Chapter 45
Managing water-related risks

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RISK MANAGEMENT

We all take risks every day—driving a car, using an appliance attached to mains electricity, leaving a wallet or purse in an unlocked room. Some people are more averse to risk than others, but we know what "risk" means. "Risk" also has a related, more precise, meaning as a technical term, combining the likelihood of something happening with the magnitude of the effect if it does. An earthquake of Richter magnitude 8 or more on the Alpine Fault of New Zealand's South Island has a relatively low probability of occurrence (large quakes last occurred there about 1717, 1620, 1450 and 1100 AD), but the magnitude of the effect on the Southern Alps, alpine rivers, Christchurch city, other population centres and regional infrastructure such as roads and power supplies, could be very severe (Stirling *et al.* 2001). The "risk" is high, even though such events occur infrequently. On the other hand, the occurrence of landslips on to roads and highways after heavy rain is quite common in New Zealand. Usually the efforts of local contractors with loaders, excavators and trucks can restore traffic flow within a few hours or days. The magnitude of the effects is low, but they have a high probability of occurrence, again leading to quite a high "risk".

Risk is not something physical; it is not synonymous with hazard. Risk is something social and cultural (Rees 2002). Managing water-related risks is done for social reasons such as human safety, and for economic reasons such as avoiding unwelcome and unnecessary costs. Risk and cost are related, but not simply. Some costs associated with high-probablility risks clearly will occur at some time. Other costs, much higher perhaps, might or might not occur, depending whether a particular event takes place. Managing water-related risks to suit one sector of society, say farmers, might increase the risk for another sector, recreational fishers perhaps.

"Risk management" has, in the last few decades, also taken on a quite precise meaning as a set of principles and methods that are now being applied to the management of risks of many kinds: financial; physical (hazard); military and health, as just a few examples (Keey 2000). It provides a way of managing diverse risks in a consistent manner. Water-related risks in New Zealand have been managed since Maori voyagers arrived here many centuries ago—well before "risk management" was defined. The management of water-related risks was one of the preoccupations of the settlers and colonists from the Northern Hemisphere from the mid-nineteenth century onward.

This chapter concentrates on the management of water-related risks in New Zealand recently and today, early in the twenty-first century. It is a period during which "risk management" principles and techniques are just beginning to be applied in resource and hazard management, including water resources and water hazards (Griffiths and Ross 1997). This is exemplified by the passing of the Civil Defence and Emergency Management Act (2002), which is firmly based on risk management principles.

For convenience, managing water-related risks is discussed here under headings related to categories of perceived risk. It is important to understand, however, that managing water-related risks is likely to be most successful if water resources are considered as systems, themselves embedded in physical and societal systems, and if the risks are considered in an integrated way. First described are risks associated with living things in water, and water in occupied places. Then the risks of excess and insufficient water are contrasted. Water risks in relation to energy, land movement and contamination are followed by the special risks from water as ice, snow and steam. Inevitably there are overlaps which result in some repetition in this linear exposition. And a lack of data on many risks ensures that the treatment is largely descriptive.

INTEGRATED WATER RESOURCE MANAGEMENT

To adequately discuss the management of water-related risks we must consider the management of water resources in more general terms. Groups of people in New Zealand society have diverse and sometimes conflicting expectations for water use, and managing water resources involves water-related risks to one group or another. The way in which water resources have been managed until the present has been somewhat piecemeal, with different agencies and groups being responsible for different aspects of water resource management.

Internationally, it has been suggested that there is an imminent risk of a "water crisis" (e.g., World Water Council 2000). According to the Stockholm-based Global Water Partnership: "The water crisis is mainly a crisis of governance. The present threat to water security lies in the failure of societies to respond to the challenge of reconciling the various needs for and uses of water." (Global Water Partnership 2000). The response to this crisis, advocated by both the World Water Council and the Global Water Partnership, involves adopting the concept of "Integrated Water Resource Management".

New Zealand has a relative abundance of fresh water (Painter 1990). Nevertheless, the water resources are managed in ways that are being labelled "unsustainable" and "fragmented" when used elsewhere. That in itself constitutes a risk to be managed. An important risk involving regional water resources is that future flexibility in their management as an integrated system could be prejudicially affected by prior resource allocation. There has been criticism of the Resource Management Act (1991)—that it encourages single-project, and first-in, first-served water allocation. Regional Councils have found it difficult to discharge their responsibilities under the Act towards sustainable husbandry of a region's water resources. There has been debate whether this is a deficiency of the Act, or of the Councils. It seems that an Act whose purpose is to "promote the sustainable management of natural and physical resources" should be able to be interpreted in a way which does that in an integrated and systematic manner. But so far, integrated risk management of water resource systems has failed to be either integrated, or applied to whole systems in New Zealand (Painter 2000).

PEOPLE, ANIMALS AND PLANTS IN WATER

People

Drowning ranks third, after road accidents and accidental falls, as a cause of accidental death in New Zealand. Although annual deaths from drowning show a decreasing trend since 1985 (Fig. 45.1) there are still more than twice as many per 100,000 people as in the USA, Canada or Australia, and four times as many as in the UK (Water Safety New Zealand web site). This has been an unfortunate aspect of New Zealand's history—drowning in early settlement times was called "the New Zealand death", or simply "settlers' disease".

Water Safety New Zealand Incorporated is the organisation charged by the New Zealand Government with "ensuring that all New Zealanders are safe in and around water—at home, in public pools, at the beach, in lakes, in rivers or out at sea" (Water Safety New Zealand web site). Water Safety New Zealand's philosophy is achieving water safety through education, training and actively promoting water safety awareness. Their main tools for influencing water safety, thus managing the risk, are web site, video, and printed and public display media, together with television advertising. They have three specialised web sites (accessible from the main web site) devoted to water safety in boating, swimming pools and rivers.

There is special national legislation (Fencing of Swimming Pools Act 1987) governing fencing of privately-

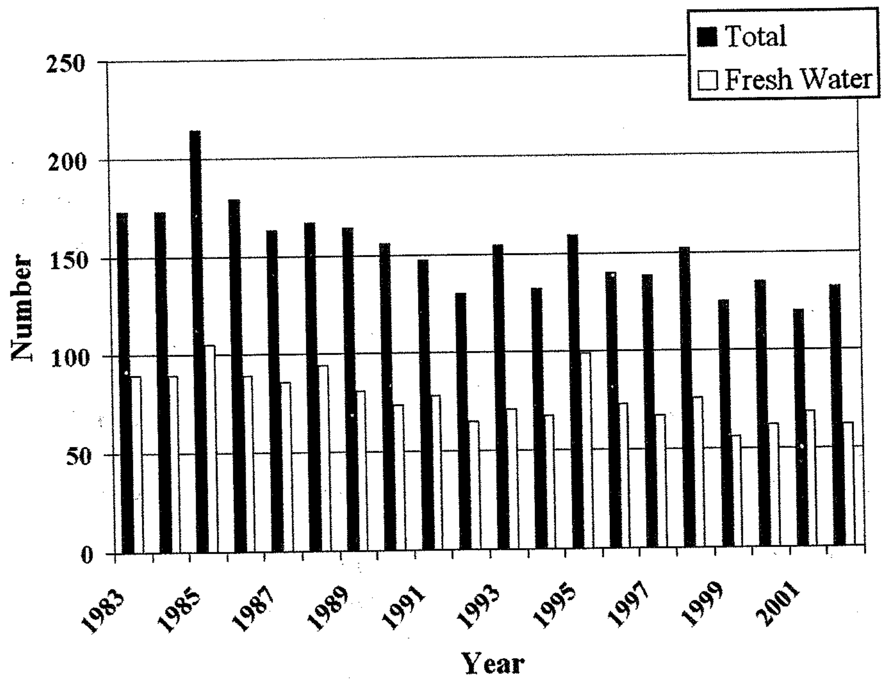

Figure 45.1 Drownings annually in New Zealand 1983-2002, total, and fresh water

owned swimming pools. This was enacted specifically to promote the safety of young children, particularly toddlers. The risk of small children drowning is intended to be greatly reduced by preventing them from having access to the pool area, unless they are with someone responsible, who is capable of opening a gate in the fence, which has to be an approved structure.

About a third of all drownings have occurred in rivers, but fewer than half of the people involved intended to be in the river. About 28% were in vehicles that crashed into rivers, 22% fell in from the banks and 2% were fishing (1983-2002 statistics, Water Safety New Zealand website). Many roads follow valley bottoms beside streams and rivers. Roadside reflectors and crash barriers, especially on bridge approaches and where roads run parallel to a stream or river, are intended to assist in keeping vehicles on the road and out of the water.

About 24% of those who drowned in rivers in the same period were engaged in swimming, canoeing or other boating, rafting or tubing, or diving or jumping in deliberately. A special category is those, such as trampers and walkers, who entered the river only to cross to the other side (6% of those who drowned). Eighty percent of those who drowned while crossing entered the river when it was in flood. Special courses available from alpine and tramping clubs provide instruction on crossing rivers safely.

Animals

It is common for farm livestock in New Zealand to graze freely up to the banks of unfenced streams and rivers. These sometimes form the boundaries between paddocks or properties. The natural or modified floodplain areas, and sometimes constructed floodways, can be grazed at all times other than during floods. Therein lies a risk to be managed. Advance notice of flooding is needed to provide time for farmers to move their livestock out of areas expected to be flooded. Some regional councils assist farmers in managing the risk to livestock by providing flood warnings on radio, web sites, or dedicated telephone answering services.

A very different type of risk is that associated with growth in the populations of unwanted fish species. These can overwhelm native and endemic species in a certain habitat, as well as having unwanted effects on vegetation and recreation. An example is the spread in the Waikato River and its tributaries of exotic koi carp, an ornamental strain of the common carp (*Cyprinus carpio*) native to Asia and Europe. Management of the risks posed by escape and proliferation of koi carp is the responsibility of the Department of Conservation. Management of their presence in ponds and lakes is primarily the responsibility of regional councils, such as Environment Waikato (see their web site).

Plants

There are risks associated with unwanted growth of plant species. The 1200-hectare Lake Omapere in Northland is a taonga (treasure) to the tangata whenua, Ngapuhi. The lake was used as a source of water for the Kaikohe region in the 1970s and 1980s. In December 1985 there was an outbreak of stomach disorders among residents whose drinking water came from the lake. There had been such prolific growth of the exotic *Egeria densa*, a larger and leafier version of the oxygen weed used in domestic aquariums, that the whole lake bed had been covered, with disastrous effects on most of the flora and fauna in the lake (Champion and Baldwin 2003). The stomach disorders were probably caused by an algal bloom, the result of the total collapse and decay of the weed beds.

Management of the weed problem has been the responsibility of the Northland Regional Council and Far North District Council. They enlisted the National Institute of Water and Atmospheric Research (NIWA) to provide scientific advice. Ironically, given the comments on risks from growth of unwanted fish species in the previous section, one successful weed management tool has been the introduction of 20,000 weed-eating grass carp (*Ctenopharyngodon idella*) in January 2002. Spraying the weed with herbicide was another part of the control strategy, but was not needed because the vegetation collapsed unaided, presumably as the climax of a "boom and bust" cycle. The use of carp was strongly opposed by the Royal Forest and Bird Protection Society. Among other risks they pointed out was the threat of extinction of the fern ally *Isoetes* aff. *kirkii*, a rare small native plant which is classified as being critically endangered and taxonomically indeterminate (unpublished media release by Eric Pyle of the Royal Forest and Bird Protection Society 2001). This species had probably disappeared from the lake prior to carp introduction, as a consequence of recolonisation of Lake Omapere by *Egeria densa* in the late 1990s and its subsequent collapse in 2000/2001. Any risk of the weed's significant return is likely to be managed by using grass carp. Further restoration of water quality will be by "riparian management and other nutrient reduction strategies, and possibly the restoration of native submerged vegetation" (Champion and Baldwin 2003).

Genetically modified organisms

There would be a water-related risk requiring management if a genetically modified organism that survived or multiplied in water, or was spread by transport in water, were to be released in New Zealand. No such event has been recorded to date (2003). A moratorium on applications to introduce new genetically modified organisms into New Zealand was applied by Parliament from November 2001 to October 2003. The deliberate introduction or development of organisms new to New Zealand is managed under the Hazardous Substances and New Organisms Act (1996). Inadvertent introduction is managed under the Biosecurity Act (1993).

WATER IN OCCUPIED PLACES

Some history

Flooding in occupied areas is the most costly natural disaster in New Zealand. The total average annual cost was estimated as approximately NZ$125 million in 1986 (Ericksen 1986), a figure confirmed as "unlikely to have diminished", in 1997 (Ministry for Environment 1997). The Insurance Council of New Zealand lists (on their web site) flood costs to the insurance industry of over NZ$400 million from 1968–2001, an average over NZ$12 million per year. This excludes contributions from the Earthquake Commission, which also contributes in some circumstances of land flooding. The direct cost to the central government of intervention in civil defence flooding emergencies is approximately NZ$15 million annually (Ministry Of Civil Defence and Emergency Management 2002). Over 70% of all emergency declarations since 1963 have been flood-related.

Many New Zealand towns and cities are sited on the banks of rivers and streams. This is a result of the relative ease of access during settlement, the need for a reliable water supply and good access to crossing places. This siting provided access to water for municipal use, both as supply and to dilute liquid wastes including sewage. Insufficient water in occupied places will be considered below under "Urban Water Supply".

But first the problem of too much water in occupied places will be considered. New Zealand rivers are rarely a constant-flow single channel which remains confined between two clearly-defined natural banks. Rather, during floods they regularly overflow onto their natural floodplain alongside the "baseflow" channel, or would do so but for river control works (q.v., below). So it is hardly surprising that river control and drainage were preoccupations from early settlement times. The earliest river boards or trusts started in 1868 in Marlborough and Hawkes Bay (Acheson 1968). There were both a Rivers Board Act and a Land Drainage Act in 1908 "to consolidate certain enactments of the General Assembly relating to the constitution of River Boards and the construction of river works", and "relating to the drainage of land". Later the Soil Conservation and Rivers Control Act (1941) was an important Act "to make provision for the conservation of soil resources and for the prevention of damage by erosion, and to make better provision with respect to the protection of property from damage by floods". It was complemented, and partly superseded, by the Water and Soil Conservation Act (1967), now repealed. The primary relevant Act now is the Resource Management Act (1991) and there are relevant provisions in the Building Act (1991).

There are two contrasting approaches to managing the risk that rivers may flood areas occupied by people and their property—to confine the river or to confine the people. These approaches are illustrated in the next two sections.

River control works

Riverbanks have commonly been occupied long before the natural habits of the river have been fully understood. "River control" was then attempted as risk management. River control schemes, as implemented from the 1940s until the 1970s, involved a whole package of central and local government financial grants and loans, and ratings for the local community share, with considerable experimentation, innovative engineering design and extensive physical works (e.g., see Acheson 1968).

River control includes built structures such as stopbanks, groynes (Fig. 45.2) and weirs, channel re-alignments and replacement channels, riprap and placed large rocks, and live streambank plantings such as willow trees (Fig. 45.3). There is an important paradox within floodplain management, including river control works—it could be called "the risk of managing risk". River control works include engineered structures such as the stopbanks visible in Figure 45.4 (called levees or dykes in other parts of the world). These are designed to contain floods within the river, up to a "design flood" level. The implication, clear to engineers and hydrologists, is that floods appreciably greater than the design flood will not be contained.

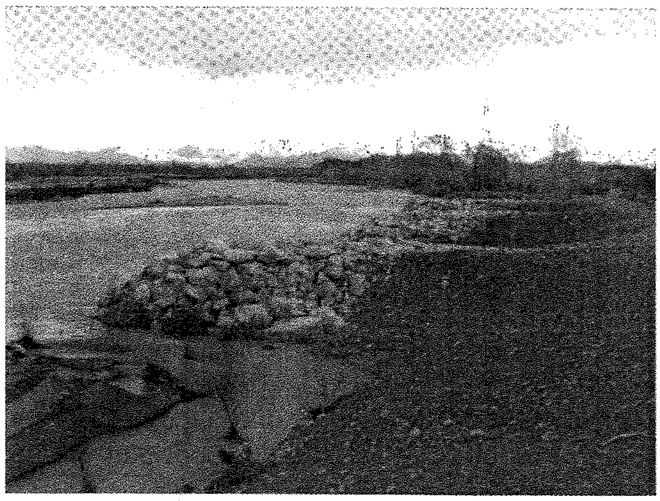

Figure 45.2 Stub rock groynes and pole planting upstream of a highway bridge, Hurunui River, North Canterbury.

Photo: River Engineering Section, Environment Canterbury

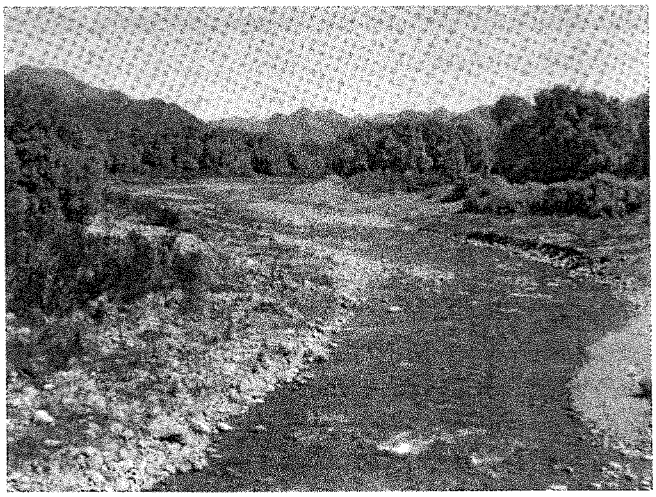

Figure 45.3 Bankside willows and channel shaping, Chatterton River, North Canterbury.
Photo: River Engineering Section, Environment Canterbury

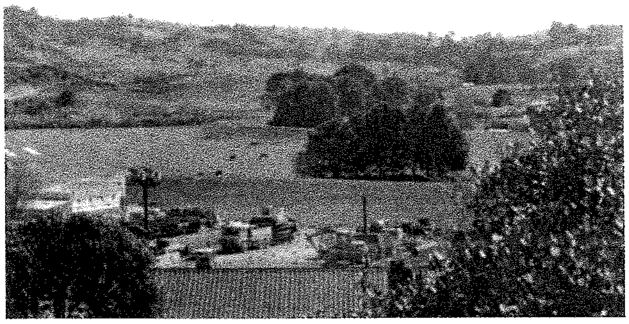

Figure 45.4 Stopbanks and berm floodways form part of the river control works where the Waipa River passes through Otorohanga, King Country, North Island.
Photo: David Painter

This is not always clear to would-be occupiers of the floodplain, including owners of residential dwellings, business owners and even elected councillors. It is quite well documented in New Zealand and internationally that the value of the assets at risk quite often increases in line with the expenditure that has occurred on flood protection (Ericksen 1986; Painter 2000).

The Lower Waikato and Waipa Flood Control Scheme was constructed between 1961 and 1982 (a small part of it in Otorahanga township is illustrated in Figure 45.4). It was put to an interesting test in 1992. A landslide dammed a tributary upstream (Tunawaea Stream) in August 1991. Prior to the dam's failure in July 1992, it was perceived that there was a risk that a rainfall-induced dam-break flood in the tributary could coincide with a flood in the Waipa River caused by the same storm, and that the river control works protecting Otorohanga could be overcome. The risk was managed by the regional council, local authority and others, using a variety of methods.

The state of the dam, the water level and the rate of leakage through the dam were monitored. All dwellings and farm buildings potentially affected by a flood wave were identified. Bridge waterways and other obstructions to flow were inspected. Computational hydraulic modelling was carried out to predict likely discharges and water levels (Webby and Jennings 1994). The overall prediction was that a flood wave would be contained within the river, in particular where it passes through Otorohanga. There was regular communication with the Otorohanga townsfolk, and more particularly with people living alongside the river in rural areas upstream of Otorohanga but downstream of the Tunawaea tributary junction. When the dam did fail, in July 1992, the predictions of safe passage of the flood were borne out.

Floodplain management

The second approach to managing the risk of rivers flooding areas occupied by people is to confine the people to areas away from where the river might go during a flood. The essential elements of this approach are mapping, planning and zoning. For example, areas can be mapped which might be suitable for recreational use, such as a golf course, but where residential building is not permitted. Then it is up to the regional and local authorities to publicise, legislate for, and enforce the rules. A degree of regulation is involved, by central, regional and local government, which has implications for citizens' views on personal freedom. A more recent development in New Zealand is floodplain flow modelling (Connell *et al.* 2001), to indicate where floodwaters can be expected to go, and their depth, in a flood of a given magnitude.

Floodplain management has become more common in New Zealand since the 1970s. In particular, it has been encouraged by the approach to integrated resource management exemplified by the Resource Management Act (1991). Floodplain management plans result from a process which involves a "flood hazard assessment", based on existing knowledge and relevant research, development of options by an authority and its community, consideration of flood control (structural) and non-structural (e.g., zoning) options, and a benefit-to-cost comparison for a predicted level of flood risk.

The two apparently mutually exclusive approaches to floodplain management outlined above are a simplification both of what actually occurs and what might ideally occur. Morrison (1995) has provided a rigorous and comprehensive doctoral thesis that presents, *inter alia*, methods to allow co-evolution of flexible floodplain management and the floodplain itself. But no current authorities have come close to implementing his recommendations.

On some occasions river control works have been built, but when the risks of floodplain occupation have been later evaluated, they have been proven to be greater than earlier believed, or perhaps greater than experts and authorities consider compatible with human safety. The town of Franz Josef in Westland is adjacent to the Waiho River. The Callery River tributary to the Waiho has been considered to pose a considerable risk to Franz Josef from a possible natural landslide dam formation and dambreak flood (Davies and Scott 1997). Even without this occurring, the Waiho River sediment and floodwaters have already caused expensive problems of river control and forced the closure of businesses. Appropriate management of the risk could involve relocation of part or all of the town (Davies 2002, OptimX 2002).

The management of risk for occupied lakeshores involves problems similar to those of floodplains of rivers and streams. On long time scales, river and lake overflows onto their floodplains have positive effects, including the development of fertile soils. In the medium term, risk management is needed when a lake level is raised slowly and deliberately, as when the lake has been modified for use as a hydro-electric reservoir. Short term, ongoing risk management is needed, similar to that for riverside communities, when lake levels fluctuate according to the vagaries of catchment rainfall. When the lake is a tourist destination as important as Lake Wakatipu, and the town has significant commercial property below recurring lake levels, as Queenstown has, the risk to be managed can be very high (Fig. 45.5). Managing water-related risks to property—well illustrated by the Queenstown example—involves financial tools such as insurance. Property values might also signal risk and the potential cost of flooding to intending purchasers.

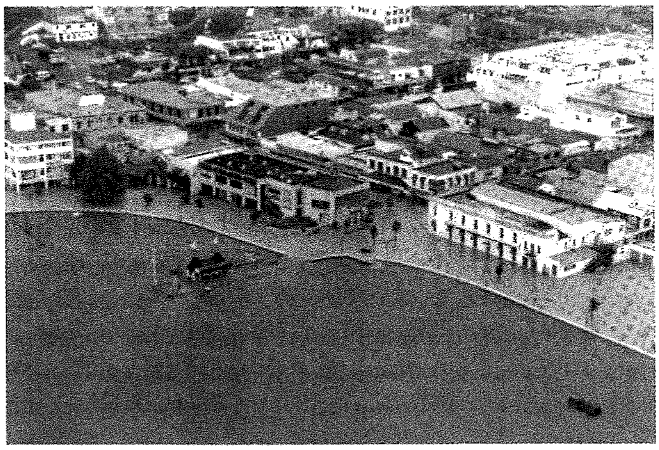

Figure 45.5 The central business district of Queenstown, with Lake Wakatipu in flood in November 1999.
Photo: Southland Times

Flood forecasting and flood warnings

Flood warnings were briefly mentioned in the section on "Animals". The term "flood prediction" is usually applied to the "likelihood of something happening", i.e., in a probabilistic sense. Phrases like "the one in a hundred year flood", or preferably, "the flood of 1% annual exceedance probability", are used in talking about flood prediction. "Flood forecasting" is a term usually applied to the real-time estimation of flood discharge or level in the immediate future at a particular site. This can be based on information such as the immediate past and present levels at the site, levels at sites upstream up to the present time, rain that has fallen in the catchment up to the present and the forecast rainfall, and experience of previous floods in the catchment. Flood forecasting is usually aided by telemetered hydrometric information, and sometimes by computer modelling.

Flood forecasting and warning has been increasingly common practice in New Zealand in the last few decades. It has been beneficially used to forecast floods on the Wairau River in Marlborough, South Island (Rae and Wadsworth 1990), and on many other rivers in both North and South Islands (Ibbitt et al. 2001; McKerchar *et al.* 1997). Channel routing models project discharge information measured upstream to a downstream location of interest. Rainfall-runoff models do a similar projection, but based on upstream measured catchment rainfall. In more recent years, forecasting has used conceptual computer modeling, with real-time measured rainfall and discharge, e.g., for the Clutha River, South Island (Ibbitt and Woods 2003).

Davies and Hall (1992) have suggested that risk management for alpine disasters (which could include flash floods in occupied places) is not accomplished well by simply combining "the likelihood of something happening" with the "magnitude of the effect if it does" in the form of a "design event" and a "benefit : cost analysis". They propose that smaller events should be controlled by structural means, and all events larger than some chosen size always managed by warning and evacuation. They provide an interesting example of a two-stage warning system put in place for the Blandswood holiday home settlement on the Kowai River near Little Mt Peel in South Canterbury, New Zealand. A Stage-1 alert begins whenever antecedent 15-day rainfall exceeds 70 mm; residents are informed that a "state of readiness" exists. Synoptic weather monitoring begins, to allow forecasting 12 hours in advance of any intense rain on the catchment. Stage 2 is invoked if such an event seems likely; an evacuation with ample time and in daylight then occurs.

Urban water supply

The human body is 60% to 75% water. Adults typically lose 2–3 litres of water per day and should consume 0.9–1.2 litres directly as non-alcoholic, non-caffeinated fluids daily. Most of us know that severe dehydration can be fatal. Less-known health risks from chronic slight dehydration include urinary stone disease; breast, colon and urinary tract cancer; childhood and adolescent obesity; mitral valve prolapse; salivary gland malfunction; and overall poor health in elderly people (Kleiner 1999). Accordingly, public water supply is a basic service, provided or regulated, in New Zealand as in other well-governed countries.

In addition to direct human consumption, water is needed in communities for hygiene, commerce, industry, gardening and recreation, fire-fighting and a host of other reasons. It is the responsibility of local government to manage the provision of water in cities and towns and to manage the risk of failure of the supply. Prior to the water supply crisis that afflicted Auckland cities in 1994, the management by local authorities of water supply risk was haphazard. The "drought management plan" produced during the crisis (by Watercare Services Ltd) may well have been the first such plan produced in New Zealand. More generally, asset management for municipal water supply is now moving to a risk management approach (Bull 2000). Together with stormwater and wastewater disposal, local authorities in New Zealand have about NZ$7500 million invested in water infrastructure. They spend about NZ$600 million on operational costs each year and will need to spend about NZ$5000 million upgrading this water infrastructure in the period 2000-2020 (Parliamentary Commissioner for the Environment 2000).

Integrated risk management (Painter 2000) requires that water supply authorities consider possible hazards related to water supply catchments, both surface water and groundwater, and the distribution systems downstream of water reservoirs and treatment plants.

EXCESS WATER

Some aspects of the occurrence of excess water, as extreme rainfall and river floods, have been covered in previous chapters (see especially Chapters 2 and 10) and in the preceding sections here on river control works and floodplain management. Such occurrence is the "likelihood of something happening" referred to in this chapter's introduction as the first half in the definition of "risk". To complete a consideration of risk, it is necessary to combine the "likelihood of something happening" with "the magnitude of the effect if it does". Many of the high-magnitude effects occur when heavy rain raises the levels of rivers and lakes, affecting occupied floodplains and lakeshores. Others relate particularly to flooding in urban areas, impacts on transport routes, and the safety of dams and reservoirs.

Stormwater and drainage

Urban areas of New Zealand have a considerable infrastructure to manage the risk that extreme rainfall will lead to stormwater in excess of what can be locally absorbed, ponded for subsequent evaporation, or put to good use on site. Both capital and operational aspects are involved in managing stormwater risk in urban environments. There is a need to deal with stormwater that has been contaminated by sewage or hazardous wastes, especially where urban authorities still have combined pipelines for sewage and stormwater. Health hazards arise from the discharge of such stormwater, especially to beaches used for swimming or shellfish gathering. These hazards are usually managed by public notices on-site, and through warnings to the public via print, radio and television media.

Surface and sub-surface drainage of farmland (Bowler 1980) is a well-known practice used as a form of risk management. Similar principles (but at a much greater cost per unit area) apply to managing the risk of excess water on sports grounds and urban recreation areas. The drainage and turf system installed in 2003 at Auckland's Eden Park (for rugby union and cricket games) cost about NZ$4 million for less than a hectare of turf (New Zealand Herald 2003). Farm drainage would typically cost about 0.1% of that.

Road and rail bridges

High discharges and water levels in rivers can undermine and wash away the banks and stopbanks of rivers and any structures within or crossing them. Bridges are usually designed to have a waterway area beneath them that is capable of passing a flood of some particular likelihood of occurrence. For example, a flood discharge with an annual exceedance probability of 2% might be used for major highway bridges. That implies that floods larger than the design flood might exceed this capability, thus risking damage to the bridge and danger for traffic. There have been fatalities and numerous injury accidents in New Zealand as a result of bridges being damaged by floods: the accidents have occurred either while road or rail traffic has been in transit, or before warning signs and barriers could be put in place. Figure 45.6 provides a recent example; fortunately the train driver escaped from the cab. The risk to vulnerable bridges could be managed by fitting monitored warning devices, but this is not current practice in New Zealand.

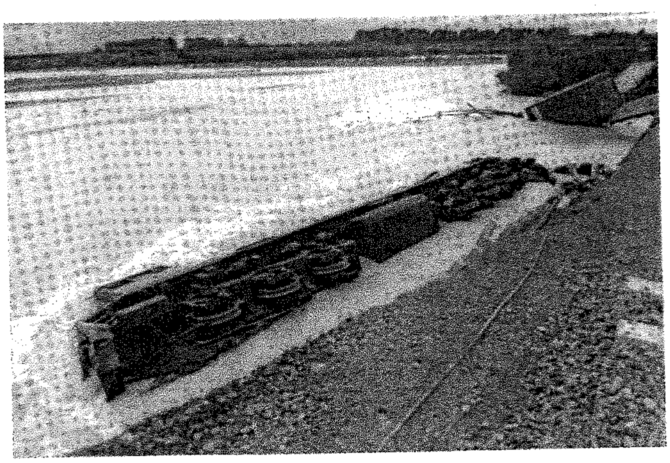

Figure 45.6 Scour failure of the southern approach to the Rangitata River Railway Bridge, 4 January, 2002.
Photo: The Press, Christchurch

Dams and reservoirs

Building dams in rivers with a substantial water catchment upstream poses a high risk for a short time during particular stages of the construction. This risk usually is managed by providing for diversion of the inflow, but a trade-off is often required between the cost of diversion structures and the magnitude of flood flow that can be catered for. A large flood (about 5% annual exceedance probability) occurred on the Rangataiki River, Bay of Plenty, North Island in July 1998, during strengthening of the Matahina dam earth embankment. A specific risk management plan had been implemented for the duration of the project and it was called in to play during the flood event (Keane 1999). The flood volumes were eventually contained and spilled without overtopping the dam, but only just.

A less fortunate outcome resulted from a storm in the catchment of the Opuha Dam, South Canterbury, in February 1997. A diversion culvert was in place while the main embankment was being built. The main spillway was 80% complete, but not usable. When the flood flows threatened to destroy the partly completed embankment, the main contractor "cut a channel in one side of the dam to avoid the water spilling over it. However, the force of the flood water through the channel caused roughly one-third of the compacted fill material that had already been placed in the dam to be eroded and washed downstream—causing damage to roads, fencing and river protection works" (Office of the Auditor General 2001).

Reservoirs can fulfill an important role in attenuating flood peaks. Flood detention dams are built specifically for this purpose, usually as part of urban stormwater management. Other reservoirs, such as hydro-electric storage reservoirs and outflow-controlled lakes, can have designated "buffer storage", whereby the water level is lowered at certain times of the year in expectation of the need to accept flood inflows and provide reduced outflows. For example, control gates on Lake Taupo are used to partially manage flood risks on the Waikato River (Barnett *et al.* 2000). But in a contrasting example, sediment deposition in Lake Roxburgh since it was formed in 1956 eventually caused flooding upstream in Alexandra, particularly in 1994, 1995 and 1999. The risk had been known, but both the rate of deposition and the flood magnitude frequencies in the Clutha River were underestimated by the designers of Roxburgh dam. A flood remediation project, involving both structural works and changes in land use, was commissioned in 2002. The NZ$22 million cost included a NZ$6 million contribution from the hydro-electricity generating company involved (Contact Energy Ltd).

The spillway capacities of dams and reservoirs are continually assessed in the light of improved meteorological and hydrological information on flood magnitudes, and changed standards of safety. Changed information in the 1999 edition of the influential Australian Rainfall and Runoff (Institution of Engineers Australia 1998) and changed guidelines issued in 2000 (Australian National Committee on Large Dams 2000) have led to much activity and expense in increasing spillway capacities on many dams in Australia. Revised guidelines have also been issued in New Zealand (New Zealand Society on Large Dams 2000), but have not resulted in the same level of spillway upgrading.

Managing the risk of damage from flood discharges on a river that has a series of dams in place has been outlined for the Waikato River (Barnett *et al.* 2000). There are risks to river users, riparian land owners and residents, dam operators, public utility operators (e.g., water treatment plants) and electricity users. Management of these risks requires, among other things, understanding of the detailed interactions between catchment rainfall and tributary inflows, the effects of travel time for releases from one dam reaching the next, the automated and human control systems, and the human dimension of the times, places and purposes of people using the river.

INSUFFICIENT WATER

Lower-than-expected rainfall over an extended period of time ("meteorological drought") leads to streamflow, lake and reservoir levels, soil moisture and groundwater aquifer levels all being lower than expected ("hydrological drought"). Risks arise for ecosystem health, primary industry, energy and extraction industries, and the general public when the period of little or no rainfall becomes extreme (see Chapter 10).

The occurrence of an extended period of little or no rainfall is the "likelihood of something happening" referred to in this chapter's introduction as the first half in the definition of "risk". The second half is "the magnitude of the effect if it does". In the case of insufficient water, it is not the absence of rainfall itself that gives rise to risk, but the cumulative effect on streamflow and other water levels. Unlike the effects of excess water, which are often most severe in occupied places, and occur over hours, days or weeks, the effects of insufficient water are often most severe in rural or wild areas and occur over months or years.

Agricultural drought

"Agricultural drought" is said to occur when soil moisture levels fail to meet the water requirements of crops over an extended period. The financial risks associated with agricultural drought in New Zealand are very high. Droughts in 1997–98 and 2001–02 are thought each to have cost New Zealand several hundred million dollars (McKerchar 2003). Just in the Canterbury region, the estimated total net impact of the 1997–99 drought on the Canterbury economy was NZ$281 million—over 2% of the total annual Gross Domestic Product for the region (Ministry of Agriculture and Forestry 2000). Individual farmers are engaged in risk management during most of their work, but especially so prior to and during drought. Reserved feed, irrigation, stock water and irrigation water supply reservoirs, access to off-farm grazing, drought-resistant crop varieties, cultivation practices to counter wind erosion of soil—managing water-related risks in farming could occupy a book on its own (e.g., see Ministry of Agriculture and Forestry 1998). Another episode of drought occurred in summer and autumn of 2003, with record low streamflows in much of the west and south of the North and South Islands (McKerchar 2003). One lesson from international experience is that more emphasis in risk management should be placed on preparedness and mitigation, complementary to response measures implemented once a drought has taken hold (Wilhelmi and Wilhite 2002).

One unusual financial tool for risk management available to New Zealand farmers is an Adverse Event Income Equalisation Scheme, administered by the Inland Revenue Department. This allows unforeseen income generated when, for example, drought forces farmers to reduce livestock numbers, to be placed in a tax-free account for use later, when re-stocking after the drought.

Irrigation water supplies

Irrigation can be a risk management tool for farmers. But farmers do not use irrigation solely for drought. As an integral part of farm management, irrigation enables dramatic productivity increases by removing a major limitation on crop growth, in a similar manner to fertilizer counteracting low soil fertility. With irrigation, there is then a risk transfer. A new risk arises from the likelihood of restrictions in the supply of irrigation water, and the consequences to dependent crops and livestock. On a regional basis, the use of water for irrigation by farmers can translate into depletion of surface and groundwater resources. This might well add to an existing hydrological drought, with mutual effects among recreational water users, hydro-electric energy generators, recreational water users and aquatic ecosystems.

The risks posed by restricted irrigation water supplies have to be managed by individual farmers. The restrictions may be physical, as supplies dry up, or legal, as minimum flow or water level conditions on consents to take water are invoked, restricting extraction. At the level of an irrigation scheme or company, the managers might be able to manage risk by using alternative supplies or by price variations to users. In New Zealand, at a regional level, the regional councils and unitary authorities under the Resource Management Act (1991) must balance the "downstream" risks to irrigators with the "upstream" risks to other users and the environment, as water supplies become depleted. The risk of insufficient water for irrigation is clearly just part of a more general risk of insufficient water for all uses, including ecological and aesthetic values, in a region.

Groundwater

Low water levels in groundwater aquifers can pose significant risk, due in part to the relatively slow rate of recharge in some aquifers. Contamination of groundwater is also likely to be high-risk, due both to the often very high quality of groundwater (e.g., suitable for drinking), and because decontamination can be slow and difficult once contamination has occurred. Christchurch city in the South Island enjoys the rare benefit of a municipal water supply from aquifers in which the water is of such high quality that it requires no treatment at all before entering distribution pipelines. Recharge of the aquifers underlying the city occurs from rainfall on the Canterbury Plains inland from the city, and from leakage of river water, particularly from the Waimakariri River. Thus contamination risks to the Christchurch city supply relate back to the likelihood of contamination of the river water, or to water passing through the soil and underlying strata in particular areas of the Canterbury Plains.

This example from a particular location illustrates two general points about groundwater risk management that are applicable elsewhere. First, the "source" and "extraction" locations for a groundwater aquifer can be separated by distances greater than those of farm properties, local authority boundaries or even regional authority boundaries. Secondly, the groundwater being extracted may have entered the aquifer months, years or even millennia before. The Moutere aquifer near Nelson, South Island, has been found to contain "high quality glacial-age water more than 20,000 years old" (Stewart 2003). Managing risks of groundwater depletion and contamination can therefore involve time and space scales much greater than those considered for surface water risk management.

Wetlands

Chronically insufficient water destroys wetlands. When drained, wetlands in New Zealand are potentially "productive" land for agricultural or urban development. In the 165 years since the Treaty of Waitangi, about 85% of New Zealand's wetland area has been "developed" in this way (Parliamentary Commissioner for the Environment 2002). The value of the remaining wetlands, to wildlife, species biodiversity and for aesthetic reasons as landscape elements, has been recognised in the last few decades. Managing risks from wetland degradation or disappearance involves securing their status, ensuring a water supply of appropriate quantity and quality, and educating the public about their value. Recently, natural wetlands have been joined in New Zealand by wetlands built for wastewater treatment.

Reservoirs and dams

Surface water storage in ponds, reservoirs and lakes can be very important in managing mismatches in supply and demand. Water in storage in reservoirs, including groundwater aquifers, is thus an important aspect of coping with low supplies. The water supply reservoirs in the Hunua and Waitakere Ranges that supply Auckland are a good example of several such systems in New Zealand. Reservoirs built for one purpose may provide additional benefits, such as flood mitigation. Often the operation of multi-purpose reservoirs involves compromises among objectives and thus involves risk management. Otherwise the risks associated with reservoirs, including drowning, hosting unwanted species and having poor water quality, are no different from those of pools, ponds and lakes.

WATER AND ENERGY

The most obvious connection between water and energy occurs when the potential energy of water at a high altitude is harnessed by passing it through turbines as it moves to a lower altitude—hydro-electricity generation. Managing the water-related risks of generating electricity from a dominantly hydro system (about 60%–70% of generation in 2000 in New Zealand) is a topic worthy of its own book, especially because there have been many changes in the way the national electricity system has been structured and managed in recent decades. There are potentially many lessons, and examples both good and bad, for other sectors of the economy engaged in managing water-related risks. Only very brief comment on the main points is given here.

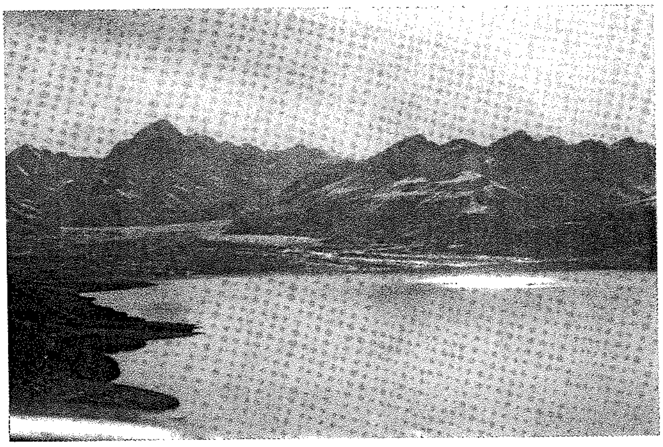

Figure 45.7 Lake Pukaki with Aoraki Mt Cook in the background. The lake has the largest single hydro storage capacity in New Zealand and feeds water to Ohau A and downstream power stations.
Photo: David Painter

The most significant water and energy-related risks in New Zealand in recent decades have been the financial, health and safety, and political risks associated with reduced electricity supplies caused by low hydro lake inflows, especially in the lakes of the Upper Waitaki catchment (Fig. 45.7). These risks have been demonstrated when they caused well-publicised and well-documented "crises" in 1992 and 2001 (e.g., Electricity Shortage Review Committee 1992).

Prior to 1992 it was intended that the then-integrated national grid would cope with a "one-in-twenty dry year" without power blackouts anywhere in New Zealand. The Electricity Shortage Review Committee (1992) concluded that the risks from this policy were too high. They recommended that a "one-in-sixty dry year" policy should be adopted. Such a policy was set aside when a wholesale electricity market was introduced in New Zealand in October 1996 and the former Electricity Corporation of New Zealand, a state-owned enterprise, was split into three generators in April 1999, to operate alongside private and public companies offering electrical energy to the market. It was assumed that security of supply would be ensured by price-response mechanisms.

That security of supply has not been ensured, and this has been the cause of much debate by the electrical generation industry, electricity users both major and individual, government, media and other commentators. In 2003, the government announced its intention to fund a dry-year reserve generation plant. This plant will not be used in "normal" hydro reservoir inflow years but is intended to secure the 1992 recommended "one-in-sixty dry year" security level. It is an extreme form of supply assurance, whose worth it will be interesting to evaluate after a few years of non-operation.

Energy is also generated in New Zealand from water in the form of geothermal steam (about 4% in 2000). Thermal generation of electricity using coal, natural gas, landfill gas or various petroleum fractions also requires water, as steam for the turbines and as cooling water. Some of the water-related risks are significant. For example, there is a risk to the ecology of the Waikato River from the temperature rises caused by the Huntly Power Station (1000 MW) cooling water extraction and return. This has to be managed by the operator and is monitored by the regional council as part of conditions on relevant resource consents.

WATER AND LAND MOVEMENT

McConchie (1992) presents a complete chapter on water and land movement, including some of the risks and costs. An example of land movement giving rise to a water-related risk has already been mentioned—the landslide dam in the Tunawaea Stream. Landslide dams give rise to water-related risks because they impound water behind a "structure" whose "design" bears no relationship to the rate of arrival and total volume of water coming from its catchment. It is therefore likely to fail at some time that is difficult to determine, causing a dam-break flood downstream. This kind of "flash flood" can be very dangerous in its immediate effects. Such a natural dam can also alter the sediment flow from the catchment in ways that have unwanted effects both before and long after the dam fails.

A dam was formed in the Poerua River valley in Westland, when a landslide fell from Mt Adams on 6 October 1999. About 10–15 million cubic metres of fractured rock and loose debris fell 1800 m from near the summit (Hancox *et al.* 1999). This dam failed in the first heavy rainfall, sending floodwater and sediment over forest and farmland down the valley. There is likely to be an ongoing risk of sediment aggradation affecting the remaining farmland and a highway bridge. The risks posed to Franz Josef township by the Waiho River, including the risk of a dam-break flood from its tributary, the Callery River, have already been mentioned.

Submarine land movement is one of the well-known causes of ocean tsunami (e.g., Goldsmith *et al.* 1999). Not so often noted is the risk of such a surface wave caused by a landslide into an inland water body such as a lake or large reservoir. A case study has been carried out for Lake Wakatipu and Queenstown in South Island, New Zealand (see Ruddenklau 1999, unpublished, cited in Painter 2000). Queenstown could look as it does in Figure 45.5 about 5 minutes after a landslide entered the lake from one of the unstable slopes identified.

There is a perceived risk to the Clyde Dam, and Clyde township, in Otago, New Zealand, from the Cairnmuir Slip and other potential mass movements alongside Lake Dunstan. Landslide stabilisation work includes over 14 kilometres of tunnels dug into the hillsides to prevent water build-up and buttresses of compacted rock and gravel placed to stabilise the toes of possible slips. There are about 3,500 measuring and monitoring instruments installed around the lake shore (McConchie 1992).

The Golden Cross gold and silver mine near Waihi, Bay of Plenty, North Island, has a tailings dam and silt pond inadvertently constructed on a pre-historic landslide. The risk became obvious in 1996 when cracks appeared near the dam, and measurements showed the dam was moving downhill several millimetres per day during wet weather. About NZ$30 million was spent in a three-year stabilisation programme that included a 760-m-long underground drainage tunnel, and pumping removes about 12,000 cubic metres of water each week (Geological and Nuclear Sciences 1998).

Water removal from aquifers can result in land subsidence. There are risks both from long-term extraction for water supply and from short-term dewatering of building or other construction sites. A scoria and basalt quarry operator in Auckland was pumping 5000 cubic metres per day of groundwater to dewater the site in the late 1990s. Land subsidence between 3 and 17 mm was reported in a zone up to 1.8 km from the quarry. The zone included "some of Auckland's most expensive suburbs" (Gardiner 2002).

In some parts of New Zealand, particularly areas with limestone karst geology (see Chapter 31), the subterranean action of water dissolving rock can lead to subsidence. The Maori name of the Waitomo Caves area in King Country, North Island, means "water entering the caves by long shafts".

WATER QUALITY

Drinking water

There are many risks related to water being of a quality unsuitable for drinking, cooking, swimming, bathing, agricultural and other industrial use. "Pollution of our rivers, lakes and beaches has featured as the top environmental concern in many surveys of New Zealanders' opinions over the past five years, so there is a clear message here for central and local government and the farming community." (Ministry for Environment 2001).

A detailed report on the chemical quality of drinking water in New Zealand (Davies *et al.* 2001) discusses the health risks of more than 100 compounds found in water. The most significant are corrosion-derived metals (e.g., antimony, cadmium, copper, lead and nickel), arsenic, disinfection by-products (mainly chlorine and other halogen derivatives) and nitrate. Fluoride is also found in drinking water in some parts of New Zealand. It is there because it is added by supply authorities to lower the incidence of tooth decay in young children. Management of that risk (tooth decay) is seen as introducing another risk (poisoning) by those who regard fluoride primarily as a toxin, even in the low doses employed. Managing the risks posed by these compounds can be as simple as ensuring people run a tap briefly before taking water to drink, to flush out the corrosion metals (reducing copper concentrations, however is best managed by using different materials for drinking water pipes). Or the risk management can be complex, such as dealing with the political, social, scientific and economic aspects of managing nitrate contamination in groundwater aquifers whose catchments include intensive agriculture, such as horticultural cropping or dairy farming.

The microbial quality of water for human contact, both internal and external, presents potential health risks. Microbial pathogens in drinking water can cause gastrointestinal illnesses, fevers, diarrhoea and dehydration. The Ministry of Health publishes annual reviews of the microbial quality of drinking water (e.g., Ball 2002). It is the responsibility of the Ministry of Health to monitor the quality of water supplied, and to manage any risks to health. There are, for example, published standards for drinking water (Ministry of Health 2000). These list the maximum concentrations of chemical, radiological and microbiological contaminants acceptable for public health in drinking water and the sampling procedures that should be used to monitor compliance.

Surface water and groundwater

Managing the water quality risks of natural surface water in streams, rivers and lakes does not imply that all water should ideally have no chemical or microbial content, only water molecules! Indeed such a state would be decidedly hazardous for dependent ecological systems. Although the Resource Management Act (1991) makes provision for national environmental standards, such as those for water quality, there are none yet in place in New Zealand. The Ministry for the Environment endorses guidelines (Australian and New Zealand Environment and Conservation Council 2000), which are used by regional councils and other agencies.

Managing the water quality risks of groundwater in aquifers, particularly, must take account of the two general points already made about time and space scales. There has been considerable effort in the last few decades to determine water quality in groundwater aquifers in many parts of New Zealand (e.g., Roberts et al. 1996). There is a close, and circular, relationship in New Zealand between agriculture and water quality, both surface water and ground water. Intensive agriculture poses risks because of its potential and actual negative effects on urban and recreational water users as a result of lowered water quality. Low water quality poses risks as a result of its potential and actual negative effects on agriculture as a result of animal and plant health, commodity prices and market acceptance—a tarnishing of the "pure New Zealand" image.

Many industrial and semi-industrial activities are very important in managing risks related to water quality. Effluent application to land or discharge to water, pollutant disposal and spills of many kinds, mining activities in or near water, farming and forestry alongside water, are just some. Most activities of this kind are intended to be avoided, mitigated or remedied under provisions of the Resource Management Act (1991), administered by regional councils and unitary local authorities.

ICE, SNOW, HIGH-TEMPERATURE WATER AND STEAM

Most of this chapter on managing water-related risks in New Zealand deals with liquid water at ambient temperatures. Expanding the scope to include water at very low or very high temperatures, or water in its solid and gaseous forms, both modifies the risks already considered and adds new risks. In drowning, death occurs by suffocation. For a person falling in to a pool of boiling water in a geothermal area, death will occur as a result of scalding instead. A person trapped under snow as a result of an avalanche may die from hypothermia instead of suffocation.

Excess water as snow in occupied places can have some effects similar to floods. Deep snow on roads can close them. There are also new risks, such as structural damage to buildings from the weight of snow accumulating on roofs. Insufficient water falling as snow in the catchments of the southern South Island hydro lakes can limit the spring melt flows, and contribute to water and hydro-electric energy supply problems. It is also a risk to New Zealand's winter tourist industry if there is insufficient snow on the skifields.

Hail has serious effects on horticultural crops, particularly some of high-value such as cherries and grapes, but also pip and stone fruit. And water changing state from liquid to solid brings its own risks: accidents due to ice on road surfaces, burst pipes in buildings, burst cells in frost-tender plants and crops. Paradoxically, spraying water continuously on to frosted crops, to keep tender parts at zero degrees Celsius as the water freezes, can protect them from damage. It can also bring a new risk, of structural damage due to the weight of ice.

Outbursts of geothermal steam and high-temperature water are a risk to human safety, as has been demonstrated quite frequently in the city of Rotorua, North Island. On the other hand, using geothermal steam for electricity generation or domestic heating poses risks for the tourism industry and tangata whenua, as formerly active geysers diminish or cease and land subsidence may occur.

Managing these and other risks related to water at very high or low temperatures, and to solid and gaseous water, can involve modifications to approaches considered earlier. But some risks, such as those arising from snow avalanches and in alpine recreation, are peculiar to this field, and their management is outside the scope of this chapter.

ECONOMIC ASPECTS

It has been emphasised here that risk is a societal construct, even when the hazards involved are distinctly physical. Human safety and social welfare involve more than financial and economic factors, but they are important aspects of risk and its management. Obtaining resources for managing risks, particularly as risk avoidance, prevention or transfer, and mitigation of effects, rather than as risk response and the recovery necessary after disasters, is often primarily an economic task. This has not been the particular emphasis in this chapter, but its importance is acknowledged.

LEGISLATION AND RESPONSIBILITIES

Many organisations play a part in managing water-related risks, especially agencies of central, regional and local government in New Zealand. Likewise, risks are the subject of various acts of parliament and regulations. Neither cover all aspects of managing water-related risks, but those mentioned are thought to play a major role in relation to particular risks, and provide a starting point or place of contact for further information.

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