the main river. One such case is the mapped Taonui Basin, which comprises both overflow paths and ponding areas. This floodway contains three components:

i. Spillways crossing stopbanks at Flygers Line, Kopane, Rangiotu and Hamiltons Line;
ii. Overflow paths transporting the floodwaters through the Taonui Basin;
iii. Ponding areas at the downstream end.

Areal Extent: The areal extent of land occupied by floodwaters tends to increase with distance from the headwaters, ie. from constricted upstream valleys to wide floodplains. Thus the area flooded is not only a function of the flood magnitude, but also channel and floodplain topography.

Flooding Duration: The overall shape of the hydrograph (river level graph) above "bankfull" stage indicates the volume of water discharged onto the adjacent floodplain. Water may flow in overflow paths for a period of time similar (but not exactly the same) as the period the hydrograph is above "bankfull". However, water may remain trapped in ponding areas for significantly longer. Prolonged flooding often leads to an increased burden of cleanup, and great chance of total loss, due to higher sediment deposition and general deterioration. For this reason some residents of Paeroa were unable to return to their homes for three weeks after a major flood in 1981 (Paeroa had a population of 3,702 in 1981, with some 1,300 people evacuated, 544 properties flooded, and floodwater water inside 219 homes, some to a depth of two metres ("Creating Flood Disasters", 1986, Dr N.J.Ericksen, NWASCA, Water & Soil Miscellaneous Publication Number 77).

Speed of Onset: The suddenness with which a flood develops is significant for human adjustment on the floodplain. The time needed for an accurate flood forecast is crucial, as is the time taken to communicate that warning to those in danger. In small catchments flash-floods quickly follow high intensity rainfall, giving little or no useful warning time. In contrast, on bigger river catchments there may be several hours or days warning time. Horizons Regional Council is progressively installing flood forecasting systems in major catchments, with an associated Interactive Voice Response (IVR) automatic communication system. In the Region the Manawatu River has the greatest advance warning time of just over a day to lower-lying areas. Advance warning helps reduce the risk to health and life, but often cannot reduce property losses – bar removal of valuable possessions in a few cases. However, flooding may well occur at night and advance warning cannot reliably be employed to reduce property losses.

c. Flood Probability

The relative magnitude of a flood for many years has been expressed in terms of an average "return period". For example a 100 year return period flood is the magnitude flood that occurs on average once every 100 years. However, when floods occur in nature is very largely a random event. They do <u>not</u> occur at preset intervals. The so-called "100 year flood" may not occur at all in any given century, and conversely, there may be several "100 year floods" in a given century, possibly only a year or less apart. This largely random occurrence in nature is represented by a binomial probability distribution.

To remove confusion about what the return period means, it is now common to express the flood in terms of an "Annual Exceedance Probability" (AEP). This is the inverse of the return period. Thus a 100 year return period equates to a 1% AEP.

This flood has a 1 in 100 chance of occurring in any given year. A 200 year flood equates to a 0.5% AEP (1 in 200 chance).

d. Climate Change Impacts

A sound basis for dealing with the impacts of climate change is presented in the publication "*Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand*", May 2004, New Zealand Climate Change Office, Ministry for the Environment. These overview guidance notes contain an effects and impacts assessment. They were prepared by scientists, planners and engineers from National Institute of Water and Atmosphere (NIWA), Montgomery Watson Haza (MWH) and Earthwise Consulting Ltd in consultation with a range of people from local government organisations and other consultancies. These guidance notes were applied to determine the likely impacts of climate change on flood risks as follows:

- A warmer atmosphere can hold up to 8 percent more moisture for every 1 degree Celsius rise in temperature. However, initial estimates reduced this percentage for longer-duration storms;
- The Intergovernmental Panel on Climate Change (IPCC), an international panel, has produced various temperature rise scenarios due to climate change;
- Based on the IPCC scenarios, downscaled projections for mean temperature rise were prepared for 58 sites around New Zealand for two benchmark dates, 2030 and 2080;
- Based on the "mid-IPCC" (International Panel on Climate Change) projections, the temperature in the Manawatu-Wanganui Region will rise by close to 2.0 degrees by 2080. This value ranged between 0.3 and 3.8 degrees, depending on the IPCC scenario considered;
- The temperature rise results in an increase in rainfall intensity in the 1% AEP storm of between 11 and 16 percent (dependent upon storm duration);
- The corresponding increase in the size of the 1% AEP flood flows is:

Whanganui River	+15-18%
Manawatu River	+19%
Small catchments	+20-24%

- The current 0.25-0.33% AEP flood (300-400 year) becomes the future 1% AEP flood by 2080;
- For the Manawatu River the current 0.5% AEP flood becomes the future1% AEP flood in 2053.

In May 2008 the Climate Change Guidance Notes were updated for more recent information. The principal changes were:

- Temperature projections were made for benchmark dates of 2040 and 2090;

- Estimates were made based on 12 global climate models (GCM), for the A1B emission scenario. This is the scenario highlighted in the guidance notes and is a mid-range scenario. The spatial variation of temperature rise under this scenario is presented in Figure 1 (from Figure 2.3, 2008 Climate Change Guidance Notes);
- The average rise in temperature in the Manawatu-Wanganui Region by 2090 is assessed at 2.1 degrees;
- The increase in rainfall intensity in the 1% AEP storm is assessed as 17 percent for storms more sever than 2% AEP for all storm durations;
- Thus the corresponding increase in the size of the 1% AEP flood flows is now +20-25% for all river systems;
- Thus the impact on the Whanganui and Manawatu Rivers (and other watercourses) will be slightly higher than previously forecast. Thus around the current 0.2% AEP flood (500 year) becomes the future 1% AEP flood by 2090;
- A revised detailed analysis of the Manawatu River shows that the 0.5% AEP flood, as assessed based on data available to 2005 (being the design data which current estimates are based upon), becomes the future 1% AEP flood in 2051.

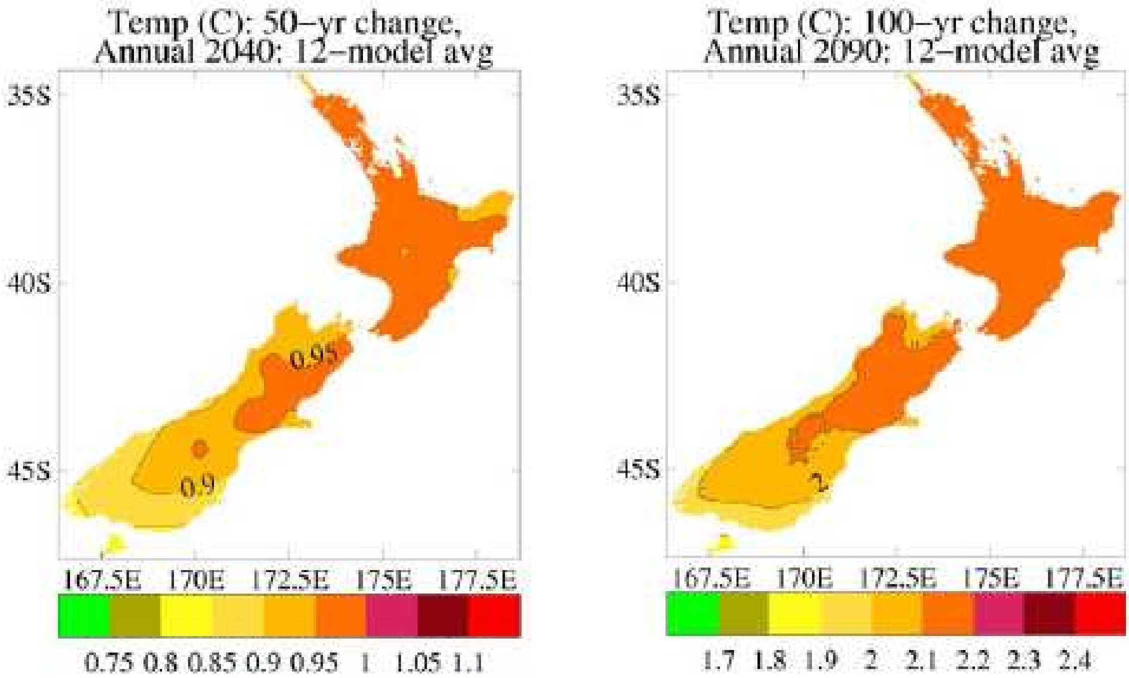


Figure 1: Projected Changes in Annual Mean Temperature (in ºC) Relative to 1990: Average over 12 Climate Models for the A1B Emission Scenario

e. Existing Flood Hazard Information

Horizons Regional Council is well advanced on a comprehensive programme of flood hazard mapping on its principal floodplains. These studies are based on state-of-the-art computer models and recorded flood data.

The first part of the flood hazard mapping is to determine the magnitude of the design flood flows. These are calculated by standard and robust hydrological analyses. Generally these analyses apply "extreme value statistical theory" to a continuous series of recorded annual maximum flows. Recorded data on "historical floods" predating the continuous series is also vital and included where available. As an illustration of this the calculation of the design flood flows for the Whanganui River at Paetawa was carried out as follows:

At-site flood frequency analysis was applied to:

a. The continuous series of annual maxima (1957-2006)

b. The continuous series of annual maxima plus the 12 historical peaks.

An L-Moments extreme value statistical fitting methodology was applied to the continuous series for both the Extreme Value Type One and General Extreme Value distributions – the latter resulted in an Extreme Value Type Three distribution. Inspection of the frequency curve shows that the data conforms to an Extreme Value Type One distribution.

A linear trend-line was applied to the "censored" dataset of the continuous series plus historical peaks plotted against the reduced 'y' variate. This produces an Extreme Value Type One distribution. Figure 2 presents graphically the resulting flood frequency estimates:

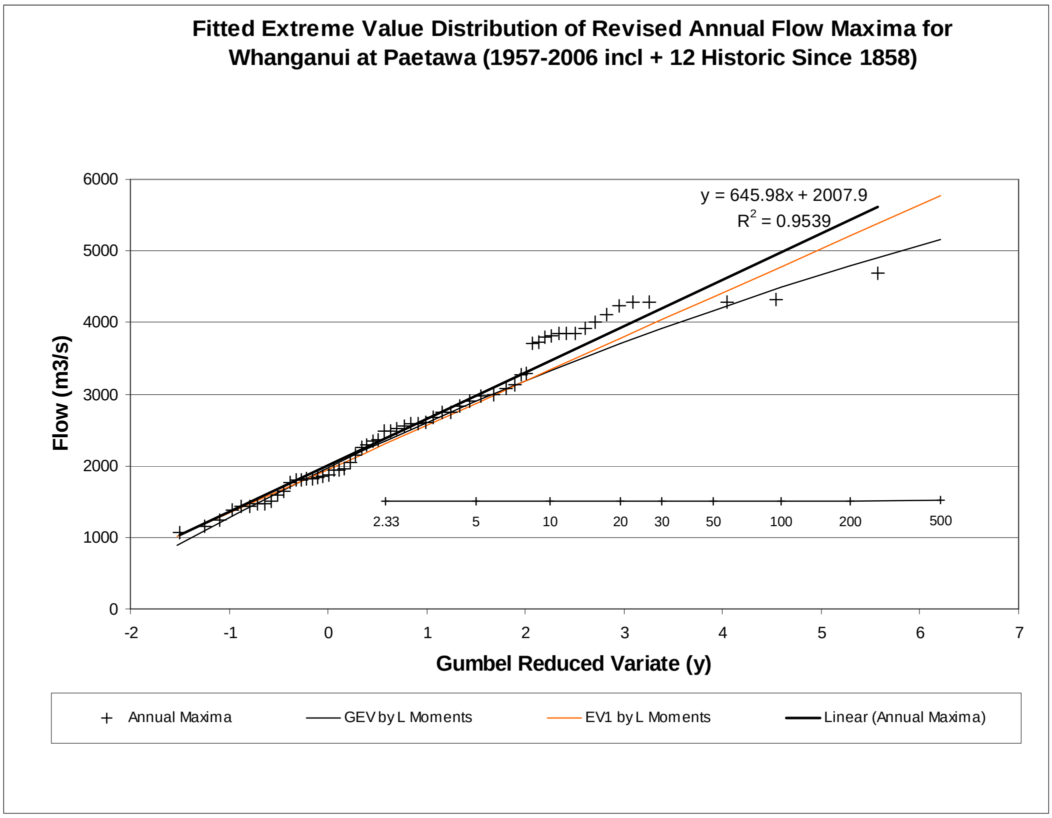


Figure 2: Whanganui River at Paetawa flood frequency

The historical flood peaks should be included in the analysis (with appropriate plotting position) as they provide good information on the rarer flood sizes. Consequently, equal weighting has been applied to the two Extreme Value Type One analyses to produce the design flood frequency estimates in Table 1.

Table 1: Whanganui at Paetawa Design Flood Frequency Estimates

RETURN PERIOD (YEARS)	PROBABILITY (%)	DISCHARGE (CUMECS)	Y VARIATE
1.5	67	1920	-0.0940
2	50	2210	0.3665
2.33	43	2344	0.5786
5	20	2926	1.4999
10	10	3399	2.2504
20	5	3854	2.9702
30	3.3	4115	3.3843
50	2	4441	3.9019
100	1	4882	4.6001
200	0.5	5321	5.2958
500	0.2	5900	6.2136

The second part of the flood hazard mapping is the application of computer hydraulic models to determine flood levels, velocities and areas inundated – usually presented on flood hazard maps. In the case of the Whanganui River the “state of the art” MIKEFLOOD hydraulic modelling package was used to simulate different flood level scenarios. MIKEFLOOD uses linked MIKE11 and MIKE21 models. MIKE11 uses an implicit finite-difference scheme for the computation of uni-directional unsteady flow in rivers. It also incorporates advanced computational models for the description of flow over hydraulic structures – including bridges, although bridges were not specifically incorporated into the model at this stage, because of minor impacts. The unsteady flow properties enable effective application of the temporal variation in flow.

MIKE21 extends the analysis to two dimensions and is particularly valuable for analysing flows across flood plains.

The MIKEFLOOD hydraulic model includes 50 cross-sections on the Whanganui River between Paetawa (river chainage 49,330 m) and the river mouth (river chainage 96,260 m). To these surveyed cross-sections are added numerous ground level points produced by LiDAR (Light Interferometry Detection and Ranging). This process measures ground levels from an aeroplane to within 150mm (at two standard deviations) and tests by Horizons Regional Council show this specification is achieved.

A key part of these models is their calibration achieved by formulating the model to match measured flood flows and flood levels from past major floods. The Whanganui model is calibrated against a set of 30 flood levels recorded in the 8 March 1990 flood. This flood had a peak flow of 4,106 cumecs, corresponding to a return period of 30 years (3.3% AEP). In order to validate the model, the calibrated model parameters were then applied against a set of 13 flood levels recorded in a slightly smaller flood on 29 October 1998. This flood had a peak flow of 3,815 cumecs, corresponding to a return period of 20 years (5% AEP). Following the validation process the model parameters were minorly adjusted to optimise the model accuracy and both calibration and validation models re-run.

For both calibration and predictive computer hydraulic models two boundary conditions are required, being:

- the downstream sea level; and
- the upstream river flow.

For the calibration flood these values are the recorded levels and flows in the 1990 and 1998 floods. The final calibrated model reproduced the flood levels recorded in the 8 March 1990 flood event to a good accuracy. Ninety percent of the computed flood levels are within ± 0.3 m, with the remaining levels within ± 0.4 m. All of the computed flood levels for the validation flood are within ± 0.35 m.

Therefore, the model calibration is accurate and the model formulation is an accurate basis for producing design flood estimates. Details of the calibration and validation are presented in Figures 3 and 4.

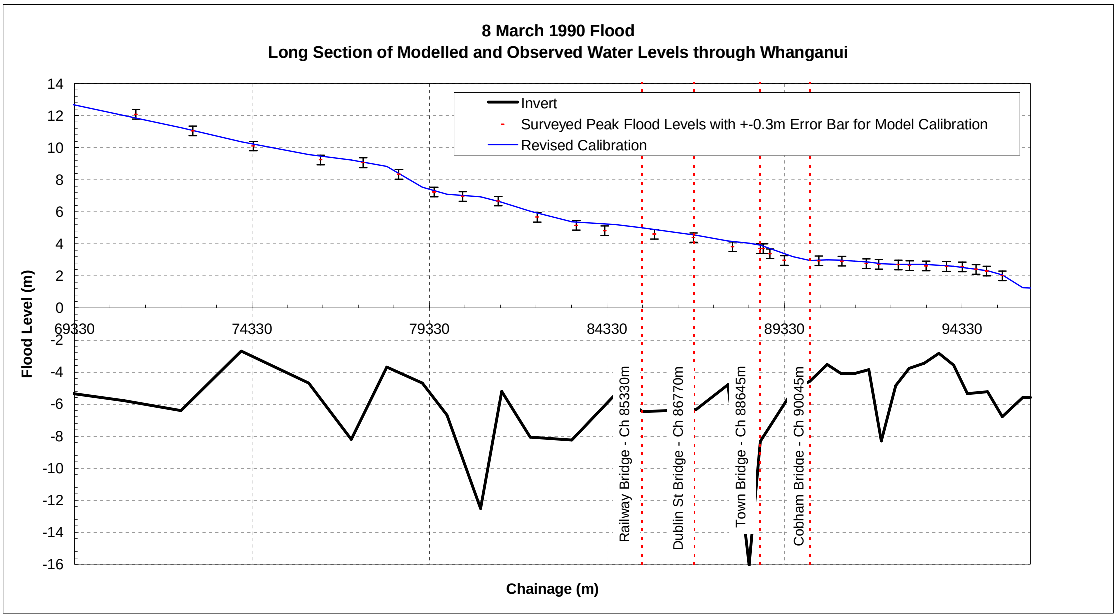


Figure 3: Whanganui River Calibration Flood 8 March 1990

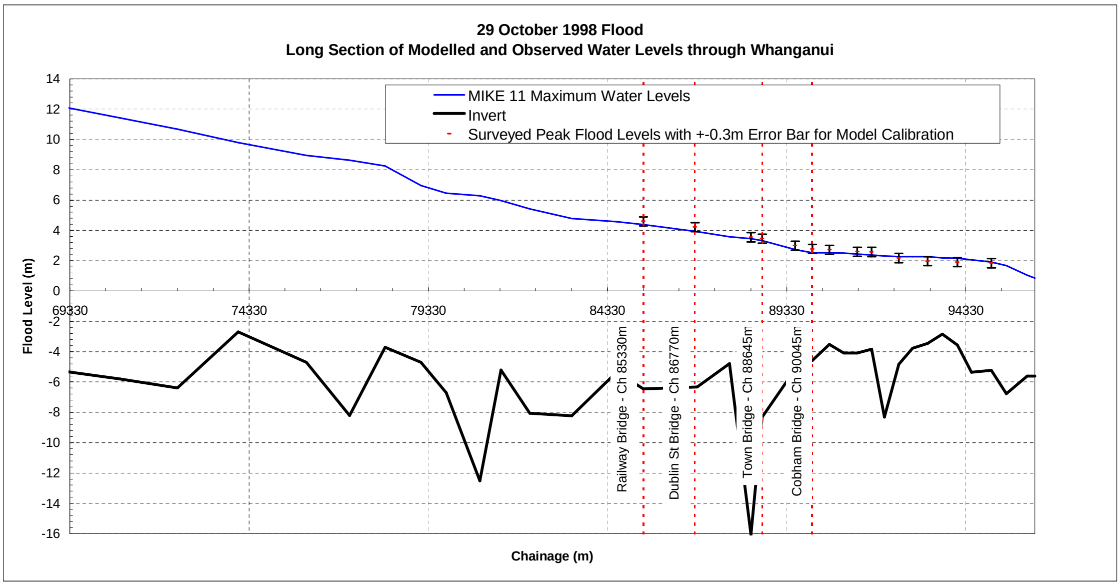


Figure 4: Whanganui River Validation Flood 29 October 1998

The final component required for the predictive hydraulic model is an assessment of the likely river levels at the downstream boundary of the computer model, which are likely to occur concurrently with the flood. For the Whanganui River the design downstream boundary condition is the sea levels at the rivermouth; themselves subject of a separate detailed analysis. These are presented in Table 2:

Table 2: Whanganui at River Mouth Design Sea Levels

RETURN PERIOD (YEARS)	PROBABILITY (%)	SEA LEVEL (M, MOTURIKI DATUM)
5	20	2.2
10	10	2.3
20	5	2.4
50	2	2.6
100	1	2.7
200	0.5	2.9

Different river levels values are needed for the following two cases:

- Design river flood plus likely coincident storm surge – it is common in New Zealand to use a combination of 1% AEP flood with 5% AEP storm surge unless the correlation is weak (eg. a thunder pump on a small coastal stream often has little or no associated storm surge); and
- Design storm surge plus likely coincident river flood. The frequencies as above but opposite.

However, after examining the available data (including over-plots of coastal and inland recorder sites on both the Whanganui and Manawatu Rivers supplied by Jeff Watson, Horizons Regional Council Catchment Data Manager, it is evident that the coincidence of storm surge with river flooding is well below normal for both the Whanganui and Manawatu Rivers. This is because the catchments of both rivers contain a significant area well away from direct west coast maritime influences – particularly the Manawatu, where the catchment extends eastwards of the Ruahine Range. It is concluded that the most likely (and possibly still slightly conservative) combination of events is design (generally 1% AEP) river flood with 20% AEP storm surge and vice versa.

As there is around a one metre rise in flood levels through the Whanganui River moles, the critical case for flood levels through Wanganui City is the design flood in combination with the 20% AEP storm surge. For assessment of the 2%, 1% and 0.5% AEP floods this design sea level is 2.2 m. For assessment of the global warming flood (being the 1% AEP at the year 2080) this design sea level is 2.5 m – based on an interpolated sea level rise component of 0.3 m to that date.

The calibrated computer model is then applied with all the aforementioned components to yield the design flood levels, velocities and areas of inundation.

For the Whanganui River inundation maps were prepared for the 2%, 1%, 0.5% and "Global Warming" (1% in 2080) floods. The 0.5% AEP flood inundation maps are presented in Appendix One.

Flood hazard modelling is completed on the floodplains and rivers of the Lower Manawatu, Taonui Basin, Mangaone, Tutaenui, Whanganui, Mangatainoka/Makakahi and Waikawa/Manakau. Some of these models also focus on design flood levels resultant from potential stopbank breaches (that is a collapse of the stopbank). Detailed computer models have also been constructed for other major rivers including the Rangitikei, Oroua and part of the Ohau. These models can be applied to determine site flood hazards.

Information on historical flooding is also held in various forms. This information cannot usually provide adequate precision on design levels for a specified probability and will no doubt contain no information on some areas that do flood.

Finally, in the assessment of the flood risk for a particular site (not covered by the detailed modelling), it is often possible to construct suitable computer models.

f. Freeboard

The information presented in the detailed computer modelling can be regarded as a sound basis for assessing flood hazards. However, it has to be remembered that in modelling allowance has to be included for the many complexities of nature. Thus to these models needs to be added design freeboard – Freeboard is described in Clause 4.3.2.5.2 of New Zealand Standard 4404:2004 Land Development and Subdivision Engineering as follows:

4.3.2.5.2 Freeboard

The minimum freeboard height additional to the computed flood protection level shall be as follows or as specified in the TA's (Territorial Authorities) district plan:

Freeboard	***Minimum height***
Habitable building floors	*0.5 m*
Commercial and industrial buildings	*0.3 m*

C4.3.2.5.2

Freeboard is a provision for flood level design estimate imprecision, construction tolerances and natural phenomenon (eg. waves, debris, aggradations, channel transition and bend effects) not explicitly included in the calculations.

Freeboard requirements are related to local conditions. The TA should be consulted on appropriate freeboard for accessory buildings, sports grounds and children's playgrounds.

A minimum freeboard height of 0.5 m is generally applicable but should be increased for sites adjoining steep rough channels and may be reduced for sites adjoining tranquil ponds.

Horizons Regional Council's specialist engineering staff generally recommend a freeboard of 0.5 m; however in the Taonui Basin it is reduced to 0.3 m for two reasons. Firstly, increases in heights of floodwaters at the spillways filling the basin are spread over a large area, with lesser increases in basin flood heights and; secondly, because of the tranquil nature of the ponding area.

Note NZSS4404:2004 is a non-mandatory document that "*if adopted by territorial authorities (TA's), serves as a basis for technical compliance for the subdivision and development of land where these activities are subject to the Resource Management Act 1991.*

This standard does not include a statement of all minimum requirements for land subdivision and development engineering. TA's may specify their own minimum requirements, citing this Standard or their own bylaws or district plans as appropriate" (Section 1.1 Scope).

g. Impact of Development in Floodprone Areas and Scheme Areas

"The *flood hazard* is defined as the interaction between two systems: the physical flood event and human use of the floodplain. Characteristics of the *physical flood event* that are important for analysing impacts on human occupation of the floodplain include in particular: magnitude, frequency of occurrence, speed of onset, and areal extent of flooding. Characteristics of *human use of the floodplain* important for analysing flood impacts include: perception of risk; types, densities and distributions of land uses and social organisation on the floodplain. Clearly, then, the flood event is not in itself the *flood hazard*. Its potential for hazard is not realised until related to people and their works. Thus, flood potential – defined mainly in terms of human casualties, property damages, and social disruption – depends not only on the characteristics of the flood event, but on characteristics of human activity on the floodplain" (Ericksen, 1986).

The factors which determine the flood hazard are summarised as (Refer Section L6 of the publication "*Floodplain Development Manual*: *The Management of Flood Liable Land*", April 2005, Department of Infrastructure, Planning and Natural Resources, New South Wales Government):

- size of flood;
- effective warning time;
- flood readiness;
- rate of rise of floodwaters;
- depth and velocity of floodwaters;
- duration of flooding;
- evacuation problems;
- effective flood access; and
- type of development.

In floodable areas developments pose two principal types of risks:

- Risks to the inhabitants and the development itself; and
- Risks to other inhabitants and developments and flood protection infrastructure and effectiveness.

The risks to the development itself are direct losses from flooding, including damage to both buildings and their contents. Furthermore, there may well be threats to health and life. Social impacts can be high due to trauma, ill-health, destruction of the environment, loss of employment and loss of services and supplies. Further details on social impacts is presented at the end of this section.

Unless the "residual risk" (risk resulting from floods either larger than the stopbank design, stopbank breaches or other causes) is low it is unwise to put developments in these areas. Even though a stopbank is constructed, the increased development behind the stopbank increases the potential vulnerability to flood risks – as been evidenced time and time again in this country. As an example of vulnerability to flooding, the economic assessment of potential flood damages to vulnerable parts of Wanganui urban area from the Lower Whanganui River is presented in Table 3 following:

Table 3: Whanganui River Estimated Potential Flood Damages

Location	Class	DAMAGE50	DAMAGE100	DAMAGE200	DAMAGEGW	Average Annual Damages
(Current Probability)		**0.02**	**0.01**	**0.005**	**0.0025**	
Kowhai Park	Residential	$10,493,000	$12,387,500	$16,702,000	$19,019,500	
	Commercial	$0	$0	$1,176,111	$1,612,929	
	Subtotal	$10,493,000	$12,387,500	$17,878,111	$20,632,429	$447,181
Putiki	Residential	$1,370,500	$1,840,500	$2,547,000	$2,991,000	
	Commercial	$1,568,754	$2,374,479	$2,806,025	$3,604,356	
	Subtotal	$2,939,254	$4,214,979	$5,353,025	$6,595,356	$105,811
Taupo Quay	Residential	$0	$0	$0	$0	
	Commercial	$6,924,630	$14,555,224	$23,344,242	$33,335,357	
	Subtotal	$6,924,630	$14,555,224	$23,344,242	$33,335,357	$390,959
Balgownie	Residential	$363,500	$531,000	$1,042,000	$1,823,500	
	Industrial	$50,369,381	$59,361,018	$93,764,527	$118,652,143	
	Subtotal	$50,732,881	$59,892,018	$94,806,527	$120,475,643	$1,763,827
TOTAL		**$71,089,764**	**$91,049,720**	**$141,381,904**	**$181,038,786**	**$2,707,778**

It can be seen that the potential flood damages to existing developments in Wanganui from Whanganui River flooding total $91 million in the 1% AEP flood and $141 million in the 0.5% AEP flood. The “DAMAGEGW” scenario is the impact of the 1% AEP flood plus climate change to the year 2080. The probability weighted average annual damages would average $2.7million per annum over time.

Estimates of potential flood damages to Palmerston North from the Manawatu River and Mangaone Stream were carried out by Dr John Bright of Lincoln Environmental (formerly called Agricultural Engineering Institute) and are summarised in the publication *“Lower Manawatu Scheme Special Project: Palmerston North Flood Protection”*, June 1994, G S Doull, Senior Design Engineer, Horizons Regional Council

Doull presents inundation maps and the associated damage estimates for five scenarios as follows:

Scenario 1: Manawatu River flood peak of 3,500 cumecs, stopbank breach at Fitzroy Bend - 1.4% AEP (70 year), previously assessed as 1% AEP (100 year);

Scenario 2: Manawatu River flood peak of 4,500 cumecs, stopbank breaches at Fitzroy Bend and College of Education – 0.2% AEP (500 year), previously assessed as 0.05% (2000 year);

Scenario 3: Manawatu River flood peak of 6,000 cumecs, multiple stopbank breaches – extremely rare flood;

Scenario 4: Mangaone Stream maximum flow (additional flow travels down Flygers Line floodway) – 10% AEP (10 year);

Scenario 5: Manawatu River flood peak of 5,000 cumecs, stopbank breach at Dittmer Drive – very rare flood.

The estimated number of buildings flooded and flood damages (as estimated in 1994 dollar terms) for each of the five scenarios is presented in Table 4 following:

Table 4: Manawatu River and Mangaone Stream Estimated Potential Flood Damages

Scenario	Flow (cumecs)	No. Buildings Flooded	Estimated Flood Damages ($1994)
1	3,500	1,060	$70.5 million
2	4,500	3,430	$241 million
3	6,000	6,500	$514 million
4	c.130	1,100	$114 million
5	5,000	1,620	$90 million

The estimated Average Annual Damages for these flood events is $681,000. This is a surprisingly low figure, when compared with the hundreds of millions of dollars generated by the larger scenarios. The reason for this is that the scheme that was in place in 1994 already provided quite a high level of protection.

After these damages were assessed, the February 2004 flood occurred. New information provided by that flood showed that extreme floods the Manawatu River at Palmerston North flow at higher levels than previously estimated. This is because the hydraulic resistance in such large floods is higher than previously measured. Higher river levels mean that stopbank breaches will direct more water through Palmerston North than previously estimated, and the estimated flood damages and number of properties flooded would correspondingly increase. Much of this is now being mitigated by the City Reach Project, whereby the flood protection standard for Palmerston North is being raised to 0.2% AEP. **However, the damages in the largest scenario will not alter significantly, as** it is not practicable **to mitigate this risk**. It is very difficult to justify spending considerably more than the $12.3 million budgeted for the City Reach Project, when the return on money spent is the reduction of an already low probability.

A detailed listing of social and psychological impacts of flooding is presented in Section 8.5 of the reference *"Waikanae River Floodplain Management Plan Phase One Investigations: Summary Report"*, June 1992, Peter Blackwood and Graeme Campbell, Project Engineers, Wellington Regional Council. The detailed listing is as follows:

Social and Psychological Impacts of Flooding

Eight primary impacts that can occur are listed below:

1. Shock and Confusion

These impacts are a result of an unawareness of flood risk or a denial of extent of possible flooding, a false sense of security as a result of flood protection works and a lack of an action plan for times of flood. All of these result in a lack of preparedness and therefore reduce the individual's ability to take appropriate action.

Mental and physical exhaustion can result in a temporary malfunctioning of memory which can be problematic for accurate completion of claim forms, especially where no mechanism exists for supplementary claims.

2. Physical and Social Isolation

Physical isolation is as a result of the level of flood water and the extent of damage. If transport and telecommunication systems are disrupted by the water, flood victims may be unable to contact friends and family and to get emergency assistance. This can be especially traumatic for those particularly dependent on the outside world such as the sick and disabled.

Social isolation can occur for those who do not have strong networks because of such barriers as language difficulties and psychiatric disability.

3. Grieving

The most common cause of grief is the loss of irreplaceable treasures such as memorabilia, heirlooms and pets and the destruction of major personal achievements such as homes, gardens and businesses. Loss of life will result in more intensive feelings of grief. Fortunately to date this has been a relatively uncommon occurrence in New Zealand flood situations.

4. Uncertainty and Loss of Control

Factors which contribute to this impact may include the loss of essential services, disruption to daily life, having to rely on others for basic needs and people not being *consulted or not feeling able to influence decision making processes which affect their personal situation. All of these factors are likely to be exacerbated in cases of evacuation.*

5. Overdependence and/or Difficulty in Making Decisions

This results from being overwhelmed when confronted by forces beyond the individual's control and from being overcome by the degree of damage and the amount of work required to restore properties. These feelings can be accentuated when the individual does not have control over essential resources such as water, food, transport and house restoration services.

6. Anger and Resentment

These feelings are likely to be manifested some days or weeks after the flood as people begin to question why the flood occurred and the adequacy of flood protection measures. At this stage they tend to seek someone to blame. Primary targets are local authority decision makers and staff.

Factors which contribute to this anger are forced dependency, lack of consultation by decision makers and exhaustion. Self-recrimination for not undertaking protective measures earlier or not taking action which could have saved property during the warning period is also a common response in the post flood period.

7. Anxiety

The most common cause of anxiety is financial insecurity. This is the result of such things as lack of insurance cover, inability to afford housing in areas outside the floodplain and loss of employment due to flood damage.

Another common anxiety which can continue for months and sometimes years after the flood event, is fear of further flooding. This manifests in times of heavy rain and can lead to a person taking extreme precautionary measures which unnecessarily restrict their daily lives.

8. Family Stress

This is an almost inevitable result of exhaustion, anxiety and the inability to control one's situation. The result can be communication breakdown between family members, disruptive or withdrawn behaviour in children, increased domestic violence and drug and alcohol abuse.

In order to reduce potential flood losses, and their economic, social and psychological impacts and threats to human life, careful controls are needed in floodable areas.

Risks to others may be created by developments themselves – either through infilling overland flow paths and diverting floodwaters onto previously flood-free land; removing valuable flood storage in ponding areas and thus causing an increase in elevation of flood levels; or by other causes.

Similarly, flood risks may well be aggravated by inappropriate development on or near flood mitigation assets (particularly stopbanks). The following activities are included in those that may cause flood threats:

- Direct damage to stopbanks, thus weakening them and possibly creating seepage paths or erosion-prone defects. This may be caused by cattle browsing during wet conditions, unauthorised planting of trees on stopbanks, or the construction of a plethora of illegal structures on stopbanks including gardens, gardens sheds, posts and fences, recreational structures (eg. skateboard ramps) and the like.
- Excavations close to stopbanks may directly lead to formation of a seepage path;
- Mass lowering of the ground profile can mean that the ground weight resisting water uplift pressures (from subterranean seepage paths) becomes inadequate;
- Unauthorised and/or poorly constructed service pipes can create flow paths leading to a "piping" failure.

Again, careful controls are required to avoid exacerbating the potential flood losses to others or reducing the effectiveness of existing flood protection.

FLOOD AVOIDANCE AND MITIGATION

15. Flood Avoidance and Mitigation

a. Methods for Avoiding Flood Hazard

Development on areas vulnerable to flooding, even though seemingly protected to the design standard, will always be vulnerable to flooding from larger floods, or stopbank breaches. Over time these larger floods *will* happen. Therefore, the only feasible way to avoid the flood hazard is to locate development away from floodprone areas.

b. Methods for Mitigation

There is an array of mitigation methods, of varying effectiveness, as follows:

Stopbanks: Stopbanks are usually designed to provide flood protection to a specified design flood standard. They are usually constructed to form a structurally sound earthen barrier. In places where space may be at a premium they may be replaced by designed concrete flood walls, which provide the same barrier to floodwaters.

Detention Dams: Detention dams detain floodwaters, so that peak flows are reduced and floodwater released subsequent to the peak flow – at a significantly reduced flow. The difficulty with detention dams is in sizing the dam to contain flood flows both at the peak of the flood and in the period leading to the peak. A prematurely full dam may provide no reduction in peak flows. Flood flows in excess of the detention dam design are unlikely to be reduced at all. Detention dams require careful structural and hydraulic design, particularly their spillway capacity. Detention dams are increasingly being used to mitigate downstream impacts of the increased flood flows generated by urban development. They can be used in combination with several other dams (as on the Tutaenui scheme), and can be a useful tool in flood mitigation.

Pumps: Pumps can strategically be used to reduce flood levels, particularly in smaller catchments.

Minimum Floor Levels: Minimum floor levels for dwellings and other structures can be determined to mitigate flood threats to a predetermined design standard. They are less effective in mitigating overdesign floods or stopbank breaches. They can be used in floodprone areas zoned for residential or other uses. Care has to be taken in ensuring that there are safe accesses/egresses from buildings with adequate floor levels. History has sadly shown a prepondency for people to access or leave buildings, which themselves may well be above flood levels – either to reach or save relatives, property or other reasons. An example of this was the deaths of two people who were swept away fording a stream whilst attempting to reach their house in the August 2008 floods in Northland. The house itself was well clear of floodwaters, but sadly not the access. Another example was in a flood in 1931 in Otaki where a lady drowned after being evacuated from her house (again the house did not flood).

Filling: Filling is a more effective way of mitigating flood risk and more likely to provide safer access/egress, although it has to be checked that there is a safe connection to higher ground. It does cost more but the flood depths in the vicinity are likely to be less dangerous. The major problem with filling is that it is likely to redistribute floodwaters, so that risks are exacerbated elsewhere – either through cutting off overflow paths or infilling ponding areas. The cumulative effects of several potential filling activities may become significant. Where feasible, filling is one of the better mitigation options.

Advance Floodwarning: Advance floodwarning can reduce threats to health and life and in bigger catchments the losses to property contents can be reduced – but not the vast bulk of potential flood damages. It is an essential mechanism for developments already built in floodprone locations. Refer also to paragraph 14(b) Speed of Onset (page 19).

Insurance: Insurance can to a degree mitigate the flood loss potential. It does not however mitigate risks to health and life. It may also be a most cost ineffective means of mitigation, compared with other options.

c. Horizons Regional Council's Flood Management Schemes

Horizons Regional Council manages nine flood protection schemes throughout the Manawatu-Wanganui Region. Two primary flood protection methods are employed, in five schemes flood control is achieved through peak flow reduction by the storage of water in detention dams, and in all other schemes control is achieved through the use of conventional stopbank structures and associated floodways. The function of these floodways is explained in paragraph 14(b) (page 19).

Flood protection assets owned and maintained by the schemes are valued at $93 million and include 437 km of stopbanks and 52 detention dams.

The schemes are designed to varying protection standards, with rural standards ranging from 5% AEP to 1% AEP. Large urban areas are typically protected to the 1% AEP standard; however in the case of Palmerston North City, a very high standard of 0.2% AEP has been agreed.

For some years measures have been in place to address progressive loss of flood capacity in certain flood protection schemes. This is dealt with in great detail by the evidence to the Hearings Committee for the Land chapters (Chapters 5 and 12) presented by Allan Cook. In particular Mr Cook has referred to the ongoing aggradation occurring in the Oroua and Rangitikei Rivers, with this aggravated by the 2004 storm. There were similar problems in the streams east of the Ruahine Ranges resulting from storms three or more decades ago.

Options for dealing with this aggradation, to maintain the current flood protection standards, include stopbank raising or mass extraction of the gravels and silts. The latter option may become very expensive over time, with questionable affordability. Raising of stopbanks may also have limitations, in particular the structural stability of the stopbanks themselves (although expensive engineering solutions are possible) and the potential for increased sub-surface seepage with the additional pressures generated by elevated floodwater levels. Therefore, it may not prove possible to retain current protection levels over time and thus considerable care is needed in considering development proposals adjacent to some reaches of these (and other) rivers.

d. Why 0.5% Annual Exceedance Probability (AEP) has been Selected as the Hazard Level

Horizons Regional Council strongly recommends that during a new development's lifetime the flood protection standard be at least to the 1% AEP level. Several studies have been made over time of acceptable/economic flood protection standards and it is generally accepted that new development should be to at least this standard. Whilst a lower standard may be advocated by a developer, they rarely are those who will be vulnerable to the flood risks over the lifetime of the development. Conversely, most in society have the expectation that they will not be flooded and in most cases have little or no preparedness for flooding.

As outlined in paragraph 14(d) (page 20), based on the mid-IPCC climate change projections contained in the 2004 Climate Change Guidance Notes there will be an increase in the frequency of flooding such that

- The current 0.25-0.33% AEP flood (300-400 year) becomes the future 1% AEP flood by 2080;
- For the Manawatu River the current 0.5% AEP flood becomes the future 1% AEP flood in 2053.

Based on the foregoing and the "normal" lifetime of a dwelling or industrial/commercial building of 50 years (or longer in many cases) the minimum level of risk tolerable for human habitation was set at 0.5% AEP – being essentially the forecast 1% AEP flood during the building's lifetime.

As previously advised, the May 2008 update to the Climate Change Guidance Notes means that the impact on the Whanganui and Manawatu Rivers (and other watercourses) will be slightly higher than previously forecast. However, it is not recommended that any change be made at this stage to the recommended flood hazard standard of 0.5% AEP.

e. Why Avoidance is Preferable to Mitigation

In the very strong majority of cases mitigation is to a defined flood standard. In almost no cases is it possible to mitigate flooding to the Probable Maximum Flood (PMF) standard. This, as the name implies, is the expected maximum flood flow that could be generated by the most adverse potential storm. Whilst economic and social impact studies may show that mitigation to a much higher standard than say 0.5% AEP is warranted, it is rare to achieve agreements to such mitigation.

This means that development in the land protected is vulnerable to floods higher than the mitigation standard. It is furthermore vulnerable to stopbank breaches.

The inevitable development that occurs behind new stopbanks means that the potential flood losses actually increase, regardless of the mitigation standard. The flood potential that remains is termed the "*residual flood hazard*". This consists of economic, social impact costs and threats to health and life.

An example of what might happen without avoidance is the case history of the 1984 Invercargill floods. These floods caused at least $55 million in insured property losses. Two-thirds of the built up area in the flooded area was created after the passage of the Town and Country Planning Act 1953. Strong controls are needed to ensure that potential flood risks are not increased.

In response to submissions an attempt has been made to reach a recommendation that does accommodate some mitigation where careful planning has taken place. In my opinion it is better that an urban or industrial growth study be carried out first by a Territorial Authority, before an area for development is identified on the floodplain; and then only provided residual risks are tolerably low and mitigated appropriately. However, several Territorial Authorities will not be adequately resourced to carry out such a study and/or may be working to more distant timelines than those for a particular development under consideration. Therefore, Horizons Regional Council is not recommending this prerequisite before mitigation is considered. In any case the more important point is to determine controls so that the residual risks from bigger floods to any development is low – as these floods will inevitably happen at some point.

In this regard it is recommended that the design flood to be considered for the one Plan should be the 0.2% AEP flood plus forecast climate change to the year 2090 (in terms of the climate change guidelines). This flood has a sufficiently high probability that it is possible to occur within a development's lifespan. The 0.2% AEP design flood standard has been determined as being the optimum protection level in economic terms for mitigation of flooding of Palmerston North from the Manawatu River. This level of flood protection was favourably received in consultations and adopted by the people of Palmerston North. Had there not been a significant restriction to flow caused by the Fitzherbert Bridge in extreme floods, then a higher still level of flood mitigation may have been warranted on economic grounds.

In regard to the tolerable risk to health and life, reference is made directly to Figure L1, NSW Floodplain Development Manual – the Management of Flood Liable Land, April 2005. This is presented in Appendix Two.

This graph shows that it is unsafe to wade in floodwaters deeper than 0.8 metre above finished ground level in still (ponded) areas, with the depth linearly reducing to 0.5 metre in waters flowing at 1.0 metres per second. Furthermore, it shows that at velocities in excess of 1.0 metres per second, safety very quickly diminishes with increasing floodwater depth. Whilst there are cases where it may be safe to wade at higher velocities and depths, the variation in velocities and depths due to localised obstructions and debris blockages make it unsafe to contemplate accepting those velocities. Consequently, the residual depth of flooding and velocities acceptable in the 0.2% AEP flood plus climate to 2090 should be based on the criteria stated above.

In addition obviously all development must be protected to the 0.5% AEP flood plus freeboard.

f. Approach to Further Development within Existing Urban Areas that are Floodprone

Further development within floodprone areas must only proceed where future increases in the risks to health, life and property can be avoided or, if that is not possible, mitigated to an acceptable standard. Flood risks within existing areas that are floodprone can be avoided by locating development on areas of higher ground that are not at risk of flooding. However, frequently the undeveloped portion is not on higher ground, meaning that this option is not available.

There are two situations to consider as follows:

i. Established residential and industrial areas with existing flood protection of greater than or equal to 1% AEP. The 1% AEP standard is considered as several flood protection schemes provide this level of protection; and
ii. Established residential and industrial areas with existing flood protection of less than or equal to 1% AEP that are susceptible to inundation.

In my opinion, for the first case an allowable increase in the density and additional infrastructure within protected areas should be permitted. This is because there is a reasonable standard of flood protection at present and, as the area is already urban, there is an expectation that development will proceed at some stage. It could be argued that this should be applied only to areas where existing protection is at 0.5% AEP. However, this would apply to fewer areas, as most schemes are to the 1% AEP, and would probably put an unreasonable restriction on those areas.

In my opinion, the practice for the second case should be:

- Encourage building in areas not susceptible to greater than or equal to 1% AEP.

- Allow additional and replacement dwellings and infrastructure within designated residential/industrial boundary but only with mitigation that meets requirements of Policy 10-2 (i – iv). In practice this mitigation would mean protection to a 0.5% AEP that doesn't adversely affect neighbours. Eg. Elevation of building platform to 0.5% AEP standard. (Additional level of freeboard required to establish finished floor level). Furthermore the residual flood risk must be such that floodwaters are unlikely to reach the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual.

This situation would apply to towns such as Marton where the protection scheme provides 4% AEP (1 in 25 year) flood protection – although this standard may now be approaching 2% AEP.

g. Approach to Rezoning and Urban Expansion Into Floodprone Areas

Most non-urban areas are rural and there are three situations within the 0.5% AEP floodable area to consider, as follows:

i. Areas with existing flood protection greater than or equal to 1% AEP and the residual flood risk is such that floodwaters are unlikely to reach the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual;
ii. Areas with existing flood protection greater than or equal to 1% AEP and the residual flood risk is such that floodwaters are likely to exceed the threshold beyond which wading is unsafe, as identified in the NSW Floodplain Development Manual; and
iii. Areas without existing flood protection greater than or equal to 1% AEP that are susceptible to inundation.

In the first situation the development requires suitable mitigation, eg. elevation of building platforms to 0.5% AEP (with additional freeboard to finished floor level). Additional and replacement structures to support farm operation (eg. farm sheds) are allowed. Thus in this situation Horizons Regional Council is clearly recommending avoidance of urban developments on the floodplain.

In the second and third situations the flood risk is somewhat higher and considerable filling of the land and/or other suitable mitigation would be required before there was a prospect of re-zoning and urban expansion.

To summarise, land that could be rezoned or developed for urban use must clearly meet both the following criteria:

- It must be protected to the 0.5% AEP flood standard; and
- The residual risk must be low. That is in the 0.2% AEP flood plus forecast climate change to the year 2090 (in terms of the climate change guidelines) the depths and velocities must be within those prescribed as safe for wading in Figure L1, NSW Floodplain Development Manual.

h. Approach to Infrastructure and Other Development that Locate in Floodable Areas

This paragraph considers such activities as pipelines, pylons, bridges, dams and the like. Policy 10-4 of the Proposed One Plan states that the placement of new "critical infrastructure" in the 0.5% AEP floodable area (including mapped floodways), or in an area likely to be affected by another type of natural hazard, shall be avoided unless there is no reasonable alternative. The reasoning for this is that these activities are critical to the functioning of the community and must not be unnecessarily threatened with damage and loss of operation. Furthermore, they should not pose a danger to health and life, through requirements to access the infrastructure during floods.

- I agree with submissions that this requirement should not be an impediment to the construction of new bridges. Quite clearly it would be extremely difficult to construct a bridge without some part of the substructure being in the 0.5% AEP floodable area. Consequently, it is recommended that the policy be amended to enable bridges to be established in such circumstances. However, it should be emphasised that in assessing resource consents due care needs to be exercised to ensure that any potential adverse effects are mitigated.

In some cases there will be no reasonable alternative and the critical infrastructure will have to be placed in the floodable area.

Policy 10.3 also enables structures and activities (not limited to "critical infrastructure") that cannot be located outside floodways and other areas likely to be inundated by a 0.5% AEP flood because of functional constraints, provided any adverse effects are avoided or mitigated.

Typical examples of critical infrastructure, structures and activities that cannot be located elsewhere include manholes for pipelines crossing a wide floodplain, flood mitigation works and possibly even a pump station. The construction of these structures must only occur where there is no reasonable alternative and must be subject to careful assessment to ensure that any potential adverse effects are avoided or mitigated. Conditions that are required to ensure this include:

Avoidance or mitigation in the 0.5% AEP flood of:

- Any restriction to flows and consequent increases in both upstream flood levels and local velocities; furthermore total avoidance of any potential to cause a change in course of flood flows;
- Mitigation of the likelihood of entrapping debris on the structure;
- Mitigation of induced erosion;
- Location of all new pipelines below the depth of scour in the waterway expected in a 0.5% AEP flood;
- Avoidance of structural failure of the structure resulting in adverse effects in the immediate vicinity, or somewhere downstream where structural parts may cause or add to a debris blockage; and
- A clear emergency action plan to cover alternative functioning or repair in the event of flood damage. It has to be stressed in this plan that emergency access can only be allowed under conditions of absolute safety (and that may well mean the structure's function becomes inoperative for a period).

i. The relationship with Territorial Authorities on transfer of information on natural hazards

As explained in paragraph 14(e) (page 22) Horizons Regional Council is well-advanced on a comprehensive programme of flood hazard mapping on its principal floodplains. These studies are based on state-of-the-art computer models and recorded flood data. The information presented in these studies can be regarded as a sound basis for assessing flood hazards.

Flood hazard modelling is completed on the floodplains and rivers of the Lower Manawatu, Taonui Basin, Mangaone, Tutaenui, Whanganui, Mangatainoka/Makakahi and Waikawa/Manakau. Some of these models also focus on design flood levels resultant from potential stopbank breaches (that is a collapse of the stopbank). Detailed computer models have also been constructed for other major rivers including the Rangitikei, Oroua and part of the Ohau. These models can be applied to determine site flood hazards.

As each of the flood hazard models and maps are completed, officers of Horizons Regional Council are transferring the information to the appropriate Territorial Authority through a series of programmed meetings. To date information on the above floodplains has been transferred to the relevant statutory authority for that area. The information transfer was undertaken via formal presentation to outline what had and had not been modelled and to ensure that the appropriate context was applied to each scenario. Information was given in both electronic and hard copy format and was accompanied with offers of technical support backup.

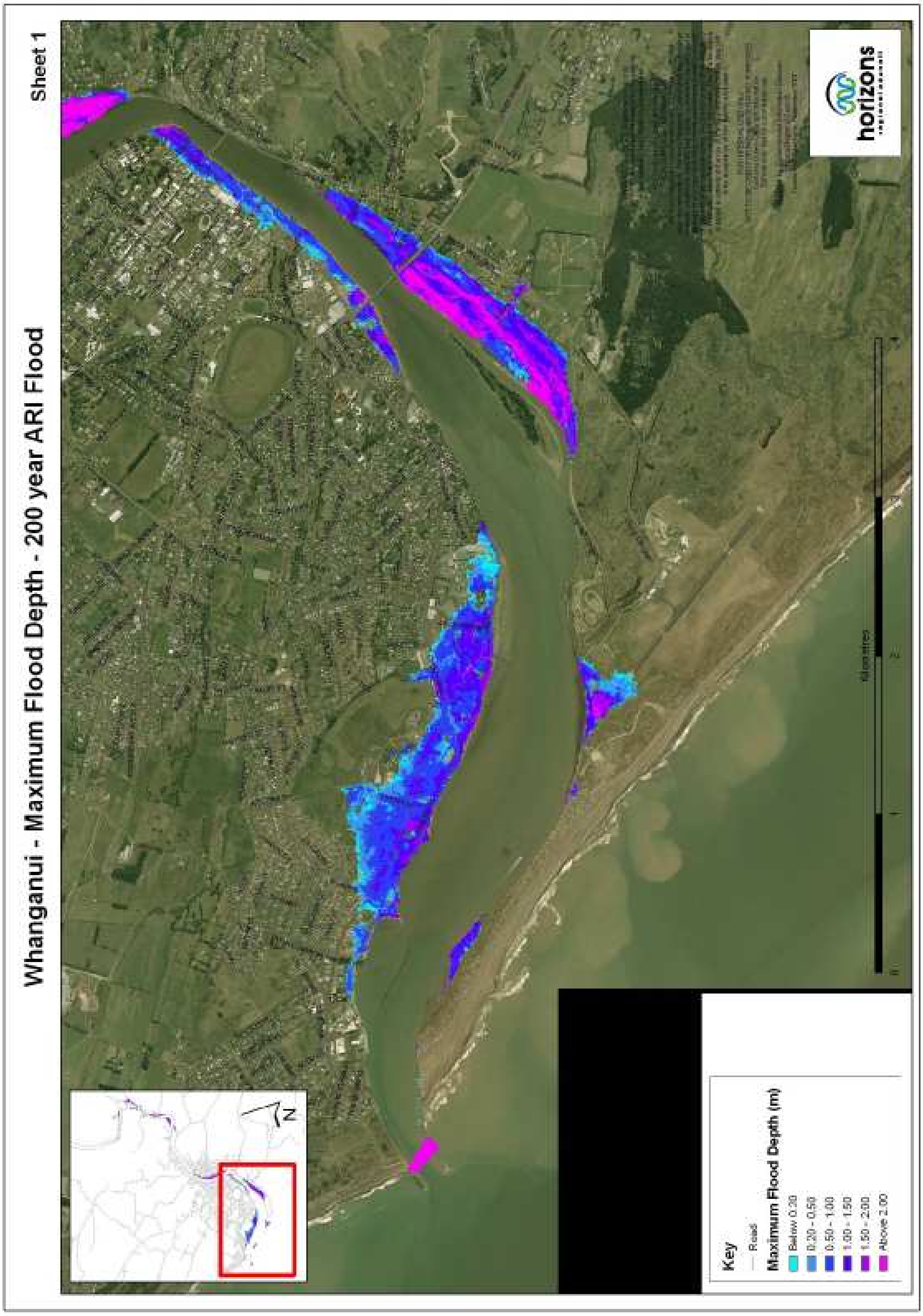
Where the floodplain mapping has not been completed, then Horizons Regional Council may provide the best available advice it holds on the flood risks to that area – with appropriate qualifications as to accuracy and whether further detailed studies are required. This information transfer is provided by the Coordinator District Advice, based on relevant expert technical input. The information transfer occurs in several instances including:

- Site specific information required for building consents;
- Subdivision appraisal;
- Plan change appraisal – including both re-zonings and plan conditions;
- General enquiries by both general public and territorial authorities.

APPENDIX ONE

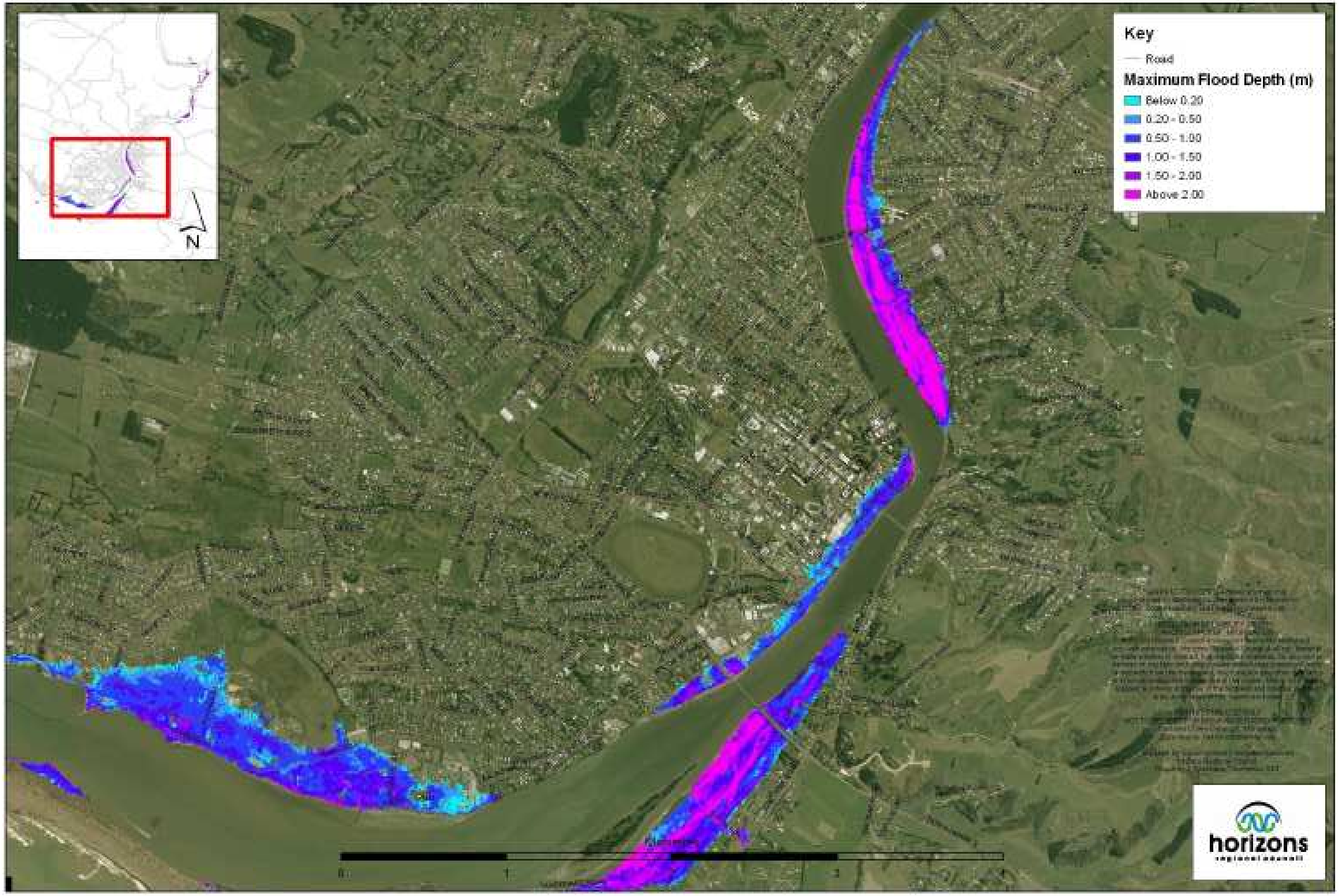
Whanganui Maximum Flood Depth

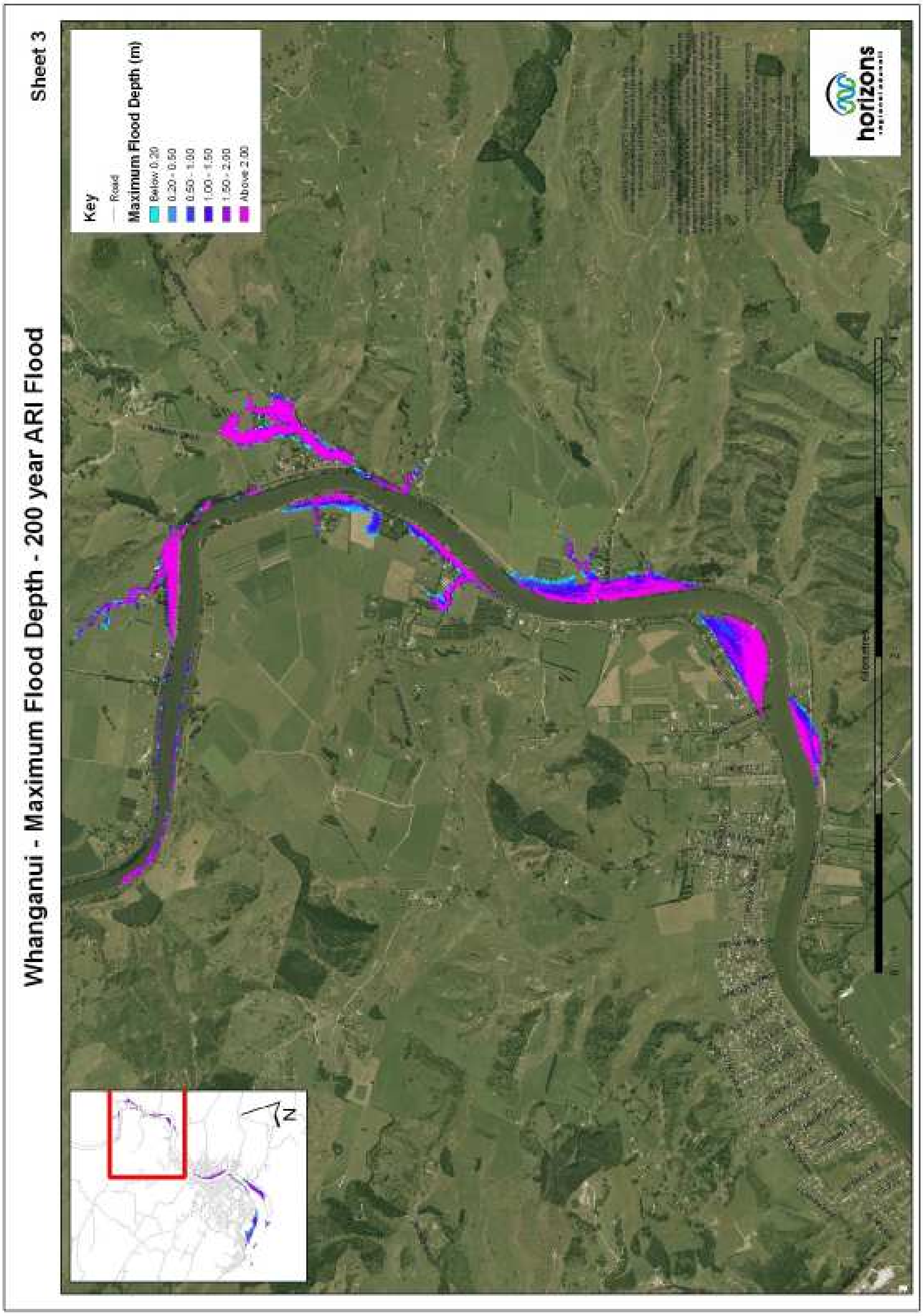
0.5% AEP (200-Year)


Whanganui - Maximum Flood Depth - 200 year ARI Flood
Sheet 1
horizons
N
Kilometres
Key
Road
Maximum Flood Depth (m)
Below 0.20
0.20 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
Above 2.00

Whanganui - Maximum Flood Depth - 200 year ARI Flood

Sheet 2




Whanganui - Maximum Flood Depth - 200 year ARI Flood
Sheet 3
Key
Road
Maximum Flood Depth (m)
Below 0.20
0.20 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
Above 2.00
horizons

APPENDIX TWO

New South Wales Floodplain Development Manual – the Management of Flood Liable Land, April 2005, Appendix L: Hydraulic and Hazard Categorisation