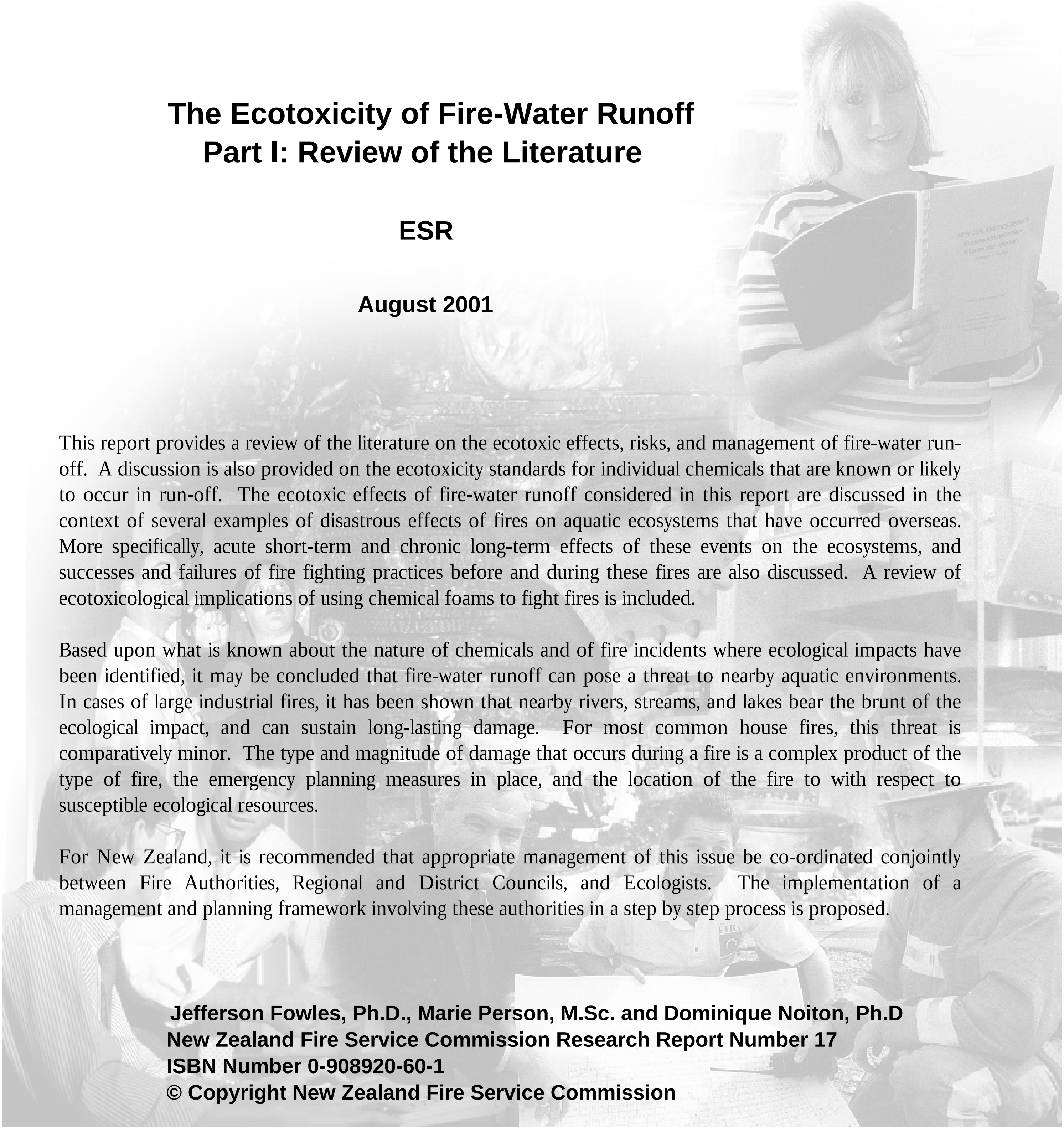
Fire Research
Report



The Ecotoxicity of Fire-Water Runoff
Part I: Review of the Literature

ESR

August 2001

This report provides a review of the literature on the ecotoxic effects, risks, and management of fire-water run-off. A discussion is also provided on the ecotoxicity standards for individual chemicals that are known or likely to occur in run-off. The ecotoxic effects of fire-water runoff considered in this report are discussed in the context of several examples of disastrous effects of fires on aquatic ecosystems that have occurred overseas. More specifically, acute short-term and chronic long-term effects of these events on the ecosystems, and successes and failures of fire fighting practices before and during these fires are also discussed. A review of ecotoxicological implications of using chemical foams to fight fires is included.

Based upon what is known about the nature of chemicals and of fire incidents where ecological impacts have been identified, it may be concluded that fire-water runoff can pose a threat to nearby aquatic environments. In cases of large industrial fires, it has been shown that nearby rivers, streams, and lakes bear the brunt of the ecological impact, and can sustain long-lasting damage. For most common house fires, this threat is comparatively minor. The type and magnitude of damage that occurs during a fire is a complex product of the type of fire, the emergency planning measures in place, and the location of the fire to with respect to susceptible ecological resources.

For New Zealand, it is recommended that appropriate management of this issue be co-ordinated conjointly between Fire Authorities, Regional and District Councils, and Ecologists. The implementation of a management and planning framework involving these authorities in a step by step process is proposed.

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A Report to the New Zealand Fire Service

October 2000

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1. PURPOSE OF THIS REPORT

This report provides a review of the literature on the ecotoxic effects, risks, and management of fire-water run-off. The identification and characterisation of hazards and risks related to fire-water run-off is an essential component in the development of a risk assessment framework for fire-water runoff management.

This report is the first of two reports relating to risks associated with fire-water run-off. The second report will contain results of monitoring runoff from up to 10 New Zealand fire scenes, including an assessment of the ecological risks from these runoffs, and a proposed framework for the assessment and management of ecological effects of runoff.

2. INTRODUCTION

It has been stated that "*Every fire represents some threat to the environment*" (CFPA, 1990). International studies suggest that chemical contamination of the environment from fire-fighting activities presents a serious hazard to aquatic ecosystems in certain situations. Locally, this is also of concern to the New Zealand Fire Service as well as Regional and District Councils, who have a responsibility to protect the environment from adverse effects. However, uncertainty lies in that little is known about the nature or magnitude of ecological risks from fires and fire-water runoff generally, apart from a number of case reports from internationally occurring ecological catastrophes. This being the case, it is difficult to effectively factor in ecological risks into the decision making process about managing fire fighting activities. Uncertainty lies in deciding what preventative measures should be taken at high risk facilities, or during fire fighting, so as to ensure minimal ecological risk from fire-run-off.

Aside from the physical damage caused by fire, chemicals may be released into the environment, either discharged to air during burning, or in the form of run-off from fire-water. Contaminants in fire-water run-off may include non-specific chemicals typically associated with combustion, as well as industrial or biocidal chemicals found in storage facilities or manufacturing plants. Some industrial chemicals, and many agrichemicals are highly toxic to aquatic or soil ecosystems and therefore present a large range of acute and chronic toxicity as well as environmental persistence. In these cases, fire-fighters must consider whether a controlled burn-out is preferable to risking the input of large volumes of fire-water runoff into nearby fragile ecosystems. Several spectacular events in Europe and North America in the past 15 years have shown disastrous consequences when fires at chemical storage facilities have occurred near to surface waters, with fire-water run-off resulting in a massive destruction of aquatic life. These destructive effects last in some cases for many months or years.

There is increasing awareness that "ordinary" fires in premises containing seemingly innocuous materials can also present a threat to the surrounding soil and aquatic environment (FPA, 1990). The majority of these types of fires would contribute runoff into the storm drainage system, which can result in discharge into coastal marine and surface waters. It is thought that in most of these cases, the ecological impacts are fairly low, however as the ecological consequences of these releases have not been widely studied, little is known of the potential impacts these events have on the ecological environment.

The ecotoxic effects of fire-water runoff considered in this report are discussed in the context of several examples of disastrous effects of fires on aquatic ecosystems that have occurred overseas. More specifically, acute short-term and chronic long-term effects of these events on the ecosystems, and successes and failures of fire fighting practices before and during these fires are also discussed. In addition to these examples, a review of ecotoxicological implications of using chemical foams to fight fires is included.

From a national perspective, the roles of the Resource Management Act and the Hazardous Substances and New Organisms Act regulations and controls are discussed, specifically in terms of successful management and planning for prevention of ecological disasters stemming from fire-water runoff.

A discussion is also provided on the ecotoxicity standards for individual chemicals that are known or likely to occur in run-off. Acute and chronic standards for water contaminants are provided, and some discussion on the appropriate use of these standards and their interpretation is given.

It is expected that these discussions will provide guidance to the New Zealand Fire Service and Regional and District Councils in the development of a framework for managing fire-water runoff and reducing ecological impacts.

3. EXAMPLES OF FIRE-WATER RUNOFF IMPACTS

The impact of fire-water run-off on the environment began to receive considerable attention in 1986, following the infamous Sandoz chemical storage facility fire in Basle Switzerland. Several other similar incidents have occurred, including the Plastimet fire in Ontario, Canada in 1997, and the Allied Colloids Fire in the UK in 1992. In addition to these incidents, a large number of smaller scale chemical or tyre fires have occurred in which toxic runoff has presented significant ecological risks and resulted in significant damage.

Sandoz Chemical Company

Basle, Switzerland, 12:30 AM, 1 November 1986 (Bendicht Hurni, 1988)

A blaze at a chemical storage warehouse containing several anti-cholinesterase insecticides, mercurical fungicides, chemical dyes and urea lasted for several hours, whilst fire fighters struggled to put the fire out. Large volumes of water were used to fight the blaze (400 litres water per second), and much of this water then flowed into the Rhine River. The fire was too large to be combated with foams, which are designed for such fires. Instead, water had to be used, and this was obtained from the nearby Rhine River. At 3 am, a catastrophe alarm was given, and people living in nearby areas of Basle were instructed to stay indoors and to shut the windows as a safety precaution. A “horrible smell” spread over a large area of the city, threatening to cause a panic in the population. Though the fire-water runoff only took place for several hours, the cocktail of biocides and other toxic chemicals killed all aquatic life near the site and this effect extended many miles downstream. Eels were found killed up to 200 km downstream of the incident site, and lasting effects to aquatic life were evident for years following the incident. The warehouse contained 1351 metric tonnes of chemicals, 987 of which were agrichemicals (Fawcett, 1988). The following compounds were of special interest in this incident due to their chemical nature and quantity.

- Endosulfan (2 tonnes)
- Tetradifon (2.3 tonnes)
- Phenyl mercury acetate (1.5 tonnes)
- Mercury compounds (11 tonnes – equivalent to 2.6 tonnes of mercury)
- Phosphoric acid esters (600 tonnes)
- Rhodamine pigment (2.4 tonnes)

The highly toxic organophosphate insecticide, endosulfan, was most likely to be the single greatest hazard to fish life, due to its LD100 (dose causing 100% lethality in fish in laboratory tests) of about 1 μg/L. Large amounts of mercurical compounds in the fire-water runoff also posed extreme toxicity to the fish life in the river. The presence of phosphoric acid esters in the fire-water runoff was also of concern as these included anti-cholinesterase compounds which can cause harmful effects at levels as low as 1 mg/L if exposed.

Another factor in this incident was the toxicological contribution of secondary reaction products during combustion. Some of the chemicals in the warehouse underwent chemical changes due to thermal decomposition and high temperature reactions in the presence of water and oxygen. Thermolysis, hydrolysis, and pyrolysis of the chemicals stored all occurred. In some cases, thermal decomposition led to products that retained some biological activity, while pyrolysis tended to break the compounds into relatively non-problematic substances, such as carbon dioxide, water, phosphate, sulphate, and nitrate. The potential harmful effects of these secondary chemical products can be more severe than the primary chemicals themselves, and therefore is of significant concern in any chemical fire.

The quenching water used in the fire fighting resulted in storm water drainage leading directly to the Rhine River. The soil and river were the principal areas of contamination. Some material was identified as having leached into the soil, contaminating the groundwater at a depth of up to 14 meters. About 10,000 sq m down to several meters depth of soil were contaminated with mercury compounds and insecticides. Fortunately, much of the groundwater contamination was able through use of groundwater recharge stations to be attracted to nearby groundwater wells and pumped out of the city groundwater supply. However, the presence of contaminated soil means that the threat of future groundwater contamination exists.

The river received about 10 tonnes of unaltered biologically active chemicals in the span of a few hours. Two months later, clearing operations had removed about 1000 kg of insecticides from the river sediment. Although the higher trophic level life was decimated, the microbiology of the Rhine remained to the extent that some degree of self-cleansing was possible. The river began to re-colonise itself in the span of 10 months, but took several years to completely recover.

The fire-boat unwittingly spread the chemical contamination through pumping contaminated river water to try to contain the fire from spreading to neighbouring buildings. Most of the unpleasant odours arose from the thermal decomposition of sulphur-containing compounds into mercaptans. Airborne contamination, despite the noxious smell, was not shown to be a serious toxicological hazard to the population following ambient testing. Mercury and dioxin levels were found to be low in the atmospheric plume resulting from the fire.

In this incident, the acute toxicities of the uncombusted biocidal agents (pesticides and fungicides) that were flushed into the adjacent river were responsible for the widespread destruction of aquatic life. The contribution to the overall toxicity from the various combustion products was minor by comparison.

The Sandoz ecological tragedy was primarily a function of poor facility placement and a lack of emergency planning. The storage facility for large volumes of ecologically hazardous chemicals was placed in close proximity to a major river waterway. Chemicals with incompatible characteristics (e.g., oxidisers and flammables) were stored in close proximity in the same facility. The turn-over of materials was very high. Sprinkler systems were inadequate, and no bunds or other means to physically control runoff were present. The influence of these factors, combined. with the toxic nature of chemicals stored in the warehouse under combustion conditions all contributed to the detriment caused to the surrounding environment.

Allied Colloids Chemical Company

South Bradford, UK, 21 July 1992.

Allied Colloids is a production plant which manufactures chemicals for a variety of uses including: effluent and water treatment, paper, paint, textiles, and agrichemicals. In 1992, a warehouse based in South Bradford, the main production site for this company, broke out into a fire due to the presence of strong oxidisers located near raw materials. The facility is located on a slope, with the warehouse located at the top. The fire burned within the warehouse and spread to drums stored directly outside the warehouse. Four million gallons (about 16 million litres) of water were used by fire fighters over a 3 hour period to extinguish the fire. During this period, materials stored in the warehouse reacted with water to form viscous polymers. These subsequently blocked site drains and pumping systems, thereby preventing adequate drainage of the fire-water runoff and causing it to spill into nearby river waterways around several manufacturing areas. Ecological effects of this spillage resulted in fish being killed up to 30 miles downstream of the incident. It was estimated that approximately 20,000 fish were killed by the run-off (Wilson, 1995).

A safety report prepared for an adjacent warehouse concluded that the primary environmental impact would result from runoff rather than the smoke, which indeed was the case. The situation was further worsened by the fact that the warehouse did not have a sprinkler system in place at the time of the fire.   Had such a system existed, it would have reduced the volume of water required to be used by fire fighters to extinguish the fire, and therefore also reduced the associated run-off. The location of the warehouse also influenced the impact of runoff, as did also the lack of water-retention structures such as bunds for each location within the site, and site-wide (storage tanks that are gravity fed, with diesel pumps, etc.).

Following the fire, the company has instituted a number of improvements aimed to retain and control any future fire-water runoff. These include: a water supply, drainage, and water retention system. A reservoir (27m x 27m x 7 m) capable of holding 4 million litres of water for fire-fighting purposes was built by the company and this can be topped up at the rate of 8000 litres per minute (the cost of this was 0.5 million pounds in 1992). A ring main water supply has been installed throughout the site, with hydrants at appropriate points. The cost of providing the ring main and hydrants was 0.5 million pounds.

An effluent retention basin was also constructed, which holds up to 8 million litres in several compartments linked by pumps. The retention basin acts to collect stormwater runoff as well as fire-water runoff. This provides for the ability to test the water, and it may be either passed to a treatment system or directly into the sewer.   The cost of providing the drainage system and retention basin was estimated at 2 million pounds.

The rebuilding of the warehouse included improved storage planning, and the installation of sprinkler and bunding systems. Chemicals were segregated, and stored separately from one another. Storage units established for chemicals included:

- a separate warehouse for raw materials and finished products
- organic peroxides
- oxidising stores
- flammable solid stores
- gases
- flammable liquid stores
- highly flammable liquid stores

Plastimet Inc.

Hamilton, Ontario, Canada 9-12 July, 1997. (The Queen's Printer for Ontario, 1997)

This facility contained large amounts of solid polyvinylchloride (PVC), amounting to about 400 tonnes, which was all consumed in the blaze which lasted several days. Runoff from the fire-water entered surface waters and nearby land areas. People located nearby the fire reported symptoms of eye, skin and throat irritations, which were most likely caused from exposure to high concentrations of hydrochloric acid (HCl) released from combustion of the PVC, but may have also been from high levels of organic irritants formed from combustion, like acrolein.

In addition to the HCl released by the burning of PVC, a number of toxic chemicals were released, including: benzene, chlorinated dioxins/furans ("dioxins"), polyaromatic hydrocarbons, and metals. Local authorities used ambient air and water quality criteria to assess the magnitude of environmental risks from the fire and runoff. Dioxins are notoriously released in PVC fires, however, measurements of air samples and soil samples in neighbouring gardens showed that the dioxin intake of contaminated vegetables from these gardens was only slightly above the WHO TDI of 10 pg/kg/day. Note that WHO have since revised the TDI to 1-4 pg/kg/day, increasing the significance of these intakes.

For the runoff itself, the chief concerns from this fire were metals, volatile organics, and PAHs. Table 1 shows the results of monitoring of the runoff. Measurements carried out during and after the blaze showed that while some of the metals were at high concentrations in the runoff, that they were low in concentration in the surface water due to dilution. Those metals found to exceed the water quality criteria initially in the runoff were: Al, Ba, Cd, Co, Cr, Cu, Fe, Pb, Mb, Ni, Ag, Va, and Zn. No acute toxicity values were available to judge potential risks, and so chronic (more conservative) values were used. The following day, there was a 2 to 23-fold decrease in metal concentrations in the runoff, with the largest decline in copper and lead. Four days after the event, all of the metals were measured to be within normal ranges for the receiving harbour and successfully met the ambient water quality criteria.

Volatile organics (VOCs) were very high in the runoff on the 10th July, but dropped by one half by the 11th and continued to drop sharply after that time. Benzene, ethylbenzene, toluene, and xylene (together known as BTEX) were the dominant VOC chemicals found.

Some PAH compounds were found in high concentrations in the runoff, including: naphthalene, 1-dimethyl naphthalene, 2-dimethyl naphthalene, fluorene, phenanthrene, and anthracene. Specific chlorinated phenols also identifed indicated incomplete combustion of the plastic. Phenanthrene was the only PAH found in soil at a location off-site, however phenanthrene was not identified at this site after the 15th July, three days following the incident.

Authorities conducted bioassays of the storm water and found that although the storm water was lethal to aquatic life during and after the fire, this was also true of storm water upstream of the input from the fire.

All chemical monitoring data showed that the chemical contamination of surface waters was short lived and that concentration levels returned to normal within days of the incident.

No biological surveys were available describing the extent of any ecological impacts of this event.

Table 1. Analyses of metals and organics in Fire-water runoff From the Plastimet fire, Ontario, Canada. 1997.

Chemical	9 July 1997	10 July 1997
Aluminium	-	2140*
Arsenic	-	-
Barium	-	650
Beryllium	7	2
Cadmium	92	60
Chromium	181	31
Cobalt	20	6
Copper	7370	70
Iron	4200	11200
Lead	5450	710
Manganese	3140	580
Mercury	-	-
Molybdenum	-	23
Nickel	145	54
Selenium	-	-
Silver	50	< 50
Strontium	1120	480
Thorium	-	80
Vanadium	-	-
Zinc	17700	5360
Benzene	-	200-830
Toluene	-	290-370
Ethylbenzene	-	95-140
Xylenes	-	11-15
Styrene	-	290-420
Phenanthrene	-	9-19
Anthracene		3.4 – 7.2

* Values are in ug/L

Tyre Fires

There have been a number of international cases of fires in tyre storage facilities. These are of significant interest for the purpose of this document as the nature of chemicals contained in tyre compounds when burned can pose severe adverse damage to human health and the environment if exposed to significant concentrations. Steer and colleagues (1995) studied the production of chlorinated dioxins and furans in a tyre fire set by vandals in Ontario, Canada in 1990. It was found that oily residue from the fire contained high concentrations of PCDD/Fs (approximately 200 ppt TEQ). The runoff from the fire was collected in a treatment plant set up on site for that purpose. The runoff water was treated before being allowed to drain into a nearby creek. Test samples were taken to ensure the PCDD/F levels were below safety water criteria values.

Similar results have been obtained in other studies on tyre fires and oily residue (Thompson et al., 1993). Although the PCDD/Fs from these types of fires do not represent an acute toxicity situation for the aquatic ecosystem, the addition of these bioaccumulative and persistent compounds into the food chain, even from a single incident, can have lasting effects on the environment and human health consequences.

4. IDENTIFICATION OF HAZARDS

It has been stated that fire-water runoff does not usually pose a serious threat to the environment (Institution of Chemical Engineers, Environment97, UK): http://www.environment97.org/framed/reception/r/all_papers/g6.htm). This statement appears to apply to typical house fires in urban areas that are not located in close proximity to sensitive ecosystems, and do not involve the potential for release of large quantities of organic materials or dangerous chemicals. In situations where fires in chemical storage facilities, warehouses, or large commercial premises are fought, the hazards and risks to the ecosystem are much greater, as demonstrated in those incidents discussed in this document, and therefore require careful management and planning.

In the first instance, it is vital to undertake identification and prioritisation of the respective hazards. The identification and prioritisation of fire-water runoff hazards includes 3 components: (i)) The type and quantity of chemicals stored or in use at the facility, (ii) the proximity of human settlements, and (iii) proximity of sensitive ecosystems.

Chemical Hazards

The types of chemicals of particular concern include:

- Biocides of any type, including pesticides, herbicides, fungicides, rodenticides, bleaching agents, or other sterilants.

- Sources of metals, especially mercuricals, but also lead, copper, and cadmium. Copper has comparatively high toxicity in aquatic systems, although its toxicity to humans is low.
- Sources of ammonia.
- Sources of cyanide.
- Chemicals strongly affecting pH.
- Halogenated organics (like PVC) capable of forming halogenated dioxins and furans upon combustion.

It is important for an evaluation of the neighbouring ecology to be made for facilities storing or using high volumes of ecologically hazardous substances. Of particular concern ecologically is the proximity of nearby waterways or coastal habitats to a chemical fire risk. Some facilities may store or use high volumes of dangerous chemicals without being located near ecologically sensitive sites.

Compounds Resulting from Combustion

All fire-water runoff contains combustion products, many of which are predictable in their nature and toxicity. Products include: phosphates, sulphates, nitrates, chlorinated dioxins/furans, BTEX, PAHs, small organic compounds (formaldehyde, acrolein, butadiene, vinyl chloride, etc.), and metals. The relative importance of these compounds for ecotoxicity assessments is discussed in general terms below.

Halogenated and Polyaromatic Compounds

All types of fires produce toxic organic or halogenated organic compounds. This is because many thermal processes lead to the formation of polychlorinated dioxins and furans (PCDD/Fs) from common ordinary organic materials. While the presence of certain chemical constituents increases the formation of these compounds, they are emitted in even common house fires (Ruokojarvi et al., 2000).

Polyaromatic hydrocarbons (PAH) are also emitted during combustion of common organic materials. Concentration levels range from 1.0 to > 7.2 ng/m^3 (I-TEQ) for PCDD/Fs, and 6.4 to 470 mg/m^3 for PAHs (Ruokojarvi et al., 2000). These compounds are found both in the smoke particulates in discharged air and in the deposited soot. Both forms would contribute to toxic chemical introduction into the fire-water runoff. Much of the concern related to these compounds is associated with their carcinogenic effects rather than their effects on ecological systems. However, at high concentrations, adverse effects on reproductive success and endocrine systems may be observed. A single acute exposure to these compounds, such as would occur in a fire-water runoff scenario, would not be expected to result in widespread die-offs of aquatic life, nor cause lasting reproductive or endocrine disturbances. Therefore, in terms of managing acute ecotoxicological risks, these are not considered to be high risk compounds as compared to other compounds. However, PCDD/Fs are environmentally persistent and biomagnify through the food chain, thus having latent sub-lethal effects on animals. They also possess the ability to find their way into the top of the food chain and enter human tissue, and therefore any contributions to the environmental and human burden of PCDD/Fs should be avoided.

Metals

The residues from combustion inevitably contain metals, as they are typically non-volatile and come through the fire unchanged. Metals are integral components of building structures, and are often components of dyes and pigments in paints. They are therefore commonly emitted during industry fires. For example, the analysis of fire-water runoff from the Plastimet fire indicated high levels of a host of metals, many of which are hazardous to aquatic life. Some metals (lead, mercury, cadmium, chromium and arsenic) are highly toxic to both humans and aquatic life, while other metals such as copper, zinc, and nickel are more toxic to aquatic life than to humans (Table 2). Arsenic, on the other hand, is much more toxic to humans.
Types of production plants whereby these metals may be commonly found include battery factories or recycling plants, plastics manufacturing plants (some pigments contain cadmium), chrome and nickel-plating facilities. Copper, zinc, and nickel are widely found in building materials, and lead is often found in paint from older buildings.

In addition to the acute toxicity posed by metals in the event of runoff incident, there is the additional concern of bioaccumulation of metals into other processes. Since elemental forms of these metals do not break down or dissipate through chemical processes, the removal of metals from the ecosystem must occur by active physical transport via organisms leaving the system or through removal of contaminated sediment.

Foams and Other Fire-Retardant Chemicals

Certain types of fires are often fought with foams in place of water. The use of foams is preferred for flammable liquid fires at aircraft crashes, and fires at refineries and petrochemical plants. In these types of applications, rapid fire extinguishing and good post-fire security are essential.

These chemical fire-retardants can be divided into *detergent* and *protein-based* varieties. Detergent fire-retardants are usually composed of ammonium phosphate, ammonium sulphate, or polyphosphate detergents with an attapulgite clay thickener such as hydrated magnesium silicate, or diammonium phosphate with a guar gum thickening agent. These ammonium and sulphate salts inhibit combustion, but can lead to corrosion in high concentrations. For this reason corrosion inhibitors are sometimes added and include sodium ferrocyanide and tolyltriazide, both of which are highly toxic to aquatic life. Protein and fluoroprotein-based foams are also available for use, although it is not known to what extent these are used in New Zealand.

‘Short-term’ fire-retardants typically consist of foams or surfactants that increase the fire-suppressing action of water by increased water retention on fuel sources or by reduced evaporation. However, surfactants also decrease water surface tension and the ability of water to carry oxygen. Fire management agencies in Australia are increasing their use of retardants and foams, particularly the short-term fire suppressant foams (Adams and Simmons, 1999).

Little is known about the effects of fire suppressant foams and chemicals on aquatic or terrestrial plant life. It is expected that the introduction of nitrogen and phosphorous containing chemicals, whether as fertilisers or fire-retardants would act to alter soil nutrient levels, and therefore also impact on plant growth. However, the addition of these nutrients can unfavourably impact certain ecosystems. Some plants favour low nitrogen and phosphorous soil levels, and therefore these plants would be expected to be particularly susceptible to toxicity of these types of foam.

There have been few acute or chronic toxicity studies carried out to investigate the effect of fire-retardants on aquatic or terrestrial wildlife or ecosystems (McDonald et al., 1997; Gaikowski et al., 1996a & b). However investigations have indicated that protein based retardants are typically less acutely toxic to aquatic organisms including fish, crustacea, protozoa, and algae, than are detergent-based retardants (Brittain, 1993). The acute lethal concentration resulting in 50% mortality (LC_{50}) values for some of these agents range from 10-100 ppm (synthetic detergents), to 10,000 ppm (fluoroproteins).

Some recent studies have shown synthetic detergent chemicals have moderate acute ecotoxicity. McDonald et al. (1997) studied the acute toxicity of 5 commonly used fire-retardants on an aquatic invertebrate test species (Hyalella azteca). Both of the surfactant foams tested at a 1% solution (Phos-Check WD-881, and Silv-Ex) showed that the 24 and 96-hour LC_{50} values (the concentration lethal to 50% of the test organisms) were in the range of 10-46 mg/L in either soft or hard water conditions. This means that a dilution factor of about 500-fold would be necessary for a 1% solution to reach the LC50 concentration. Application of a typical safety factor of 100 would result in the need for a dilution of about 50,000 to achieve a safe concentration level (USGS, 1999). In other words, 20 litres of 1% Silv-Ex foam would require a million litres of water to dilute it to a level that would be considered safe to most aquatic life.

Ammonia on it’s own, which is present in synthetic detergent foams, presents a wide variety of toxicity to aquatic life, and the magnitude of the risk is very species dependent. The USEPA has adopted a value of 0.02 mg/L (ppm) with which all aquatic life may be protected (USEPA 1986).

Although the toxicity of these fire-retardant agents is less than one would expect to find for many biocidal chemicals, fish kills have still been reported in streams contaminated with fire-retardant chemicals. In one reported instance up to 25 tonnes of synthetic detergent foam was applied to a rapidly spreading tyre fire, the runoff resulted in the complete destruction of fish life in a nearby stream (Brittain, 1993). In this case, extremely high concentrations of foam making a foam “raft” in the nearby river was attribute to be responsible for the destruction of aquatic life that occurred.

Chemical Biocides and Storage Facilities

Facilities that store and/or use large quantities of biocidal chemicals such as pesticides, herbicides, fungicides, or sterilants, pose a great hazard to the ecosystem in the event that these chemicals become uncontrolled and released into the surrounding environment. Several of the most infamous ecological disasters overseas, including the Sandoz incident, have involved these types of facilities. For this reason, it is vital that such facilities are identified and assigned a prioritisation for inspection for contingency planning and preventative measures to safeguard against ecological catastrophe.

The Auckland Regional Council have identified approximately 1000 high risk sites in the Auckland region alone that may undergo inspection (Campbell Sturrock, 2000). The intent of the Council has been to work with the relevant property owners to ensure that pro-active measures are taken to reduce the likelihood of a fire occurrance, and to have the capacity to effectively reduce possible environmental damage from contamination due to runoff.

5. WATER QUALITY STANDARDS

The protection of ground and surface waters in New Zealand is governed by local territorial authorities. Responsibility to protect water quality lies with those respective authorities, which may differ from region to region. Hence, there is no single set of national criteria for all locations. However, it is useful to have science-based numerical limits when comparing pollution episodes or assessing the significance of changes over time in ambient concentrations. Water Criteria developed by the United States Environmental Protection Agency (USEPA) for protection of aquatic ecosystems and human health are shown in Tables 2a and 2b. Both acute and chronic values are given for aquatic ecosystem protection, whereas only a single, chronic exposure level is given for human health protection. These water quality criteria values are based solely on prevention of adverse effects, and therefore do not consider the technological or economical feasibility of achieving the standard.

A number of the compounds of concern which are typically associated with fire-water runoff have water quality standards associated with them, either based on protection of aquatic organisms, or protection of humans for drinking water and consuming food taken from the water. A considerable number of compounds that are important in fire-water runoff, do not have water quality criteria, for example polyaromatic hydrocarbon compounds. In most cases, a value based on humans will also be protective of aquatic life, especially in the case of carcinogens. However, it is noteworthy that water concentration limits designed for the protection of human health do not always provide for the protection of aquatic organisms, for example, zinc, copper, and cyanide are much more toxic to aquatic life than to humans. Conversely, levels of some chemicals, such as arsenic, are of much greater concern to humans than is the case for most aquatic animals. These differences are all functions of species differences in metabolism and detoxification of the substances involved.

Table 2a. U.S. National Water Quality Criteria for Protection of Aquatic Ecosystems and Human Health

	Freshwater		Saltwater		Human Health for Consumption	
Priority Pollutant	CMC - acute µg/L	CCC - chronic µg/L	CMC - acute µg/L	CCC – chronic µg/L	Drinking water + eating organisms µg/L	Organism only µg/L
Antimony					14	4300
Arsenic	340	150	69	36	0.018	0.14
Cadmium	4.3	2.2	42	9.3		
Chromium III	570	74				
Chromium VI	16	11	1100	50		
Copper	13	9	4.8	3.1	1300	
Lead	65	2.5	210	8.1		
Mercury	1.4	0.77	1.8	0.94	0.05	0.051
Nickel	470	52	74	8.2	610	4600
Selenium		5	290	71	170	11000
Silver	3.4		1.9			
Thallium					1.7	6.3
Cyanide	22	5.2	1	1	700	220000
Zinc	120	120	90	81	9100	69000
Asbestos					7 million fibres/L	
TCDD					1.30E-08	1.40E-08
Acrolein					320	780
Acrylonitrile					0.059	0.66
Benzene					1.2	71
Bromoform					4.3	360
Carbon tetrachloride					0.25	4.4
Chlorobenzene					680	21000
Chlorodibromomethane					0.41	34
Chloroform					5.7	470
Dichlorobromomethane					0.56	46
1,2-Dichloroethane					0.38	99
1,1-Dichloroethylene					0.057	3.2
1,2-Dichloropropane					0.52	39
1,3-Dichloropropane					10	1700
Ethylbenzene					3100	29000
Methyl bromide					48	4000
Methylene chloride					4.7	1600
1,1,2,2-tetrachloroethane					0.17	11
Tetrachloroethylene					0.8	8.85
Pentachlorophenol	19	15	13	7.9		
Aldrin	3		1.3			

	Freshwater		Saltwater		Human Health for Consumption	
Priority Pollutant	CMC - acute μg/L	CCC - chronic μg/L	CMC - acute μg/L	CCC – chronic μg/L	Drinking water + eating organisms μg/L	Organism only μg/L
gamma-BHC (lindane)	0.95		0.16			
Chlordane	2.4	0.0043	0.09	0.004		
4,4'-DDT	1.1	0.001	0.13	0.001		
Dieldrin	0.24	0.056	0.71	0.0019		
alpha-endosulfan	0.22	0.056	0.034	0.0087		
beta-endosulfan	0.22	0.056	0.034	0.0087		
Endrin	0.086	0.036	0.037	0.0023		
Heptachlor	0.52	0.0038	0.053	0.0036		
Heptachlor epoxide	0.52	0.0038	0.053	0.0036		
PCBs		0.014		0.03		
Toxaphene	0.73	0.0002	0.21	0.0002		

CMC – Critical Maximum Concentration (for acute exposures)
CCC – Critical Chronic Concentration (for chronic exposures)

Table 2a *(continued)*. U.S. Priority Pollutants for which no numerical value is given.

Beryllium
Chloroethane
2-Chloroethylvinyl ether
1,1-Dichloroethane
Methyl chloride
Vinyl chloride
2-Chlorophenol
2,4-Dichlorphenol
2,4-Dimethylphenol
2-Methyl-4,6-dinitrophenol
2,4-Dinitrophenol
2-Nitrophenol
4-Nitrophenol
3-Methyl-4-Chlorophenol
Phenol
2,4,6-Trichlorophenol
Acenaphthene
Acenaphthylene
Benzidine
Benzo[a]anthracene
Benzo[a]pyrene
Benzo[b]fluoranthene
Benzo[g,h,I]perylene
Benzo[k]fluoranthene
Bis2-Chloroethoxymethane
Bis2-Chloroethyl ether
Bis2-Chloroisopropyl ether
Bis2-Ethlyhexyl phthalate
4-Bromophenyl phenyl ether
Butyl benzyl phthalate
2-Chloronaphthalene
4-Chlorophenyl phenyl ether
Chrysene
Dibenzo[a,h]anthracene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-n-octyl phthalate
1,2-Diphenylhydrazine
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno[1,2,3 -cd]pyrene
Isophorone
Naphthalene
Nitrobenzene
N-nitrosodimethylamine
N-nitrosodi-n-propylamine
N-nitroso-diphenylamine
Phenanthrene
Pyrene
1,2,4-Trichlorobenzene
alpha-BHC
beta-BHC
delta-BHC
4,4'-DDE
4,4'-DDD
endosulfan sulfate
Endrin aldehyde

Table 2b. U.S. National Water Quality Criteria for Protection of Aquatic Ecosystem and Human Health: Non-Priority Pollutants.

	Freshwater		Saltwater		Human Health for Consumption	
Non- Priority Pollutant	CMC - acute µg/L	CCC - chronic µg/L	CMC - acute µg/L	CCC – chronic µg/L	Water + organism µg/L	Organism µg/L
Alkalinity		20,000				
Aluminum	750	87				
Barium					1,000	
Chloride	860,000	230,000				
Chlorine	19	11	13	7.5		
Chlorophenoxy herbicide 2,4,5-T					10	
2,4-D					100	
Chlorpyriphos	0.083	0.041	0.011	0.0056		
Demeton		0.1		0.1		
Guthion		0.1		0.1		
Hardness					0.0123	0.0414
Iron		1,000			300	
Malathion		0.1				
Manganese					50	100
Methoxychlor		0.03		0.03	100	
Mirex		0.001		0.001		
Nitrates					10,000	
Nitrosamines					0.0008	1.24
Dinitrophenols					70	14,000
Nitrosodibutylamine					0.0064	0.587
Nitrosodiethylamine					0.0008	1.24
Nitrosopyrrolidine					0.016	91.9
Parathion	0.065	0.013				
Pentachlorobenzene					3.5	4.1
PH		6.5 – 9.0		6.5 – 8.5	5.0 – 9.0	
Phosphorous				0.1		
Solids					250,000	
Hydrogen sulphide		2.0		2.0		
Tetrachlorobenzene 1,2,4,5-					2.3	2.9
Tributyltin	0.46	0.063	0.37	0.01		
Trichlorophenol					2,600	9,800

Table 2b *(continued)* Other Non-Priority Pollutants with no numerical value given

Ammonia
Aesthetic qualities
Bacteria
Boron
Color
Ether, bis chloromethyl
Gases, total
Lindane
Oil and grease
Oxygen, dissolved
Phosphate

For the purposes of assessment of rare and episodic events lasting for short durations, it is appropriate in most cases to base a risk assessment on acute (CMC) rather than chronic (CCC) values. However, the CCC values provide a conservative value in absence of other data.

The water quality criteria from the USEPA form a reasonable basis for conducting a site-specific ecological risk assessment for individual chemicals, assuming the chemicals involved at the site are included in the list. However, many agrichemicals, industrial chemicals, and some household chemicals are not present on this list, and therefore require the development of separate criteria. Furthermore, the margins of safety for these values are not based on specific protection of NZ species, although in most cases may be considered to be adequate. It is reasonable to assume that chemical toxicity data for NZ native species will not exist for most chemicals in commerce.

6. LEGISLATION

Hazardous Substances and New Organisms (HSNO) Act

The HSNO Act requires that substances be classified and controlled based on their intrinsic properties, which includes ecotoxicity. Key areas of concern for ecotoxicity include:

- Aquatic (effects on fish, crustacean, algae)
- Persistence/bioaccumulation
- Soil (effects on plants and invertebrates)
- Terrestrial vertebrate toxicity (birds or mammals)
- Terrestrial invertebrates
- Biocidal properties

Knowledge of these properties will enable single chemical ecological risk assessments to be carried out, which will aid in the facilitation of decisions related to appropriate storage and containment of individual chemicals and products. The Environmental Risk Management Authority (ERMA) is currently undertaking to classify all new and existing substances according to these and other thresholds. Once this task is completed, site-specific risk assessments will theoretically be simplified and become more consistent.

Resource Management Act

The Resource Management Act in New Zealand empowers regional and/or city or district councils to see that adequate plans and safety measures are taken in regards to facilities that may present a risk to the environment. Specifically, Section 17 of the Act (Duty to avoid, remedy, or mitigate adverse effects) reads as follows:

(3) Notwithstanding subsection (2), an enforcement order or abatement notice may be made or served under Part XII to:

(b) Require a person to do something that, in the opinion of the Planning Tribunal or an enforcement officer, is necessary in order to avoid, remedy, or mitigate any actual or likely adverse effect on the environment caused by, or on behalf of, that person.

7. CRITICAL ECOLOGICAL RECEPTORS

It is important to identify what it is that is being protected at or near a particular site. Not all ecosystems will be equally vulnerable, and knowledge of these differences will simplify and expedite the decision-making process when considering options during a fire situation.

General Considerations

Each high risk facility should have an ecological risk assessment carried out to assesss the impact of fire on the surrounding aquatic environment. The susceptibility of different species to runoff toxicity will be dependent upon the chemicals involved at the facility and upon the species exposed, and therefore these considerations also need to be addressed in the assessment.

However, some generalisations can be made regarding sensitive ecosystems. These include:

1. slow-moving or still waterways or wetlands are more sensitive
2. small water volumes in the receiving waterway giving less dilution to the runoff increases the system’s vulnerability
3. a low biological filtration capacity resulting in greater pH changes (lower buffering capacity) and less binding of chemicals to organic matter increases bioavailability of the substances
4. the presence of threatened or endangered species is always a major concern
5. pre-existing or chronic environmental impacts from pollution from other sources may make the system particularly sensitive to added inputs

New Zealand Specific

New Zealand has 29 indigenous and 20 introduced species of freshwater fish. Of these, 10 indigenous species are listed as threatened (MfE, 1997). The distribution of these species in inland lakes ranges throughout NZ from Northland to Southland, and from coastal to alpine habitats. There are some indications that native NZ species may be more susceptible than conventional laboratory species to acute toxic effects from pollutants. Generally, the faster moving, high volume waters in major rivers are much better able to sustain and recover from a single contaminant episode than are slower moving waters of such as that observed for a swamp, wetland, or inland lake.

New Zealand has a particularly diverse set of vertebrate life, including one third of the world's known species of cockabullies, in rockpools, as well as a range of plant, native bird, and other animal life in estuaries. A sizeable percentage of these species are threatened and these habitats are very fragile and susceptible to permanent damage from a contaminant exposure event.

It is recommended that a comprehensive preventive strategy for fire-water runoff include links to other groups such as the Department of Conservation and Regional Councils that are able to provide a biological inventory of the most critical aquatic systems in a specific region.

8. MANAGEMENT OF THE IMPACTS OF RUNOFF

Containment Systems

If the risk assessment shows that fire-water runoff is likely to cause serious harm to the environment, measures can be taken to reduce this potential impact before a fire occurs. It may be necessary to build structures that will contain the runoff, where it can then be transferred and disposed of without harm to the environment. Examples of containment systems include:

- Lagoons
- Tanks
- Sacrificial areas
- Site containment (using bunds)
- Portable flexi-tanks
- Catch-pits
- Interceptors
- Separators
- Booms
- Drain seals; and
- Sand bags

Deciding on what structure is appropriate would require an estimation of the quantity of runoff expected in the event of a worst case fire scenario.

The Sandoz incident in 1986 illustrated the impact of inadequate safety provisions. No bunding system existed at the Sandoz facility at the time of the incident, which resulted in more devastating effects to the surrounding ecological environment. In response to the lessons learned from this incident, several companies have implemented a fire-water runoff management system. The Bayer warehouse in Bromsgrove, West Midlands now uses a combination of 30 mm high bunding which serves to channel the fire-water to a lagoon designed to hold 1200 cubic meters of water. This capacity was decided on following discussions with Emergency Services. The lagoon is pumped out on a regular basis to ensure that the total capacity of the containment system is always available (Environment97 website). In each of the 3 storage bays inside this facility, the floors were lowered, providing an effective bunding system. Additionally, underground storage tanks were added to each bay to provide anadditional level of protection. Roof ventilation allowed for a rapid dissipation of smoke from the warehouse.

Bayer UK also built a separate storage facility for each type of dangerous chemical (flammable, irritant, corrosive, toxicologically harmful). Sandoz now categorises chemicals into 10 different groups, and stores only about one-fourth the previous quantities of chemicals in its warehouses. The new facility is separated from other structures by a 4-hour fire-wall, and has built in-house foam generation

Storm water pollution prevention plans

The United States Environmental Protection Agency emphasises the need to promote and practice pollution prevention at the source, before it can cause environmental problems (USEPA, 1993, cited in http://www.txnpsbook.org/bmps/URBMPS-4.html). Large industrial facilities or commercial sites that have considerable chemical storage on site have a correspondingly high potential to cause large-scale pollution to storm-water drainage in case of a fire. In the case of facilities like these, overseas agencies require Storm Water Pollution Prevention Plans (SWPPP). These plans consist of a series of phases and activities which encompass characterisation of the site and precautionary options for prevention of pollution from entering surrounding water systems.

These management plans include source controls and treatment controls. Treatment controls are those in which the storm water is treated during a discharge event to remove the pollutants from the waste stream. These conditions are for episodic but predictable emissions into the waste stream. This situation would not typically apply to a fire fighting situation. A greater reliance on source controls is stressed. Source controls have a better chance of achieving 100% pollution prevention (USEPA 1993), and also do not interfere or complicate the fighting of the fire itself. Low and modest cost planning options can be identified initially, with more sophisticated and costly options pursued if necessary. Good housekeeping, preventive maintenance, spill prevention and control plans, and soil erosion control measures are important considerations in any prevention control strategy. It is recommended that consideration be given to methods for diverting runoff water around the activity area of interest so as to reduce the amount of polluted storm water leaving the area.

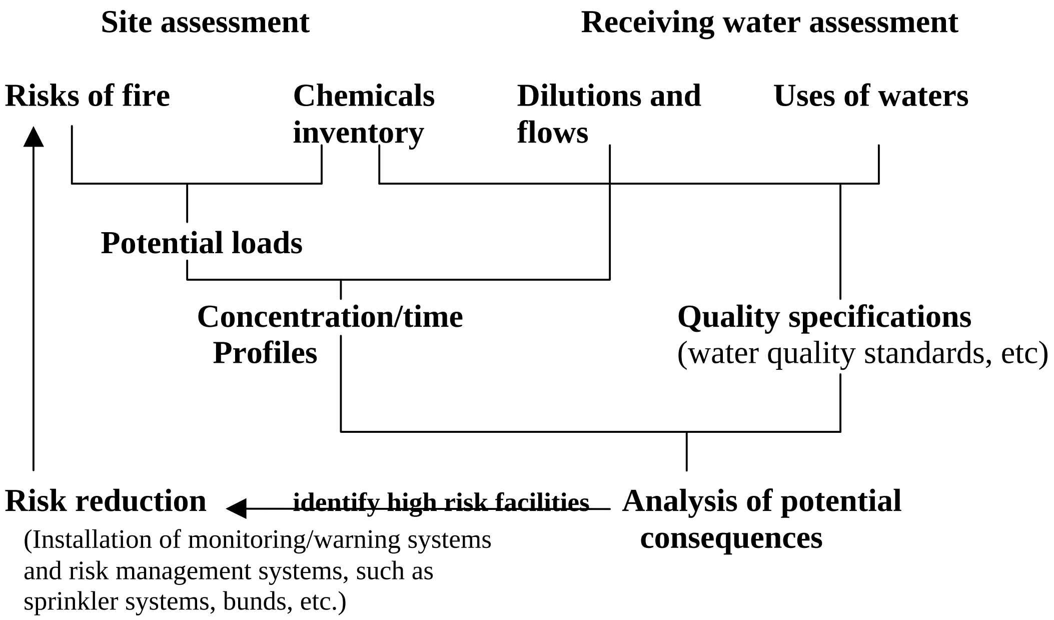
9. FRAMEWORK FOR DECISION-MAKING

A basic approach to assessment and management of ecological risks from fires is given below in Figure 1. This basic scheme is based on a facility-by-facility evaluation of plans and procedures put in place to reduce runoff impacts.

Figure 1. Basic approach to ecological risk assessment for a particular site for hazardous chemical incidents (from Hunt and Johnson, 1991).

A slightly more complex and detailed diagram for this type of framework is shown in Figure 2. This scheme involves a combination of facility, waterway, and chemical assessments.

Figure 2. Aquatic ecological risk assessment framework from the publication "Fire and its Environmental Impact", Confederation of Fire Protection Associations Europe (Cole and Hunt, 1990).



10. CONCLUSIONS

Based upon what is known about the nature of chemicals and of fire incidents where ecological impacts have been identified, it may be concluded that fire-water runoff can pose a threat to nearby aquatic environments. In cases of large industrial fires, it has been shown that rivers, streams, and lakes near to large fires bear the brunt of the ecological impact, and can sustain long-lasting damage. For most common house fires, this threat is comparatively minor. The type and magnitude of damage that occurs during a fire is a complex product of the type of fire, the emergency planning measures in place, and the location of the fire to with respect to susceptible ecological resources.

For New Zealand, it is recommended that appropriate management of this issue be co-ordinated conjointly between Fire Authorities, Regional and District Councils, and Ecologists. Together, experts in these areas could efficiently plan for and avert these situations from occurring if possible, or to at least minimise the collateral damage that results from extinguishing the fire.

A management and planning framework involving these authorities could be implemented by a step by step process in the following way:

1. Development of a priority list based on identification of high hazard potential facilities for fire-water runoff damage (i.e., chemical storage facilities, storage warehouses, tyre storage facilities, factories and manufacturing plants).

2. Combine these site priorities with an inventory of high priority aquatic biological resources in the region requiring protection.

3. Co-ordinate with local authorities to ensure that management plans exist for high-risk facilities near such resources.

4. Develop a decision-making framework that would provide recommendations to fire fighters on actions at fire scenes which may have potentially adverse effects on surrounding ecological environments. (i.e., decide in advance, based on a risk assessment, whether to let fires at certain facilities burn under certain conditions, and when to try to extinguish the fire).

5. Decide if and when low toxicity fluoroprotein foams can be cost-effectively used to minimise ecological damage in place of conventional surfactant foams.

From a chemical risk perspective, the presence of biocidal chemicals (pesticides, herbicides, rodenticides, or fungicides) or large stores of tyres presents the greatest runoff hazard to the ecosystem. Facilities that store or use these chemicals, and are located near to waterways should receive the highest priority for site assessments. It may be preferable in some cases to let fires at these types of facilities burn themselves out to eliminate the possibility of runoff carrying uncombusted biocides into the river, stream, or lake. This will depend on other factors, such as the impact of air pollutants on nearby human population centres.

Industrial facilities of any kind located adjacent or near to sensitive waterways or coastal areas are also recommended for site assessment. The materials in such facilities can lead to organic and metal pollutants in runoff that could be seriously damaging to the aquatic ecosystem.

The use of fire-retardant foams presents a moderate ecological hazard and is of less concern compared with biocides. However, there is a range of toxicity among foams, with fluoroprotein foams being the least toxic. Heavy use of surfactant foams in a fire can result in serious acute toxicity to aquatic organisms if the dilution factors in the receiving waters are small (less than 1000-fold) compared with the volume of foam applied.

The impacts of common combustion products from a typical house fire on municipal storm water systems is unlikely to pose a significant ecological threat. In most cases, these drainage systems contain water that is already toxic to aquatic life, and the dilution factor involved at the final reservoir is expected to be sufficient to reduce concentrations to near ambient levels in a short span of time.

The weighing of risks to human safety and the environment, as discussed in this report, need to be considered collectively by the Fire Service, Regional Councils, ecologists, and property owners. Decisions at fire scenes are complicated by the limited information available to fire fighters, and difficulties are compounded in situations where industries have not implemented adequate safety measures to prevent such disasters from occurring.

There is clearly a need for industries themselves to consider these risks, and for local authorities to ensure that the risk to the surrounding ecological environments is managed in situations where the potential for serious damage is high. Furthermore, fire fighters need to be able to access and use information quickly on potential risks that will aid them in decision-making when dealing with chemical fires. Until such time that this information is made available, and industries in particular take a preventative approach to manage ecological risks, the potential danger of fire-water runoff from chemical fires to ecological systems remains high and largely uncontrolled.

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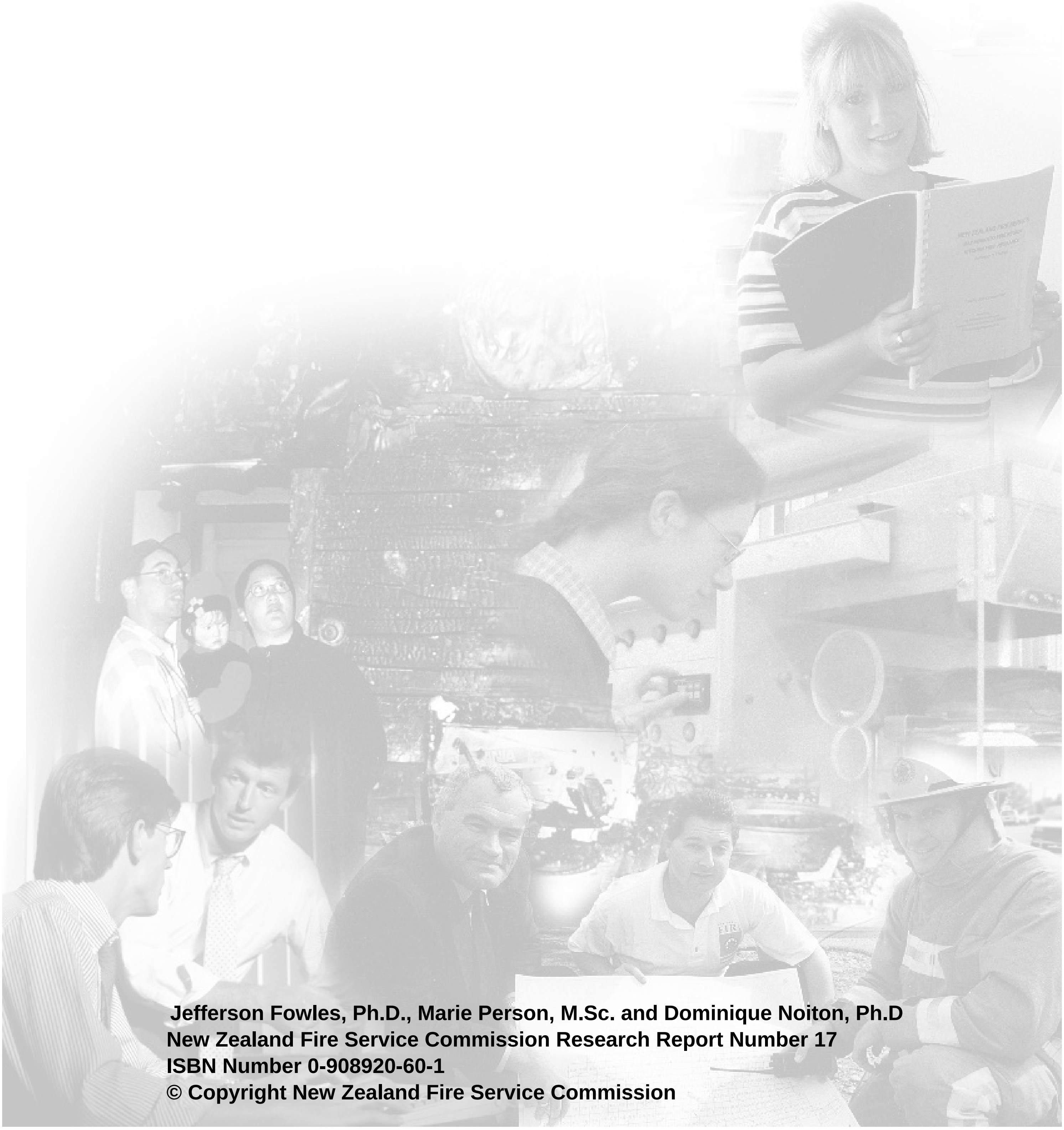

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