According to information provided by Environment Waikato (Environment Waikato, 2002), at about 8.30am on Wednesday 19 June 2002, the first of many severe weather warnings was issued by the MetService advising that a potentially damaging low (called a Weather Bomb) was likely to affect northern New Zealand. Areas particularly at risk from heavy rain and strong winds were Northland, Waikato and the Coromandel Peninsula. Predictions included wind gusts up to 120 km/hr and rainfall totals of 150 to 200 mm in the Coromandel Ranges (with intensities up to 15 to 20 mm/hr).

A weather bomb is simply defined as a low pressure system which rapidly deepens causing barometric pressure to drop by at least 25 hPa in a 24 hour period.

On Thursday 20 June 2002 the Weather Bomb made landfall bringing high winds and torrential rain across most parts of the upper North Island. The resulting floods and damage led to many communities being evacuated from their homes and one fatality. There was also disruption to sewage, water supply and power services. The feature of this storm was the speed at which it developed.

The Weather Bomb caused a state of civil defence emergency to be declared in both the Thames-Coromandel and South Waikato Districts. Thames Coromandel District Council (TCDC) declared at 2:30am on Friday June 21 due to a significant number of homes being flooded (forcing evacuations), widespread power cuts, and water treatment issues.

The event produced rainfall intensities of the order of 100 mm in one hour registering return periods of 100 years and rapidly creating flood flows in local rivers equivalent to 100 year return interval events. In places the flows were of sufficient strength to move caravans, garages, boats and cars (see Plate 1, below) as well as carrying fallen trees, boulders, and many thousand of tonnes of mud through homes, properties and across roads.

Plate 1: The Waiomu Motor Camp, which was devastated by the flood.

Plate 2:
A reach of the Tararu stream upstream of Tararu township showing the stream channel much enlarged and stripped bare.

Plate 3:
Natural slope instability above Tararu township.

Details of actual rainfall measurement during the weather bomb and estimated stream flows are presented in Table 2-1 below. Damage in the TCDC area included:

- Widespread power failures and damage to wastewater and water supply systems.
- Most streams experienced significant debris infilling. This required considerable resource application to clear stream channels in as short a time as possible to reinstate the normal streamflow capacity.
- Widespread scour of stream banks and many culverts and bridge approaches suffering erosion damage.
- Damage to roads in the area was considerable with many cases of washouts and slips.

- Between Tararu and Waikawau 356 properties were inundated. This included 118 houses and structural damage noted in 35 cases. There were 148 basements/sheds affected. In Coromandel 50 homes were affected with rooftop damage in several cases.

- Damage was reported to have cost TCDC around $3.1 million for repairs to assets managed by the Council over the Coromandel Peninsula.

Overall the weather bomb resulted in 14,000 insurance claims totalling $25 million across the country. Events of this kind highlight the natural disaster potential that local and regional agencies must plan for.

A draft Flood Management Plan (FMP) is under development for Coromandel. FMPs for Tararu (TCDC, 1999) and Te Puru (TCDC, 1999) have been prepared as part of the hazard management plans being developed by TCDC. These FMPs provide graphical representation of low, medium and high flood hazard areas. They are one of the key tools used by Council to plan flood mitigation measures and reduce the potential impact of floods on the community. The FMPs were developed by TCDC and complement the regional Flood Risk Mitigation Plan (FRMP) issued in 1997 (Environment Waikato, 1997). The FRMP, as reported by Environment Waikato "*…confirms the principles accepted by Environment Waikato as the basis of the Flood Risk Mitigation Plan. These include integration of the various flood management statutes, while recognising the primacy of the Resource Management Act 1991. There is also an emphasis on working in partnership with district councils and communities to find acceptable solutions to flooding issues*."

The Coromandel FMP contains details of past flooding events in the areas as well as a summary of flood mitigation measures that may be possible or have been implemented. Further information is also available on specific historical events from reports prepared by the Hauraki Catchment Board (HCB) and the Regional Water Board (RWB), including reports in 1981 and 1985 (Smith and Cameron, 1981 and HCB, 1985). For areas other than Coromandel, the HCB and RWB were responsible for catchment management matters in conjunction with District and County Councils prior to the formation of Environment Waikato in 1989. The Coromandel area was administered by the Coromandel County Council until Environment Waikato, in conjunction with TCDC, assumed responsibility for these issues. This QRA makes use of this available data, particularly with respect to catchment and stream characteristics, experience of flood damage and proposed flood mitigation options.

Table 2-1: Rainfall and Streamflow from June 2002 Weather Bomb and Catchment Modelling

Location	Recorder site	Rainfall			Streamflow		Catchment area	Specific discharge	
		Total[1]	Intensity[1]	Return period[2]	Peak flow[1]	100 yr AEP flows[3]			
		(mm/hr)	(mm/min)	(years)	(m^3/s)	(m^3/s)	(km^2)	($m^3/s/km^2$)	
Coromandel	Rings Road	270/48	125/25	100					On Karaka Stream.
Tapu		215/24	160/120	100					
Waiomu		160/24	30/15						
Pinnacles		200/24	37/60						
Waikawau	SH25				340		34	10	
Te Mata	SH25				330		27	12.2	
Tapu	SH25				275	283	26	10	Similar to 1985 event.
Waiomu	SH25				145	148	11	14	110 m^3/s recorded in 1985 (estimated to be 50 to 100 year event).
Te Puru	SH25				345	300	24	15	170 m^3/s recorded in 1985 (estimated to be 10 to 20 year event).
Tararu	SH25				260	218	16	17	
Karaka	SH25 (Thames)				80		5	16	June 2002 event.
Whangarahi						155	11.1	24 to 38	
Karaka (Coromandel)						94	6.5	33 to 65	

[1] Experience from Weather Bomb. [2] For one hour rainfall. [3] From catchment modelling.

3.1 Risk Assessment Overview

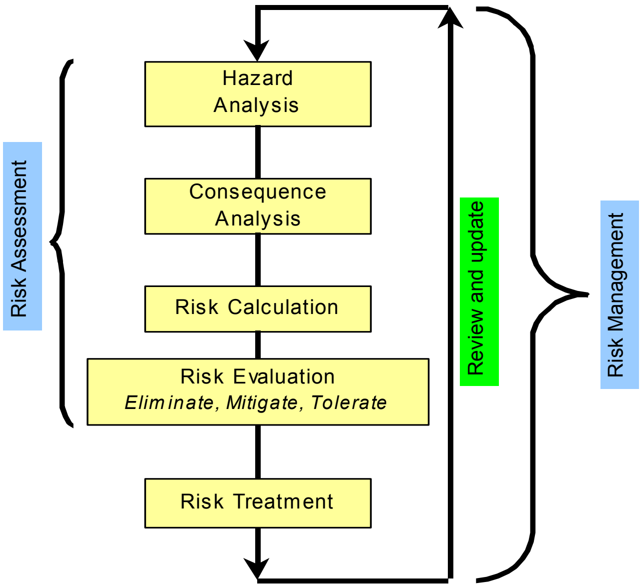
The overall risk assessment methodology, which is consistent with the Australian and New Zealand standard for risk management (AS/NZS 4360) and what is now becoming the industry standard for risk assessments dealing with natural hazards such as landslides (AGS, 2000), comprises the following steps:

1. Definition of the problem and setting the terms of reference for the study (context).
2. Hazard analysis, including:
   - Identification of the hazards and characterisation of the nature and geometry of the hazard.
   - Mechanics of the flood flow in terms of water depth, velocity and damage potential.
   - Estimation of the extent of flooding.
   - Estimation of the probability (or frequency) of flooding.
3. Consequence analysis, which includes:
   - Estimation of the potential numbers of people impacted by the flooding.
   - Assessment of the likely property damage due to flooding.
   - Assessment of other flooding impacts such as costs to businesses, environmental damage etc.
4. Risk calculation.
5. Risk evaluation incorporating:
   - Comparison of the risks with available guidelines.
   - Investigation of risk mitigation options.
   - Assessment of the costs and benefits of risk mitigation options.
6. Risk treatment through the development of a Risk Management Plan, including implementation, reviews and update.

This overall approach is also consistent with the guidelines published by the Australian National Committee On Large Dams (ANCOLD, 1994), which has been accepted by the Australian dams industry and regulatory authorities as providing an appropriate methodology for the systematic and defensible evaluation of dam safety. The 1994 guidelines have been widely used in Australia and New Zealand and there is now a considerable body of knowledge and experience of their use. This has lead to the updating of the guidelines, which are currently in draft form.

Figure 3-1 (following) presents the various steps in the risk assessment and overall risk management process, once the context is established, emphasizing its iterative nature.

Figure 3-1: Risk Management Diagram



3.2 Thames Coast Risk Assessment

Risk is defined in general terms as the product of the frequency (or probability) of a particular event and the consequence of that event, be it in terms of lives lost, financial cost and/or environmental impact. The risk calculation may be carried out quantitatively. In this case the probability of the event occurring is multiplied by the probability and quantum of the consequence. The probability of the consequence may itself be the product of the probabilities of several factors (conditional probabilities) resulting in the final outcome of the event.

Alternatively, the risk may be estimated qualitatively by combining the probabilities of the event and the consequences in a non-product form, such as a risk matrix. For this, the probabilities and resulting risk are defined descriptively.

A more detailed discussion on risk assessment, the processes involved and interpretation of results is presented in Appendix A.

For this risk assessment a quantitative approach has been used. However, there is a significant judgmental aspect to estimating several of the input parameters for the numerical model. Strictly speaking this means that the risk assessment is at best only semi-quantitative. However, professional judgement and experience are valid and accepted means of developing realistic models of complex natural or behavioural mechanisms and guidelines are available for the use of judgement in engineering risk assessments (Barneich et al., 1996). Given the following aims of this study a quantitative methodology is required, namely:

- Estimation of the lives risk due to flooding at each of the subject communities and comparison of the lives risk with available guidelines or criteria.
- Prioritisation of the risks to facilitate the development of a defensible and transparent risk management plan.
- Quantification of the benefits from risk mitigation works to aid in the evaluation of the identified risks and mitigation measures.

The risks due to flooding for each community are estimated using a spreadsheet model that incorporates the frequency of the nominated flood event together with various factors reflecting the probabilities of various outcomes.

The general expression for quantitatively estimating the risk is:

$$\mathbf{R} = \mathbf{P_{(H)}} \times \mathbf{P_{(S:H)}} \times \mathbf{P_{(T:S)}} \times \mathbf{V} \times \mathbf{E}$$

Where,

R	=	annualised risk (which may be thought of as the annual probability of fatality or property damage in financial terms).
$P_{(H)}$	=	annual probability of the flood event.
$P_{(S:H)}$	=	probability of spatial impact given the hazardous event i.e. the likelihood of homes, businesses etc. being in the path of floodwater.
$P_{(T:S)}$	=	temporal probability of the consequence occurring i.e. probability of the element at risk being present within the area affected by the flooding when the flood occurs.
V	=	vulnerability of the element at risk given the presence of the element at risk within the area affected by the hazardous event.
E	=	the element at risk i.e. an individual, a group or community, or property etc.

The risk assessment procedure is similar to that used over that last few years by URS for numerous dam safety evaluations in Australia, the United States and New Zealand. The overall risk assessment approach has been used to quantify risk to life due to flooding of the Waiho River adjacent to Franz Josef township (Optimx, 2002) and the risk to life due to an anticipated lahar from the Mt. Ruapehu crater lake (TTAC, 2002). It is also used overseas to assess flood risks, particularly in the Netherlands (Jonkman and van Gelder, 2002). Details of the hazard and consequence analysis, the risk calculation models and model outputs are discussed in Section 4.

The basic question to be addressed in the risk assessment is - what is the likely consequence in terms of lives lost and property damaged due to the 100-year flood? This section provides a detailed discussion of how we have addressed this question and developed the algorithm to quantify the risk. Firstly the lives risk calculation is discussed followed by the financial risk.

4.1 Lives Risks

The quantitative risk model has been developed using an Excel spreadsheet. The calculation process is standardised for all communities as far as possible to ensure that a consistent methodology is used for the calculation of risk for each location, to keep the number of variables to a manageable level and to make the whole process as transparent as possible. This structure also facilitates sensitivity checking of the base assumptions. The inputs to the model are summarised step by step below.

The spreadsheet model is based on event tree analysis, which is a widely recognised tool to logically and systematically represent potential pathways that map various events and consequences. Each branch point in an event tree represents a key decision point (or node) that has been identified in de-convoluting the problem to be studied into a series of sequential steps. Each decision point may have alternative outcomes. A probability is then assigned to each alternative and under most situations the probabilities for the branches from each node will sum to 1.0. The use of event trees simplifies the problem into manageable steps and helps to clarify the risk calculation. Each branch of the event tree is referred to as a "scenario". For each scenario the potential consequence in terms of fatalities is estimated, which is then multiplied by the probability of that scenario (itself the product of the conditional probabilities along each branch of the event tree) to give the risk.

4.1.1 Hazard Analysis

The exercise of developing the event tree is the hazard analysis phase of the risk assessment. The event tree that we have developed to de-convolute this situation into a series of small steps that can be logically examined is shown in Figure 4-1 (at the end of this section) and incorporates the following points (nodes):

1. What is the hazardous event that can cause an adverse consequence?
2. Given the 1 in 100 year event, will this generate the 100-year flood?
3. If there are any flood mitigation measures in place, to what degree will they reduce the flooding impacts?
4. Are the assumed inundation areas appropriate?
5. During which part of the year will the flood occur (given that this affects the potential numbers of people at risk)?
6. At what time of day will the flooding occur (which will influence the potential numbers of people at risk, how much warning they receive and their chances of escaping the flood water)?

7. Is there any warning available (which directly affects the chances of people escaping the floodwaters and hence the likelihood of fatalities due to the flooding)?

These are examined in more detail below.

Hazard Event

For this risk assessment the hazard event is assumed to be the worst case flood resulting from a rainfall event with a 100 year return period (a frequency of 0.01 per year). This same frequency has been used for all of the communities examined.

The 100-year event was selected for this risk assessment as this is the standard used by Environment Waikato for assessing flood hazards throughout the EW Region, and because considerable useful data were already available on the extent of flooding from such an event. This information included Hazard Zones that were developed by Environment Waikato for the subject townships. These Hazard Zones define the 1% AEP (annual exceedance probability) flood flows and have been developed using computer modelling of the respective stream catchment areas, surveyed contour maps of the flood prone areas with subsequent "ground truthing" based on field observations from the weather bomb event of July 2002 and other anecdotal evidence.

Figures 4-2 to 4-8 (at the end of this section) present the estimated inundation areas for each community. These figures include hazard lines that delineate the Environment Waikato hazard zones, comprising:

- High Hazard (red line) – characterised by overland flow up to approximately 1 to 2 m depth at a velocity of 1 m/s (or more).
- Medium Hazard (orange line) – water flows less than about 1 m/s and 1 m deep and ponding areas with water depths up to 1 to 1.5 m.
- Low Hazard (yellow line) –ponding areas only.

These inundation areas are also coincident with the boundaries used in the risk assessment to delineate areas with different flood severity (refer Section 4.1.2), which describes the destructive potential of the floodwater (refer Section 4.1.2).

Probability of the Flood Event

It is not always the case that a rainfall event with a certain AEP generates a flood with the same AEP. The main factors that affect flood conditions include:

- Topography.
- Catchment size and characteristics (i.e. soil cover, land use etc).
- Soil moisture conditions prior to an event (i.e. antecedent rainfall).

- Intensity and duration of rainfall.

It is assumed that the catchment conditions are reasonably uniform across the subject areas. Storms may vary from site to site but the general catchment characteristics are similar. All catchment areas are relatively small and contain steep topography in the upper reaches. Specific storm patterns are assumed to be uniform over each individual catchment. Inspection of Table 2-1 indicates that the specific discharge for most areas due to the June 2002 event was around 10 to 14 m^3/s per km^2 (although some areas varied up to 17 m^3/s per km^2). Land uses are generally similar over the catchment area with a mix of bush-clad hills and flood plains occupied by residences, light industrial areas and commercial/tourist businesses. The time of concentration for all catchment areas is relatively short (i.e. of the order of 45 to 90 minutes). Therefore, in this case there is a high likelihood that the AEPs for rainfall and flooding will closely correlate.

Performance of Mitigation Works

We have constructed the risk model to account for a reduction in the degree of flooding due to physical flood control measures. For the initial model run representing the current catchment conditions, we have assumed no works are in place i.e. the estimated inundation areas reflect the likely impacts from a 1% AEP flood as at March 2003. We have assumed that all stream channels are clear of any accumulated debris and therefore at their full design or natural capacity. In reality, considerable quantities of debris are transported down the channel in high flow events, which is a significant issue for post-event recovery operations.

Various factors can be introduced into the model at this point to account for physical flood control measures within the catchment that reduce the potential flood inundation areas and depth/velocity of flood water. For example, stop banks may reduce the flood frequency and or flood severity. The degree to which the measures reduce the flood impacts is estimated based on subjective judgement taking into account any design criteria for the works, increased stream flow capacity, reduced flood flows etc. Sometimes flood mitigation measures may be relevant to specific scenarios rather than the whole catchment or potential hazard areas. In these cases the benefits of the works are incorporated into the risk model as appropriate, rather than adjusting this overall factor.

Flooded Area

At this stage we have assumed that the inundation areas provided by Environment Waikato represent the likely worst-case scenario for a 1% AEP flood event. This parameter may be altered to account for some aspects of flood mitigation works, which would need to be subjectively assessed based on a logical consideration of the catchment characteristics and the proposed mitigation method(s).

Season

A seasonal variation over the year has been accounted for in the number and distribution of people in the flood zones. Three seasons have been defined:

- High season encompassing 20 December to 31 January.
- Medium season (or shoulder season) encompassing 1 Feb to 30 April and 1 September to 19 December.
- Low season encompassing 1 May to 31 August.

These dates are based on the 2003 calendar year and reflect school holidays and occupancy of visitor accommodation.

Type of Day

In calculating the flood risk, the model considers whether the flood hazard occurs on:

- A weekend or public holiday.
- A normal work or school day, or
- On a school holiday.

This impacts on the number and location of people at risk. The probability of each depends on the season, and is determined from the 2003 calendar. For example there are 43 days in the high season, of which 17 are weekends and public holidays. For the low season, there are 123 days in total of which 37 are weekends and public holidays.

Time of Day

The time of day accounts for whether the flood strikes in daylight or darkness, which in turn affects the likelihood of flood warnings and to some degree the efficiency of any evacuation. The probability of it being day or night varies with the season – there are more daylight hours during the summer as opposed to winter.

Is There Warning Available?

In determining what level of warning may be available to the population at risk and hence the likelihood of evacuation from areas potentially exposed to flooding, we believe that the following factors must be considered:

- *Ability to detect or anticipate the onset of flood conditions:*
  - Is heavy rainfall forecast?
  - Are there rain gauges and stream gauges installed?

  - Are they an effective indicator of potential flooding?
  - Are they telemetered and alarmed i.e. how accessible is the information from them?
  - Catchment size and characteristics – how quickly does heavy rainfall lead to flood conditions?

- *The ability of the authorities to take action to warn people:*
  - Is there an established Civil Defence network in the community and are people well trained?
  - Is there an established plan of alert levels and response actions?
  - Are communications reliable in adverse weather?
  - How easy is it to communicate with people in locations at risk (by phone, road etc?)
  - Are there adequate resources to cover the area and contact everybody in the available time?

- *The ability to evacuate to a safe location in the available time:*
  - How far do people at risk have to move to get to a safe location?
  - Are there physical barriers to negotiate eg. steep slopes, or escape routes likely to be blocked?
  - Are there established evacuation plans and safe locations identified, both for householders and facilities such as camping grounds?
  - Have these plans been exercised?
  - What level of awareness and preparation is there in the community in relation to the flood hazard?

In light of these factors we have assigned the following subjective probabilities to reflect consideration of the above factors, in consultation with EW and TCDC. The probabilities adopted for this risk assessment are presented in Table 4-1.

Table 4-1: Probabilities of Level of Flood Warning Available

Level of warning	Day	Night
Adequate warning	0.5	0.4
Little warning	0.4	0.4
No warning	0.1	0.2

For example, this means that in the event of flooding during daylight hours, there will be no warning in 10% of cases and the highest fatality rate (no warning) will apply to the people at risk. We have assumed at this stage that the probabilities are the same for all locations and all activities (refer to Section 4.1.2, below for an explanation of activities).

4.1.2 Consequence Analysis

For the lives risk calculation the elements at risk are people, hence the consequences of the flood event are expressed in terms of fatalities. The number of fatalities is estimated based on an overall population at risk (PAR), which is then factored for different scenarios according to various activities or land uses to calculate the loss of life (LOL).

Population at Risk (PAR)

The PAR is the number of people potentially exposed to the flood hazard at each location and for each activity. These numbers have been developed from data provided by EW and TCDC, in particular the overlay of the inundation areas, the cadastral maps and aerial photographs. In the model we have defined the following activities or land uses for the purposes of determining PAR. These are:

- Private residences.
- Schools.
- Retirement villages.
- Camping grounds.
- Hotels and motels.
- Business.

Each community has a base PAR that provides the *maximum* numbers of people potentially located in each flood hazard zone within each activity. Not all locations will have people in every activity in a flood-affected zone. The base PAR is then modified to reflect the time of year, season and time of day. For example, there will be no children present at schools in the evenings or during holidays. Similarly, the numbers of people at home in private houses will generally be greatest at night, whereas during the day people will be out and about. Seasonal variations have been applied to the PAR for camping grounds and hotels and motels, where the PAR reflects the increased occupancy during high season. There is no seasonal variation for other activities.

It is noted that the model does not rigorously account for the movements of each representative individual over the whole year. Suffice to say the number of people engaged in any activity in any particular flood hazard zone will vary over the course of a day, a week or a year. A summary of the PAR figures used for each location and activity is provided in Appendix B.

Loss of Life (LOL)

From the PAR the LOL was estimated based on factors for fatality rates published by the United States Department of the Interior Bureau of Reclamation (USBR). The fatality rate is defined as the fraction of the PAR likely to be killed as a result of the flood hazard. The fatality rates depend on the severity of the flood, available warning time and the level of understanding that those at risk are likely to have with respect to flood warnings. The USBR fatality rates were derived from a statistical analysis of fatalities caused by floods that have occurred in the US due to dam failures and storm events over the last 50 years. The USBR study assigned the various floods one of three severity ratings based on the destructive nature of the events. The highest flood severity rating was for floods that caused massive damage by washing the flood areas clean. A medium flood severity rating represented the situation where houses were essentially destroyed but debris and trees remained for survivors to cling to. A low severity rating represents situations where floodwater passed through an area but houses remained standing.

In assigning the fatality rates for this study, we have correlated the USBR flood severity levels to the *flood hazard zones* defined by TCDC/EW. In general, a USBR severity rating of VERY LOW to LOW was assigned to ***low*** and ***medium*** flood hazard zones, respectively. A flood severity rating of MEDIUM was assigned to ***high*** hazard zones. A flood severity rating of HIGH is associated with areas expected to be completely destroyed in the event of a flood. This would typically require very high water velocities (of the order of several metres per second) and several metres deep. This level of damage is not expected in a 100 year event. However, camping areas with tents and caravans could be susceptible to this level of damage in a 100 year event, consequently these areas have been assigned a ***very high*** flood hazard and hence a HIGH flood severity category. The adopted factors are listed in Table 4-2, following:

Table 4-2: Fatality Rates

	Flood hazard and severity classification			
TCDC/EW flood hazard zone	***Low***	***Medium***	***High***	***Very High***
USBR flood severity rating	**VERY LOW**	**LOW**	**MEDIUM**	**HIGH***
Adequate warning	-	0	0	0
Little warning	-	0.002	0.01	0.015
No warning	-	0.005	0.03	0.15

* Applied to camping grounds only

In general, we have adopted the lower end of the range in fatality rates suggested by the USBR. This is a reflection of the typically high destructive forces caused by dam break floods that feature in the USBR study, which generally have more severe consequences and less warning than an extreme rainfall-generated event. Except as noted, we have assumed at this stage that the probabilities are the same for all locations and all activities.

In estimating the LOL we have introduced a susceptibility factor into the algorithm in addition to the USBR fatality rate to reflect the "sensitivity" of the exposed population. While the USBR figures reflect average historical fatality rates over a whole population, it is expected that in an emergency, the young and the elderly will be less able to respond or protect themselves. We have therefore applied a factor of 1.2 for school and a factor of 1.5 for retirement villages to the fatality rate factors to reflect these sensitivities.

4.1.3 Uncertainty

Risk assessment is not an exact science. There is insufficient, and often no actuarial data on which to make statistically valid assumptions on the frequency of various input parameters for the risk calculation. In many cases the estimates of the consequences of the specific events also contain uncertainty. Therefore, data are developed through empirical analysis and the collaborative efforts of experienced practitioners best qualified to make such assessments. A structured framework for making subjective judgements also helps in the assessment of the various input parameters and probabilities (refer Appendix A). While producing the best available information, the resulting estimates contain uncertainty.

The uncertainties associated with this type of assessment may be described in three broad categories:

- uncertainty associated with the probability of occurrence.
- uncertainty associated with predicting the scale of consequences if a failure occurs.
- uncertainty associated with accurately estimating costs for the consequences.

In the lives risk assessment uncertainty in the various input parameters is assessed by testing the sensitivity of the outputs to these parameters. The results of a sensitivity analysis for the lives risk outputs are provided in Appendix A.

4.1.4 Risk Calculation

For each location, the model calculates the frequency of occurrence (f) of 54 scenarios representing separate combinations of season, day, time of day and level of warning. The number of fatalities is estimated based on the PAR within each flood hazard area and according to each activity, then summed to give the total number of expected fatalities for that scenario (ν). This calculation is summarised below:

Annual probability of 100 year flood:	0.01
Probability that it is high season:	0.12
Probability that it is a weekend or public holiday in high season:	0.4
Probability that it is daytime in high season:	0.67
Probability that no warning is received given that it is daytime:	0.1
Total annual probability of this scenario (f):	$0.01 \times 0.12 \times 0.4 \times 0.67 \times 0.1 = 3.22 \times 10^{-5}$

The base PAR in the ***high*** hazard zone in private residences at location X is 60 (in this case the only activity that has people at risk is residences). Because it is a weekend or public holiday and during the daytime, the number of people actually at risk will be lower (90% of this). The fatality rate for the ***high*** hazard zone, given no warning is 0.03. The LOL for this event is then $0.03 \times 0.9 \times 60 = 1.6$ (ν). If other activities such as “school” or “business” had people at risk for this scenario then ν would be the sum of the LOL values for all activities for each particular scenario. The lives risk due to this scenario is then $f \times \nu = 3.22 \times 10^{-5} \times 1.6 = 5.22 \times 10^{-5}$ fatalities per year. This can also be expressed as 0.0052 fatalities per 100 years or a 0.5% chance of a fatality occurring under this scenario given a flood with a 1 % AEP.

4.1.5 Lives Risk Model Outputs

This Section provides a brief explanation of how the lives risks are presented for this QRA. Further discussion on lives risk and the interpretation of risk levels is provided in Appendix A. The results from this lives risk assessment are presented in Section 5.

Individual Risk

Individual risk (IR) is usually defined as the annual probability that a specific individual, or specific group of individuals, would be killed because of the identified hazards and considering their actual presence in the area affected by the hazard. A more detailed discussion on individual risk is provided in Appendix A. To provide an indication of the likely range of estimated individual risks for this study we have calculated the IR for the following cases:

1. A resident spending on average 50% of the available daytime and 90% of available night time in a house located within a high hazard area over the year.
2. A resident spending on average 50% of the available daytime and 90% of available night time in a house located within a medium hazard area over the year.
3. A school pupil.
4. A person using a campground tent or caravan site in a “very high” hazard area for three weeks during the high season and spending 50% of the available daytime and 95% of the night time at the campsite.
5. A person using a campground tent or caravan site as above in a high hazard area.

There are other individuals or groups of individuals that can be identified, however the above cases provide an indication of the likely range of individual risks for this study.

The IR is calculated by summing the frequency numbers (f) for the scenarios that cover the time that the individual is exposed to potential flooding over the year. For a permanent resident this may be 70 to 80% of the time. For a school child this may be of the order of 15% of the year (in this case assuming that out of school hours they are not exposed to flood risk).

Societal Risk

Societal risk is defined as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards. For comparison, individual risk gives the likelihood of a fatality at a certain location due to a particular person’s pattern of exposure. The societal risk gives the risk for the population within a whole area no matter where the people are located and covering all potential exposure patterns within the area that harm may occur.

Societal risk is calculated in the following two ways:

1. Annualised Lives Risk (ALR).
2. Cumulative frequency (F) of N or more deaths, usually plotted on a F-N chart.

The ALR is a kind of societal risk in that the risk is represented as the likelihood of a fatality that is calculated based on the total number of people that may be considered to be at risk. In some cases this is also referred to as the Expected Value (EV) or Probable Loss of Life (PLL). This is different to individual risk where the risk is calculated expressly for a particular individual or group of individuals. The ALR is probably the most difficult measure of risk to define because it can be calculated in many ways that may give rise to considerable variation in the level of risk for a given site. There are limited cases where guidelines on limits for ALR are available, due mainly to the relatively high potential for varying results depending on how the risk is calculated. ALR is also useful to compare risk levels across the various communities and it can help prioritise risk mitigation works.

The contributions to the ALR from the various activities within a community can be displayed, which can be used to indicate whether one or a few activities dominate the level of risk and hence where specific risk mitigation measures can be targeted.

Societal risk is also presented on a chart that plots the cumulative frequency (F, or probability) of N or more deaths occurring per year against the number of deaths (N), which is referred to as a F-N chart. A F-N curve can also be thought of as illustrating the incremental risk of death. Typically, F-N charts are used to demonstrate risks where there are potentially large numbers of fatalities involved. Guidelines are available regarding societal risk that reflect society's aversion to disasters that involve multiple fatalities in that the greater the expected loss of life the lower the tolerable chance of occurrence.

4.2 Financial Risk

The financial risk model is essentially the same as the lives risk model except that the consequences of the hazard event are assessed in economic terms instead of fatalities.

4.2.1 Elements at Risk

The economic elements at risk due to flooding are listed in Table 4-3, following.

Table 4-3: Economic Elements at Risk

Activity or asset	Economic elements at risk
Residences	Direct damage to buildings and contents including repairs, replacement and cleanup costs.
Schools	
Retirement villages	
Camping grounds	Direct damage to specific buildings and contents for caravans, units and tent sites. Loss of business costs to the campground.
Hotels and motels	Direct damage to specific units. Loss of business costs.
Commercial businesses	Direct damage to business premises and contents including repairs/replacement and overall cleanup costs/ Loss of business costs
Local agency response	Direct costs of managing flooding emergency including personnel, machinery, external resources etc. River channel/floodway maintenance (clearing channels and debris). Repair of erosion damage. Water supply system costs for damage and repair to the infrastructure including costs associated with temporary facilities. Wastewater and sewage system costs for damage and repair to the infrastructure including costs associated with temporary facilities. Local roads and bridges covering direct damage and repair to the infrastructure including costs associated with temporary facilities.
Regional agency response	Direct costs of managing flooding emergency including personnel, machinery, external resources etc. Maintenance of flood management assets.
State Highway	Highway and bridges covering direct damage and repair to the infrastructure including costs associated with temporary facilities.

Data on the economic consequences of flooding have been obtained from Environment Waikato, TCDC and reports on previous flood events in the area. This is summarised in Appendix C along with the economic consequence costs developed for each element at risk.

4.2.2 Uncertainty and Cost Distribution

For the financial risk assessment the uncertainty in the input parameters is dealt with by estimating the aggregate of the uncertainties as a single element. The magnitude of uncertainty is accounted for by determining a range of possible economic costs due to the flooding hazard and expressing these as a distribution. In estimating these distributions, expected "mean" and "high" values of that element at risk have been adopted as input parameters. These are considered, respectively, as the most likely cost if the consequence occurs and as a reasonable upper level of the cost that is unlikely to be exceeded in 95% of the instances when the consequence occurs. The input values for the financial risk model are the mean (50%) and 95% confidence levels for the consequential costs. The spread between the mean and 95% values provides a relative comparison of uncertainty. The larger the spread of values, the larger the uncertainty contained in the estimates. Further discussion on uncertainty is provided in Appendix B.

4.2.3 Risk Calculation

The financial risk model is the same as for lives risks except that probabilistic calculations are included in estimating the economic consequences for each element at risk. Probabilistic calculations performed as part of the analysis are done using the @RISK™ v4.5 simulator, which is a commercial add-in software package to Microsoft Excel. The simulation software samples all distribution variables a large number of times using the Monte Carlo sampling strategy. The number of samples is specified by the user – 2000 samples have been used in this analysis.

The probabilistic approach used in this QRA assumes that there is virtually no upper limit to the cost distributions used in the financial risk model, and that for each cost distribution the higher costs have concomitantly lower probabilities of being incurred. When making decisions based on the risk assessment, it is important to be aware that the distribution parameters chosen for the analysis are indeed estimates only, and that in reality there is some chance that the figures calculated by the risk model could be exceeded.

4.2.4 Financial Risk Model Outputs

Outputs from the financial risk model include economic exposure values and financial risk quotients. Exposure values are the economic consequences of a flood event given that the event occurs. The exposure values can be used as a check on the inputs used for the economic consequences i.e. the costs, listed in Appendix B, for each of the financial elements at risk. The exposure values are expressed in real dollars.

The financial risk model also provides the financial risk quotients. The financial risk quotients are not real dollars; rather they represent the financial consequences multiplied by the probability of the event. The financial risk quotients can be output for any forecast cell as a tabulation of cost at selected confidence levels or as a probability distribution. The tabulated data are selectively extracted to produce risk profiles that show the financial risk quotients for the hazard event at selected confidence levels. The financial risk quotient (which is the economic equivalent of the ALR) can be used in the calculation of the benefit cost ratio for the various mitigation works options (refer Section 5.10.5). In this case the 50th percentile risk quotients are used in calculating the benefit cost ratios. Other values such as the 80th or 95th percentile values could be used. However, the 50th percentile values are considered the "best estimate" values for the consequential costs in the risk calculation model. In general terms the benefit cost ratio is calculated for each assessed option by subtracting the post mitigation risk quotient from the current risk quotient (which is the "benefit") and dividing by the capital cost of the works.

Figure 4-1: Event Tree Layout