Fire Research Report

Impact of Fire Service Activity on the Environment

Landcare Research

March 2007

The aim of this research was to understand the potential impact of fire-fighting operations on the environment and to determine the types of pollutants generated by fire-fighting activities, and how these might affect particular species and ecosystems.

The research identified a range of alternative fire control and effluent management tactics that could be implemented to prevent or minimise contact between pollutants and organisms or ecosystems. It also suggests other areas where further research would be beneficial.

New Zealand Fire Service Commission Research Report Number 69
ISBN Number 1-877349-41-0
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Impact of Fire Service Activity on the Environment

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Landcare Research Contract Report: LC0607/098

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DATE: March 2007

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Contents

Summary

Project and Client
The New Zealand Fire Service commissioned Landcare Research to help understand how fire-fighting activities can adversely affect the environment, and to provide advice on how these activities could be modified to minimise adverse effects. This project was funded by the New Zealand Fire Service Contestable Research Fund.

Objectives

- To attain greater understanding of the potential impact of fire-fighting operations on the environment, particularly the impact on native organisms including those that are threatened, and how this might be minimised;
- To determine types of pollutants generated by fire-fighting activities, how these might affect particular species and ecosystems, and under what circumstances these pollutants, species and ecosystems might come into contact;
- To identify a range of alternative fire control and effluent management tactics to prevent or minimise contact between pollutants and organisms; and
- To identify information gaps that would benefit from ongoing research.

Methods

- Recent literature on environmental impacts of fires and fire-fighting was reviewed.
- Case studies involving past New Zealand fire-water pollution incidents were obtained from regional council pollution control officers and reviewed.
- Fire-water from two controlled burns was collected and analysed for chemical constituents, and for its toxicity to mayfly larvae.
- Information on the distribution of freshwater fish around New Zealand urban areas was obtained from the NIWA New Zealand Freshwater Fish Database. These data were mapped using GIS to show how they may be used to inform Fire Service personnel of areas where most effort should be expended to prevent fire-water discharge to stormwater systems.

Results and conclusions
Regional Council records of fire related pollution incidents concentrate on those from industrial complexes where other contaminants occur on site. There were none that recognised that fire-water from fires of non-industrial buildings can also carry significant levels of toxic compounds as shown by our analyses of fire-water collected from controlled burns. Regional Council records of fire-related pollution incidents reflect the wide diversity of contaminants that can be carried by fire-water from industrial complexes or vehicles, into stormwater systems and eventually to streams. Fire-water in these instances was highly toxic and considerable efforts were expended to prevent it reaching water courses. Nevertheless, in several instances, significant negative effects to stream life were noted.

Fire-water collected from both control burns had levels of toxic compounds and heavy metals much higher than those previously reported for house fires in New Zealand and higher than freshwater quality criteria. This suggests fire-water from house fires should be prevented from entering stormwater systems whenever possible. Fire-water collected was hazardous even without any other contaminants because of the heat of water draining from a fire scene.

Habitat maps showing the presence of significant native fish can be created with sufficient urban detail to help the Fire Service pinpoint a fire scene in relation to stormwater networks and likely fish habitat values. The Fire Service and Council pollution control officers can use

such maps to assess the likely significance of fish populations affected by a discharge, and to locate opportunities to intercept contaminants.

Recommendations

- Because of the likelihood fire-water will contain toxic compounds, it should be prevented from entering stormwater systems whenever possible. This also includes fire-water that might be generated after the fire is extinguished and during post-fire site cleanup.
- As chemical foam fire suppressants can be toxic in aquatic ecosystems (Adams & Simmons 1999), fire-water containing foam should be prevented from reaching waterways.
- Techniques to achieve these outcomes might include the following:
    a. divert fire-water from stormwater systems and pond fire-water to allow removal by sucker trucks or discharge to tradewaste;
    b. use oil/chemical absorbent pads, booms, sand, sawdust, zeolite, etc., capable of soaking up spillages, and hay bales as temporary filters;
    c. use stormwater network maps to identify possibilities to intercept and remove contaminants;
    d. give higher priority to preventing the discharge of contaminated fire-water to receiving waters that offer little dilution;
    e. use of earth dams (in serious cases, and with regional council approval) in streams to retain significant pollutants for removal by sucker trucks.
- Further research should be directed at the following:
    a. determining levels of contamination occurring under smoke plumes from fires;
    b. determining levels and persistence of soil contamination at the fire scene;
    c. designing filtration devices that could be placed in stormwater drains immediately by Fire Service personnel arriving at a fire scene;
    d. developing effective systems or means to inform Fire Service personnel when a fire scene connects to a stream network of high environmental sensitivity;
    e. more detailed studies of the effect of fire suppressant foams and fire retardants on New Zealand ecosystems would be warranted if enhanced use of these technologies gains favour.

1. Introduction

The New Zealand Fire Service commissioned Landcare Research to investigate how fire-fighting activities can adversely affect the environment, and to advise on how these activities could be modified to minimise adverse effects. This project was funded through the New Zealand Fire Service Contestable Research Fund.

2. Background

Fires generally have negative impacts on the environment, and fire suppression and fire-fighting activities occur to avoid and reduce these and other types of impacts (i.e. threats to life and property). However, fire-fighting activities can have environmental impacts in their own right (e.g., the use of chemical foams or retardants for control of some fires, water abstraction from natural waterways, and toxicity due to chemicals released from burning activities), and these impacts need to be evaluated to minimise the overall impact of fires on the environment, with due regard for other priorities. In terms of environmental impacts, a useful distinction may be between extensive fires (e.g., wildland fires) in which the fires and fire-fighting impacts cover large areas, and fires that occur at a single location (e.g., fires of structures or mobile properties) in which the products of fires and fire-fighting disperse from the fire into the surrounding unburnt environment.

2.1. Extensive Fires

Fire-fighting activities for fires occurring over extensive areas, e.g., forest fires, can have a range of impacts on land, water and air (Backer et al. 2003). Effects on land can include those associated with the construction of fire breaks, temporary roads and temporary helicopter pads such as vegetation clearance, increased erosion, and increased access and opportunities for invasive species, e.g., weeds. Effects on water can include temporary abstraction of water from natural waterways, increased sedimentation and turbidity of water, and potential chemical contamination. Effects on air can include emissions from vehicles and aircraft used to fight the fires.

Chemical foams and fire retardants are part of the range of tools available for fighting more extensive fires in New Zealand, though their usage is low here (New Zealand Fire Service 2006). However, they are used extensively for wildfires overseas (Angeler et al. 2004; Gimenez et al. 2004) where their ecological impacts are under some scrutiny.

Fire suppressant foams are primarily detergent based and act by increasing water efficiency (Adams & Simmons 1999). Studies of the toxicity of these foams suggest they have toxic effects in aquatic ecosystems but few effects to terrestrial ecosystems. Fire suppressant foams have shown toxic effects to fish (Gaikowski et al. 1996a, 1996b) and to some aquatic invertebrates (McDonald et al. 1996, 1997). Impacts on terrestrial vegetation communities, however, may be minor. Larson et al. (2000) found that plant species richness declined immediately after application of suppressant foam to shrub steppe vegetation in northern Nevada, but recovered by the end of one growing season. Hartskeerl et al. (2004) found that applications of foam to seedlings of seven Australian plant species showed no detectable impacts on a range of vegetative growth characteristics.

Fire retardants are mainly composed of nitrogen and phosphorus salts but may also contain sodium ferrocyanide. Retardants have both a toxic effect and a fertilising effect on ecosystems and their use may affect water quality, and impact flora and fauna. Fire retardants can cause eutrophication of standing surface waters in ponds or lakes (Angeler & Moreno 2006), but have at most small and temporary effects on stream ecosystems (Boulton et al. 2003; Crouch et al. 2006). The toxicity of fire retardants in aquatic ecosystems appears to be relatively low (Adams & Simmons 1999), although rainbow trout actively avoided waters containing retardants where possible (Wells et al. 2004), and the presence of sodium ferrocyanide increased toxicity in water when exposed to sunlight (Calfee & Little 2003). The addition of nitrogen and phosphorus from fire retardants can have a fertilising effect on vegetation that may be particularly disruptive when applied to naturally low-fertility native ecosystems (Bell et al. 2005). Their application can lead to increases in growth rates and may have an effect on species composition by selectively killing or advantaging some species (Bradstock et al. 1987). It can also enhance weed invasion (Adams & Simmons 1999). Fire retardants can also affect animals. Northern bobwhite quail eggs suffered a decreased hatching success and hatching weights when exposed to fire retardants at field concentrations (Buscemi et al. 2002). More detailed studies of the effect of fire retardants on New Zealand ecosystems would be warranted if enhanced use of this technology gains favour.

2.2. Point-source Fires

The chemicals and heat developed in point-source fires and in fire-fighting these can affect three areas in the environment. First, smoke particles travelling from a burn will carry products from the fire to surrounding locales downwind, where they may be deposited dry or dissolved in rainwater. Second, chemicals contained in fire-water or leached from fire residues can enter soil beneath the site of the fire. Third, fire-fighting involving water or other liquids can dissolve chemicals or transport ash developed at the site of the fire and heated by the fire, and this heated fire-water, if not contained, can leave the site of the fire and enter local waterways. This latter process can carry substantial quantities of heat and chemicals to sensitive adjacent ecosystems and is probably the most important dispersal process to be considered.

Fire smoke carries fire products including chemicals and particulates. The introduction of synthetic polymers in household furnishings has meant that a range of inorganic acids and hydrogen cyanide are amongst those contaminants commonly carried by smoke (Alarie 2002). Automobile fires also release gases in fire smoke with potentially negative impacts on the environment or chronic toxic effects on humans (Lonnermark & Blomquist 2006). Smoke plumes from fires carry these contaminants and gases downwind where they eventually disperse into the atmosphere or precipitate out into the environment. The effects of these smoke plumes on surrounding environments are little known although dispersion from small one-off events probably dilutes the contaminants to such an extent that they probably have little effect (Trewin 2003; Fowles et al. 2000).

Experiences with the effects of contamination from smoke plumes of large events are mixed. Studies carried out following the Buncefield oil depot fire, UK, and the Environmental Quality (EQ) hazardous waste facility fire in Apex, North Carolina, USA, suggest low levels of contamination from these smoke plumes. Samples of soil and grass taken downwind of the 2006 Buncefield oil depot fire, the largest fire in Europe since WWII, were analysed for the presence of polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, heavy metals, fluorides, and perfluorooctane sulphonate (PFOS) (Kibble et al. 2006). Compared with control sites and background levels of pollutants, none of these samples showed evidence of contamination from fallout from the smoke generated by this fire. Similarly, wipe samples taken downwind of the 2006 EQ fire in Apex, North Carolina, and tested for heavy metals and other potential contaminants, found very low levels, equivalent to those expected in urban locations (Jordan & Barrows 2006).

Other studies, however, show elevated levels of some chemicals under smoke plumes following large industrial fires. Wildlife sampled in the area contaminated by smoke from the 1988 St-Basile-le-Grand fire of oil containing polychlorinated biphenyls (PCBs) found significantly increased levels of PCBs and polychlorinated dibenzofurans (PCDFs) in their tissues (Phaneuf et al. 1995). However, these levels were still similar to those found in wildlife in urban and agricultural areas in other parts of Canada. In a separate study, levels of PAHs measured in vegetation and soil under the plume of a large-scale plastics fire in the UK were 70 and 370 times higher respectively than in areas outside the smoke plume (Meharg et al. 1998).

Products of fire combustion may also enter soils at the site of the fire through leaching or from infiltration of fire-water. Meharg and French (1995) sampled soil near to 4 large industrial plastics fires in the UK using the presence of heavy metals as indicators of contamination by fire products. Soils were generally contaminated with heavy metals close to the site of the fire, although one fire caused soil contamination up to 100 metres away. Meharg et al. (1997) also found that wood mice (*Apodemus sylvaticus*) caught within 10 metres of a factory that had experienced a large plastics fire, had livers with higher concentrations of dioxins and furans than mice caught 200 metres away. The livers of the mice with the higher concentrations of contaminants were significantly larger, suggesting liver damage. Apart from these industrial-scale fires, however, the effects on soils at sites of smaller scale fires (e.g., house fires) have not been examined. There is little information available on the level of contamination of these soils following fire events and how long contaminants persist.

Previous reports have in part described the chemical contaminants in fire-water in New Zealand (Fowles et al. 2000; Noiton & Fowles 2001), and Lonnermark and Blomqvist (2006) show that runoff water from automobile fires are contaminated with elevated levels of both organic compounds and metals. It is thought that contaminated fire-water run-off can lead to serious environmental damage (McGlashan 2001; Trewin 2003). In comparison with industrial fires that involve hazardous chemicals, typical suburban house fires are not thought to pose a significant environmental threat (Fowles 2001). However, there is an increasing awareness that all fire-water runoff contains combustion products including phosphates, sulphates, nitrates, dioxins and furans, and PAHs, small organic compounds and metals (Trewin 2003).

In this report we focus further on the effect of fire-water on the environment as this is the most likely way contamination from fire-fighting activity will occur. We do this in three ways:

1. We summarise New Zealand case studies involving pollution events resulting from fire-fighting activities. We describe how fire-water and associated contaminants reached watercourses in each case, and how such discharges were (or could have been) minimised. Methods used during these events (or recommended after the events) to minimise the adverse effects of environmental pollution by contaminated fire-water are also discussed.

2. We directly investigated the potential aquatic impacts of fire-water generated by fires and from fire-fighting activities by collecting fire-water from two controlled burns: a tennis-shed building located at a primary school; and a house fire. The tennis shed was filled with items of second-hand furniture depicting a lounge room scene, subsequently set alight, and the resulting fire was then managed using various fire-fighting techniques. Fire-water was collected during these burns, from a hose down following one of the fires, and from the final fire in which the entire building was intentionally allowed to burn down. These fire-water samples were returned to the laboratory for chemical contaminant determinations and ecotoxicity tests. In the house fire burn, fire-water was collected after setting fires in three different rooms of the house to determine the difference in contamination resulting from different types of fixtures.

3. We also suggest how the locations of receiving habitats can be identified, and how information on freshwater fish species locations can be obtained for a given area, helping with decisions relating to the urgency of minimising the discharge of untreated fire-water to specific watercourses.

3. Objectives

- To attain greater understanding of the potential impact of fire-fighting operations on the environment, particularly the impact on native organisms including those that are threatened, and how this might be minimised;
- To determine types of pollutants generated by fire-fighting activities, how these might affect particular species and ecosystems, and under what circumstances these pollutants, species and ecosystems might come into contact;
- To identify a range of alternative fire control and effluent management tactics to prevent or minimise contact between pollutants and organisms; and
- To identify information gaps that would benefit from ongoing research.

4. Methods

4.1. Review of past fire-water pollution incidents

A call for case studies involving past New Zealand fire-water pollution incidents was posted on a New Zealand-wide email network for pollution control officers with regional councils and territorial local authorities. Key personnel at major regional councils were also approached individually for such information. This provided pollution incident files from a number of regional councils. Information extracted from these files included descriptions of techniques used to minimise the discharge of fire-water and associated contaminants to the environment, and recommendations on site changes or procedural changes designed to reduce pollution risks in the event of future fires. These incidents are described in the results section below.

4.2. Intentional burns and fire management methods

Field methods

Two controlled burns were conducted under the direction of the New Zealand Fire Service. This first one was a tennis shed located at St Mary's Primary School, Onewa Rd, Northcote, Auckland City on 22nd January 2005. The tennis shed was filled with unwanted household items in order to depict a typical 'lounge room' scenario to mimic the conditions of a residential fire (Appendix 2, Fig. 1).

Six fires were lit in sequence (Appendix 2, Fig 2), and managed in three different ways (two replicates of each):

- with a fire-fighting foam (ForExpan 0.1-1%*)
- with a high pressure (HP) hose (fast extinguish)
- with a low pressure (LP) hose (slow extinguish)

*ForExpan is a Class A foam comprising a hydrocarbon surfactant, a glycol solvent and a foam stabiliser (Angus Fire MSDS 1997). The foam acts by enhancing the ability of water to penetrate fuel sources, thus reducing the ability of the fire to ignite (Hamilton et al. 1998).

Fire-water was collected in plastic bins located under holes cut in the floor of the shed (Appendix 2, Fig. 3) and removed as soon after the individual fires had been extinguished as was possible. Each fire was described in terms of the approximate time to manage the fire, the approximate volume of water required to extinguish the fire, and the temperature of the water following collection.

Nine samples were collected in total (Appendix 2, Fig. 4), consisting of 5 fire-water samples from the 'lounge room' burns, water collected from a hose down following the first low pressure burn (where no fire-water was collected due to such a minimal amount being used), one fire-water sample collected from the storm water drain during the final burn (Appendix 2, Fig. 5), and two controls (a foam-water and a hose-water control):

1. Foam control
2. Foam burn 1
3. Foam burn 2

4. Fire-water following high pressure hose burn 3
5. Fire-water following high pressure hose burn 4
6. Fire-water following hose down after burn 5
7. Fire-water following low pressure hose burn 6
8. Final burn
9. Hose water control

The second controlled burn was conducted at a house located at 68c Marae O Rehia Road, Waiuku, South Auckland on 19 June 2005 (Appendix 2, Fig. 10). A series of three burns were conducted in separate areas of the house – bedroom (Appendix 2, Fig. 11), bathroom (Appendix 2, Fig. 12), and lounge. All fire-fighting was done using a low-pressure hose only and there was no runoff of water to the stormwater drains. Again, fire-water was collected in plastic bins located under holes cut in the floor of the house.

A total of 6 samples was collected:

1. Firehose water (control)
2. Bedroom sample 1
3. Bathroom sample 1
4. Lounge sample
5. Bedroom sample 2
6. Bathroom sample 2

Chemical characterisation

The samples were roughly sieved to remove large particles, placed in the appropriate sample containers, placed on ice, and sent to Hills analytical laboratory for testing of the following analytes (Table 1).

Table 1. Analytes tested in fire-water samples.

Analyte	Method used	Detection limit
Total Ammoniacal-N	Phenol/hypochlorite colorimetry	0.01 mg/L
Total Cyanide	Distillation following sulphuric acid, alkaline trapping solution. Colorimetry.	0.001 mg/L
Total Arsenic	Nitric acid digestion. ICP-MS.	0.001 mg/L
Total Cadmium	Nitric acid digestion. ICP	0.00005 mg/L
Total Copper	Nitric acid digestion. ICP	0.0005 mg/L
Total Nickel	Nitric acid digestion. ICP	0.0005 mg/L
Total Lead	Nitric acid digestion. ICP	0.0001 mg/L
Total Zinc	Nitric acid digestion. ICP	0.001 mg/L
Semivolatile organics*	GC-MS, full scan (base-neutral and acid extractables)	Varies for each analyte

*refer to Appendix 1 for full list of semivolatile organic chemicals measured

Aquatic toxicity assessment

One-litre samples (three one-litre samples for the second burn) of fire-water were collected and passed through a coarse sieve to remove large particles and stored in acidrinsed plastic bottles. Samples were stored in an icebox for transport to Lincoln for testing. Conductivity and pH were measured in each sample.

The St Mary's School burn samples were passed through a glass wool filter, then a Whatman No 1 filter, then finally a Whatman No 3 filter under vacuum to remove soot. As the air bubbler caused excessive foaming, all foam samples were diluted 100-fold before toxicity testing. Figure 1 shows the difference in clarity in some of the filtered samples.

Figure 1. Fire-water samples following filtration

Many of the samples foamed with the addition of air, indicating that the foam used to fight the initial 2 fires had contaminated subsequent samples (Figure 2).

Figure 2. Experimental set up of the aquatic toxicity tests with mayfly larvae.

The Waiuku burn samples for each treatment were combined and mixed thoroughly, then half the sample passed through a Whatman No 1 filter to remove soot. The remaining sample was used unfiltered in the biological tests.

An aquatic toxicity trial was conducted with the common mayfly larvae *Deleatidium* sp. (Ephemeroptera: Leptophlebiidae). *Deleatidium* sp. are indigenous mayflies, and are the dominant benthic macroinvertebrate in many New Zealand streams (Quinn & Hickey 1990) and known to be sensitive to aquatic contaminants. Mayflies were collected from a clean Canterbury stream using a hand net and were transported in cool aerated containers to Landcare Research in Lincoln on the day of testing.

Toxicity tests were conducted using 7 – 10 animals assigned randomly to four or five replicates of disposable plastic exposure vessels containing 100 mL of the sample fire-water. The number of animals per replicate and the number of replicates per treatment were limited by the number of suitable mayflies caught on the day of the test.

Each exposure vessel was supplied with a gentle stream of air from the end of an air stone, as generated by an airpump. Treatments were distributed in a random manner, ensuring an even spread of mayfly larvae size across all replicates and treatments. In the St Mary's School test a clean acid-washed river stone (with the biofilm scrubbed off) was placed into each container to provide shelter for the larvae. As this caused some problems, stones were not used in the second set of tests.

Animals were not fed throughout the 96-h exposure period. Animals were checked at 24-hr time points for mortality. Experiments were conducted in the controlled temperature rooms at the Landcare Research invertebrate facility at a temperature of 15°C and a photoperiod of 16 light: 8 dark hrs to replicate summer conditions.

Assessment of dioxin equivalents in samples from the St Mary's School fire

The fire-water samples used in the aquatic toxicity tests as described above (with the exception that foam samples 1, 2 and 3 were not diluted) were extracted into dichloromethane (DCM) and blown down under compressed air at 45°C. Once dried, the samples were reconstituted into dimethylsulfoxide (DMSO), filtered (0.45μm) and stored at 4°C until used in the H4IIE bioassay for determination of dioxin equivalents.

The release of dioxins from fires is known but rarely characterised due to the high cost of dioxin analysis. The H4IIE bioassay uses a measurable biological response to dioxin and dioxin-like chemicals, standardised to a known amount of 2, 3, 7, 8-tetrachlorodibenzo-*p*-dioxin (2, 3, 7, 8-TCDD or 'dioxin'), to evaluate the level of 'dioxin equivalents (TEQ) in a sample. The method was performed according to Clemons et al. (1996). The test comprises a rat hepatoma cell line (H4IIE) containing a high level of liver metabolic enzymes including the cytochrome P450 enzyme system. In the presence of certain organic compounds, cytochrome P-4501A1 activity is 'induced' and the level of induction is assessed by measuring the activity of ethoxyresorufin-O-deethylase (EROD). While dioxin causes the strongest induction response in AROD activity, other compounds such as PAHs will also cause induction although the response is much weaker. It is widely accepted that this assay is able to estimate the level of dioxin-like contaminants in an environmental sample.

4.3. Mapping the distribution of important fish species at risk of fire-water pollution

Information on the distribution of freshwater fish around New Zealand urban areas was obtained from the NIWA New Zealand Freshwater Fish Database. Information on the locations of important freshwater habitats was also requested from key personnel at regional councils and the Department of Conservation.

Freshwater fish data were mapped using GIS to show the distribution of species in urban streams and rivers, particularly those species of conservation or recreational significance. GIS was also used to show City Council maps of stormwater networks, roads and buildings, to illustrate how fire-water drainage from a hypothetical fire scene could be traced to a particular watercourse (allowing the most relevant fish data to be identified). Areas of potentially high risk, including industrial areas were also highlighted where they were in close proximity to important fish habitats.

5. Results

5.1. Review of past fire-water pollution incidents

Regional councils are New Zealand's primary local government resource management agencies. These councils issue resource consents allowing the discharge of stormwater from urban areas and, like most discharge consents, these usually come with conditions designed to avoid, remedy or mitigate any adverse effects caused by potential contaminants. Regional councils are also required to monitor the state of the environment, and respond to pollution incidents. The larger councils have pollution control departments or teams, and these provide 24-hour pollution hotline services.

Pollution control teams compile incident files relating to each call-out, and some have databases allowing searches of past pollution incidents under various categories such as catchment names, type of discharge or type of receiving environment. The two councils able to provide the most relevant information to this project were the Auckland Regional Council (ARC) and Environment Waikato (EW). Fire-water related pollution records provided by these councils are summarised below.

ARC – Carter Holt Harvey Pulp & Paper, Penrose, 26 Dec 2003.

In December 2003, a fire developed in stockpiled paper bundles at a Carter Holt Harvey Pulp & Paper yard in Penrose, and this fire burned for several days. Unfortunately, the water used to extinguish the fire carried large quantities of ash and waterlogged paper into the site stormwater drains (Appendix 2, Fig. 14), and then into stormwater settling ponds (Appendix 2, Fig. 15)

Council staff observed fish climbing out of the water in the muddy stream channel below the fire-water discharge, and this could have been the result of elevated concentrations of contaminants or elevated temperature (fire-water is often hot, and hot water holds little dissolved oxygen).

While concern over fire-water contaminants often focuses on toxicity of elevated concentrations of metals and organic compounds, possibly the most significant water quality problem associated with this pulp and paper fire was the oxygen demand of the paper decomposing in the site's stormwater ponds. The ponds were sandbagged to prevent discharge to the environment and contaminated fire-water was pumped out of the stormwater ponds during the days following the fire. The paper-contaminated water was disposed to trade waste.

Despite the initial pumping, sufficient anaerobic sludge remained in the ponds to cause the pond water to become anaerobic during the 2 weeks following the fire, causing the ponds to turn black (Appendix 2, Fig. 15). The discharge of such anaerobic pond water could have significant adverse effects on a small receiving water stream providing little dilution. The bottom sludge was therefore removed in early 2004 (Appendix 2, Fig. 16).

Following this fire event, changes were proposed for the Carter Holt Harvey site, including:

- preparation of a fire-water plan outlining how to contain and dispose of fire-water at the site;
- the installation of fire-fighting water cannons at the site;
- provision of a stockpile of materials useful for diverting fire-water from the site's stormwater system toward the tradewaste system (including drain mats to block off stormwater cesspits); and
- installation of a large tank where fire-water could be pumped before discharge to trade waste.

ARC – Duffett Doors, Papatoetoe, 21 Dec 03.

In December 2003 a fire at the Duffett Doors property in Papatoetoe was thought to be the cause of a subsequent leakage of oil from at least one storage drum (Appendix 2, Fig. 17). Oil on the ground was washed with fire-water into a stormwater cesspit, before discharging to a small tributary of the Puhinui Stream. Oil may have been carried into the drain with fire-water as fire-fighting occurred, but the ARC file also suggests fire fighters had washed down the area, hosing oil into the drain.

The ARC arranged for a sucker truck to remove the remaining oil from the ground and cesspit, preventing further discharge to the stream. Oil-absorbing pads and pillows were used to soak up oil from below the stormwater outfall in the small tributary just above the confluence with the Puhinui Stream (Appendix 2, Fig. 18). Regional councils and some city councils keep oil-absorbing mats, pads, pillows or booms suitable for use on the surface of slow-flowing or stagnant waters. Fortunately, the stormwater outfall below Duffett Doors was located in a small side channel of the Puhinui Stream and this provided more of an opportunity to intercept the oil, compared with an outfall directly entering the main stream. This incident highlights the need for a quick response, because the oil would have been held up in the short side channel for only a short period of time. Given that the Fire Service is usually on the scene of such incidents well before regional council staff, it may be beneficial for the Fire Service to carry oil-absorbing materials able to deal with small spills.

Clearly the risk of such a discharge can be reduced by storage of oils and other harmful substances in safe areas unlikely to be harmed by fire and with bunding to catch spilt or leaked material. All commercial property owners/managers should be aware that stormwater drains are designed only for stormwater, and that they generally carry water to natural watercourses without any treatment. Keeping chemicals in locations where spillages or leakages would result in contamination of stormwater could result in prosecution should a leakage/spillage occur.

ARC – Colourplus paint manufacturers, Mt Roskill, 24 – 25 Jan 2002.

A January 2002 fire at the Colourplus paint manufacturers Mt Roskill workshop had the potential to result in the discharge of fire-water mixed with large quantities of paints and solvents (Appendix 2, Fig. 19). Fire-water ran down a driveway beside the Colourplus building, and eventually to a small grassy stream (Appendix 2, Fig. 20).

Despite the potential for the discharge of significant quantities of paints and solvents, observations in the ARC file do not suggest there were significant adverse effects on the receiving water stream. ARC staff commented that the front of the fire-water (presumably identified by discolouration by paint) travelled approximately 450 metres from the site in 18 hours, and it is likely that the slow-flowing, weedy nature of the stream provided some natural filtration. Dense masses of plant matter of varying sorts are often used in water treatment systems, and the large surface areas of submerged vegetation in slow-flowing grassy streams is likely to provide a high capacity for the binding of contaminants. The disadvantage of this is that grassy habitats binding contaminants such as paints and solvents may be unsuitable for most aquatic life until a flood event occurs capable of scouring the contaminants out of the system.

Because flooding is the ultimate natural cleansing mechanism capable of flushing/scouring contaminants (including those introduced by fire-water) out of the system, the Fire Service could be justified in expending less effort in intercepting small quantities of contaminants during times of heavy rainfall and floods, but conversely should give higher priority to intercepting contaminants during dry periods when receiving water streams provide least dilution.

ARC – Otahuhu Chromeplaters Ltd, 7 – 8 May 2000.

In May 2000 a fire at the Otahuhu Chromeplaters Ltd plant resulted in the flushing of chromic acid into the stormwater system. Fire-water displaced the chemical from acid baths to the workshop floor, which led to a driveway and then to the stormwater system leading to a stream.

ARC pollution control staff used sand as a bund and absorbent to reduce/halt the flow of acid to the stormwater system (Appendix 2, Fig. 21). However, a considerable quantity of chromic acid had reached the stream, and because of the high toxicity of the discharge, an earth dam was built in the stream approximately 150 metres downstream of the outfall to retain the discharge (Appendix 2, Fig. 22). This allowed Chemwaste sucker trucks to remove 170, 000 litres of contaminated water from the stream. The construction of earth dams can cause significant impacts to stream ecosystems, particularly relating to smothering of the streambed with sediment, flooding upstream of the dam, drying of stream reaches downstream, and possible dam collapse. The construction of earth dams should only be undertaken following regional council approval.

The ARC considered the diversion of contaminated water to the sewer system but this was not permitted by Watercare, given the chemical nature of the effluent.

Following this incident, Otahuhu Chromeplaters Ltd changed their chemical containment system, claiming it would be virtually impossible for a future discharge of chemicals to the stormwater system.

ARC – Pacer Car Clean Products, Otahuhu, 21 March 2004.

In March 2004 a fire at Pacer Car Clean Products in Otahuhu resulted in the discharge of fire-water to stormwater drains leading to the Tamaki River (Appendix 2, Fig. 23). Given the possible chemical contaminants in fire-water from this site, ARC staff arranged for the pumping of fire-water to a safe containment area, but this was delayed because a drum of acid was not accounted for. This allowed fire-water to escape to the Tamaki River. The company was instructed to employ a waste disposal operator to remove the remaining fire-water from site (discharging fire-water to the sewer was suggested, given approval from Watercare).

While ash from the fire-water was visible in the Tamaki River, the ARC pollution control officer considered there would be negligible environmental effect due to the large dilution factor and the flushing provided by the out-going tide.

A follow-up report recommended changes at Pacer Car Clean Products, including:

- the installation of bunds around storage tanks;
- the company was required to develop a Spill Response Plan outlining action in the event of a spill, details on staff training, signage, an accurate drainage plan, storage of clean-up materials, provision of rubber mats to cover stormwater drains, and stockpiling a non-reactive, absorbent material such as “Absorb-it” zeolite, to absorb or direct water to a bunded area.

ARC – Rentokil Initial Ltd, Onehunga, 12 June 2000.

In June 2000 a fire at the Rentokil Initial Ltd Onehunga property resulted in the discharge of fire-water contaminated by pesticide chemicals and green dye (Appendix 2, Fig. 24), into stormwater drains leading to Pikes Point (Manukau Harbour). A Chemwaste sucker truck was used to pump fire-water from the Rentokil loading bay and from the stormwater system. The ARC pollution control team also used stormwater plans to track the stormwater network, and to be able to inspect the stormwater outfall. Fortunately flushing provided by rain and the tide quickly removed the effluent from the stormwater outfall at Pikes Point, leaving no visible trace.

Following this incident key issues were raised including:

- Watercare expressed concern about the spillage of such chemicals to groundwater given the location in the Onehunga water supply aquifer catchment, stressing the need for ARC to inform them of such events in water supply catchments,
- redevelopment of the site provided an opportunity to eliminate contaminant discharge risks;
- all chemicals needed to be stored in a bunded and covered area to contain spilt or leaked material and prevent contamination of stormwater or fire-water runoff.

EW – Cobham Drive, Hamilton, chemical truck fire, 23 Sept 2002.

In September 2002 a chemical truck caught fire on Cobham Drive in Hamilton. This truck carried a wide range of toxic chemicals including:

- 242 kg Formalin (25% formaldehyde),
- 360 kg sodium hydroxide,
- 200 kg Corrosive (biocide),
- 44 kg pesticide,
- 2200 kg phosphoric acid,
- 250 kg ethanol/methanol,
- 130 kg aerosols,
- 4700 L of paint,
- Rhodamine dye (used in paints and markers for animal health products).

Eight fire engines attended the fire and crews worked through the night to remove the goods from the trailers. The drain below the chemical spill was butted with soil, causing the chemicals to pool. Soil was placed in the kerb and channelling to divert any overflow away from drains and across the road to a containment area. A woollen boom was also placed behind the butted area to capture any chemicals that leached through the soil. Absorbent pads were also placed in front of the drain in order to absorb any chemicals that were still flowing into the drain. Wymers and Allens United sucker truck companies were called in to remove chemicals from the drains and pooled areas. In total 80 to 100, 000 litres of contaminated water were tankered away for treatment at a hazardous waste disposal facility in Auckland.

A sweeper truck was used to collect contaminated solids from the road and this material was transported to Auckland for disposal.

While much of the chemical was incinerated or taken away in water pumped from the site, there was no way of determining what proportion had been discharged into the river. A Hamilton City Council drains engineer identified where the drain went so downstream water users could be notified. EW staff calculated the travel times for a parcel of water to move down river given the flow conditions and notified water users downstream when a contaminated "slug" of water might pass.

A chemical truck fire or accident might be expected to result in the discharge of chemicals to the road and roadside drains prior to the Fire Service arrival, but the application of water in fire-fighting or site cleanup is likely to accelerate the flushing of such contaminants into the stormwater system, and in this case to the receiving water tributary of the Waikato River. The spilt dyes and paints produced a pink and foamy plume in this tributary (Appendix 2, Fig. 25) and a visible plume continued for approximately 50 metres in the Waikato River below the confluence.

Some dead fish (eels, bullies) were observed on the riverbank where the stream flowed into the river and EW staff considered these fish were most likely to have come from the tributary and not the river itself. Some paint was marine anti-fouling paint and there was potential for copper and zinc contamination.

Follow-up monitoring by EW showed that the stream organisms had been badly affected by the chemical spill. Repeat monitoring for stream biology 9 days after the spill event revealed the contaminated streams had begun to recover quickly, indicating stream sediment contamination was probably not a major issue for organisms in the water.

Two days after the fire, the earth dam from the major discharge site had breached, allowing a further discharge of "pink" water to the river. This highlights the need for on-going checks and maintenance of any temporary bund, dams or diversions, and the need to remove such structures after the site cleanup, as they could become future hazards.

After the event, EW, Hamilton City Council and the Medical Officer of Health decided on appropriate measures to protect the public from potentially contaminated sites remaining after the site cleanup.

5.2. Controlled fire exercises

Fire descriptions

The Fire Service exercises involving the burning of an unwanted tennis shed at St Mary's School and a condemned house at Marae O Rehia Rd, Waiuku, provided opportunities for Landcare Research to collect fire-water for chemical and toxicity analysis, to observe possible fire effects on the environment, and also to observe the dispersal of fire-water from the sites.

In total, seven fires were conducted at St Mary's school using different fire management techniques. The quantities of water used to put out the six trial fires varied between 18 and 294 litres (Table 2). Large quantities of water (72, 000 litres) were used to manage the final burn of the shed to prevent damage to other nearby buildings. Conductivity and pH of the fire-water samples varied considerably between samples (Table 3).

Detailed descriptions of the fires were not collected for the Waiuku fire samples, and the sample from each burn sometimes came from several fire exercises where several fires were lit and put out in the same room. However, the techniques used to fight the fires were still representative of the quantities of water used in a typical situation, except for the lounge sample where the runoff was from a wash-down at the end of the fire, as water was unable to be collected from the actual fire-fighting event. Several of the fire-water samples from the Waiuku fire were highly acidic.

Table 2. Description of fire and fire management at St Mary's School

	Description of fire	Control measures used	Volume water used	Runoff	Comments
1	Very fast burning material – hot burn	Foam	224 L	Plenty	
2	Slower burning fire	Foam	78 L	Plenty	Building flushed with water after burn to remove foam
3	Very quick fire	High pressure hose	117 L	Plenty	
4	Very quick fire	High pressure hose	18 L	500 – 600 ml	
5	Slower burning fire	Low pressure hose	42 L	No volume recovered	100% evaporation so hosed out to recover sample
6	Longer burn	Low pressure hose	294 L	Plenty	
7	Final burn of entire shed	?	72, 000 L	Plenty	Runoff collected from stormwater drain

Table 3. Fire-water samples for biological tests from St Mary's School

Sample	Description of fire	pH	Conductivity (uS/cm)
1*	Foam control	9.2	220
2*	Foam burn 1	4.4	580
3*	Foam burn 2	5.6	310
4	High pressure 3	4.4	430
5	High pressure 4	6.9	840
6	Hose down burn 5	6.7	230
7	Low pressure burn 6	5.2	810
8	Final burn	7.0	250
9	Hose water	7.7	140
10	Deionised water	6.4	10

* These three foam samples had to be diluted 1:100 for the toxicity tests. pH and conductivity of diluted sample used in tests was 6.4 and 10, respectively, in all three samples.

Table 4. Fire-water samples for biological tests from the Waiuku fire

Sample	Description of fire	pH
1	Fire hose water	7.7
2	Bedroom unfiltered	9.5
3	Bedroom filtered	9.3
4	Bathroom unfiltered	3.0
5	Bathroom filtered	3.1
6	Lounge unfiltered	3.4
7	Lounge filtered	3.5

In both cases, smoke plumes generated from the fires were probably sources of some air-borne contamination to downwind areas (Appendix 2, Figs 5 and 12). It is unclear whether such smoke would have persistent effects on the environment, and this could be the subject of further investigation. As well, we were struck by the heat of the fire-water even some time after the fires had been put out. Fire-water temperatures were recorded at up to 42 °C 18 minutes after the fire had been put out.

Hot water at this temperature could be harmful to freshwater life in small receiving water streams even if there were no chemical contaminants in the fire-water. Temperature effects may be of no consequence when a fire-water discharge reaches a large river or estuary, but most stormwater outfalls in urban streams in the Auckland Region enter small streams where there may be little dilution, particularly during summer low flows when aquatic life may already be stressed by warm temperatures and low dissolved oxygen levels. Fire-water discharges could raise stream water temperatures to lethal levels for some freshwater species, and the combination of elevated temperature and toxicity of fire-water may be lethal to other species.

Fire-water generated at the Waiuku fire did not enter the stormwater system. However, fire-water from the St Mary's burn drained to two separate stormwater drains (Appendix 2, Figs 4 and 6) that had their outfall into the Onepoto Stream (Appendix 2, Fig. 6) approximately 500 metres away. From a visual estimate of flow it appeared the flow of black fire-water coming out of the stormwater pipe was similar to the flow of the stream above the stormwater outfall. The firewater discharge therefore had a significant visual effect on the stream, as seen in the comparison of upstream and downstream photos (Appendix 2, Fig. 7).

The visible pulse of firewater in the Onepoto Stream lasted for approximately half an hour, and during this time accumulations of ash were observed forming on the water surface in backwaters (Appendix 2, Fig. 8). When combined with the dark grey colour and smoky odour, the discharge was easily recognisable as fire-water. The reach affected was approximately 200 metres of stream upstream of the estuarine mangrove area.

Despite the dark colour of the water during the discharge, native bullies, tripplefins and elvers were observed fleeing downstream as they passed a shallow stony section. Such behaviour is not normal for these native fish and was clearly a sign of stress and a natural attempt to escape the fire-water discharge. A pole net was used to catch fish drifting downstream at a point where the flow was concentrated into a small area

(Appendix 2, Fig. 8), and over a period of 20 minutes 40 fleeing fish, most of which were common bullies (Appendix 2, Fig. 9), were caught. While all of these fish were alive when caught and transferred to clean water, some were showing classic signs of stress such as staggered swimming motion and reduced ability to remain upright (also observed in the stream before the net was positioned). Some juvenile bullies died within minutes of being transferred to the fresh water (Appendix 2, Fig. 9), though it is possible the stress of capture and transfer may have contributed to this.

Chemical analyses

The concentrations of contaminants measured in the fire-water and control samples of the St Mary's School burn are given in Appendix 1a. A wide range of contaminants were found in the fire-water, including heavy metals, polyaromatic hydrocarbons (PAHs), and phenolic compounds. Lead and zinc were the two metals found in the highest concentrations, while phenol was the organic compound found in the highest levels.

The fire-water samples managed using high and low pressure hoses contained the highest levels of lead, zinc, and cyanide, but had only very low levels (or in many cases no measurable amounts) of PAHs. The second low-pressure hose burn (burn 4) had the highest levels of phenolic compounds (2-methylphenol, 3&4-methylphenol, and 2, 4-dimethylphenol). The highest measurable levels of PAHs were split between foam sample 1 and the final burn sample, with foam sample 1 containing the highest levels of the lower molecular weight PAHs (2, 3, and 4-ring PAHs), while the final burn sample had the highest levels of the higher molecular weight PAHs (5 and 6-ring PAHs). The foam samples also had the highest levels of copper, cadmium, nickel, di-n-butylphthlate, phenol and dioxin equivalents (TEQ, Table 11). Burn 4, managed with the high-pressure hose, also had a high level of TEQ (Table 11).

The concentrations of contaminants found in the St Mary's fire-water samples were almost all higher than concentrations found in a previously monitored house fire burn (Noiton & Fowles 2001). Due to differences in the chemical analyses conducted, data are only available for a selection of contaminants (Table 5).

Cyanide was found in all St Mary's fire-water samples but was not detected in the previous results. Arsenic, copper and nickel levels were similar to those found in the sample from the 2001 house fire reported by Noiton and Fowles (2001). However, cadmium, lead, and zinc levels were much higher in the St Mary's fires (up to 78-fold, up to 94-fold, and up to 6-fold higher respectively). Naphthalene and phenanthrene were not detected previously in the 2001 house fire, but were found in a number of samples here. One reason for the difference in contaminant levels is the volume of water used to control the burn. The volume of water used in the previous house fire burn (based on an estimate) was 2800 L, which is much higher than the volumes used in the fires at St Mary's in all cases, except for the final burn.

Table 5. Comparison of contaminants in fire-water samples from St Mary's School with water quality criteria values and a previous house fire. Values are in mg/L

Analyte	Foam 1	Foam 2	HP 1	Hose down	LP2	Final Burn	House fire (2001)[1]	Trigger values 95%[2]	Trigger values 80%[3]
Cyanide	0.04	0.02	0.138	0.007	0.01	0.046	<LD	0.007	0.018
As	0.07	0.06	0.04	0.007	0.06	0.08	0.05	0.024[4] 0.013[5]	0.36[4] 0.14[5]
Cd	0.065	0.094	0.018	0.0209	0.0565	0.0024	0.0012	0.0002	0.0008
Cu	0.127	0.11	0.112	0.029	0.111	0.042	0.12	0.0014	0.0025
Ni	0.026	0.043	0.018	0.0052	0.011	0.0011	0.013	0.011	0.017
Pb	0.991	5.6	1.26	2.9	16.1	1.53	0.17	0.0034	0.0094
Zn	1.85	4.54	2.46	4.75	10	3.07	1.6	0.008	0.031
Naphthalene	0.46	0.05	<LD	<LD	<LD	0.02	<LD	0.016	0.085
Phenanthrene	1.01	0.143	0.049	0.04	<LD	0.134	<LD	0.0004[6]	NV

[1] some analytes were <LD; however, detection limit was not specified in the Noiton and Fowles (2001) report for comparison.
[2] Trigger value protective of 95% species (suitable protection level for a slightly to moderately disturbed environment) ANZECC/ARMCANZ 2000
[3] Trigger value protective of 80% species (suitable protection level for a highly disturbed environment) ANZECC/ARMCANZ 2000
[4] As (III)
[5] As (V)
[6] Interim Canadian Environmental Quality Guideline: a long-term no-effect concentration (CCME 2002)
LD is below limit of detection
HP = Fire managed with high pressure hose
LP = fire managed with low pressure hose
NV = no value derived due to insufficient data

The concentrations of contaminants measured in the fire-water and control samples of the Waiuku burn are given in Appendix 1b. The bathroom sample had the highest levels for most metals of the three types of fire, while the lounge had the highest levels of cyanide of the three rooms. The solubility of metals is generally pH dependent which may have contributed to the lower metal concentrations found in the bedroom samples (Table 6). Lead and zinc were the two metals present in the highest levels across the three rooms, but copper was also very high in the bathroom sample (Table 6). The bedroom and bathroom samples did not contain many organic compounds, except for phenolic compounds, and these were much higher in the bathroom sample than in the bedroom sample. The lounge sample had a huge array of organic compounds, including PAHs, phthalates, and phenolic compounds.

Metal analysis of filtered and unfiltered samples showed a general decrease in metal levels in the samples (a difference of more than 20% was considered to be a decrease). This was especially so for the bedroom sample where metal levels for all metals except As were reduced by over 50%, and Cd, Pb, and Zn levels were reduced by over 90%. However, filtering of the bathroom and lounge samples did not have such a large effect. The bathroom samples showed a 20 – 40% reduction in metal levels in samples, while for the lounge samples, only Cu and Pb were reduced by 21% and 36% respectively. The levels of organics were generally not greatly affected by filtering in either the bedroom or bathroom samples, except perhaps the phenolics in the latter. Filtering the lounge sample almost universally reduced concentrations of all organic compounds.

Table 6. Comparison of contaminants in unfiltered fire-water samples from the Waiuku fire with water quality criteria values. Values are in mg/L

Analyte	Bedroom	Bathroom	Lounge	Trigger values 95%[2]	Trigger values 80%[3]
Cyanide	0.385	<LD	0.591	0.007	0.018
As	0.506	0.72	0.591	0.024[4] 0.013[5]	0.36[4] 0.14[5]
Cd	0.00123	0.325	0.0279	0.0002	0.0008
Cu	0.147	8.06	0.423	0.0014	0.0025
Ni	0.0572	0.598	0.039	0.011	0.017
Pb	3.08	3.31	1.34	0.0034	0.0094
Zn	1.21	23.2	4.56	0.008	0.031
Naphthalene	<LD	0.07	0.0298	0.016	0.085
Phenanthrene	0.0005	<LD	0.03	0.0004[6]	NV

[1] some analytes were <LD; however, detection limit was not specified in the Noiton and Fowles (2001) report for comparison.
[2] Trigger value protective of 95% species (suitable protection level for a slightly to moderately disturbed environment) ANZECC/ARMCANZ 2000
[3] Trigger value protective of 80% species (suitable protection level for a highly disturbed environment) ANZECC/ARMCANZ 2000
[4] As (III)
[5] As (V)
[6] Interim Canadian Environmental Quality Guideline: a long-term no-effect concentration (CCME 2002)
LD is below limit of detection
HP = Fire managed with high pressure hose
LP = fire managed with low pressure hose
NV = no value derived due to insufficient data

Hazard ranking of contaminants

Contaminant levels were compared with freshwater quality criteria for the protection of aquatic life, using the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000). These guidelines have derived trigger values for protection of 80% and 95% of species. The 80% trigger values are a suitable protection level for a highly disturbed environment, while the 95% trigger values are a suitable protective level for slightly to moderately disturbed environments. To calculate the chronic risk from each of these contaminants, results were expressed as a hazard indice using the following equation:

Hazard indice (HI) = Contaminant concentration/Trigger value from Table 5.

For the St Mary's School samples and based on the 80% trigger values, arsenic does not pose an ecotoxicological risk to aquatic invertebrates (Table 7). Nickel poses a low risk, but principally in the foam samples, while cadmium, copper, lead, and zinc pose a significant risk in all the fire-water samples. The highest HIs were observed for lead and zinc across all fire-water samples, followed by cadmium, and then copper. Naphthalene poses a risk in foam sample 1 only, but the risk of phenanthrene could not be evaluated due to insufficient data to derive a value in the guidelines.

When the contaminants levels in each sample are compared with the 95% trigger values, all metals pose a risk in almost all samples, with cadmium, copper, lead, and zinc being worse than nickel or arsenic (Table 8). Naphthalene poses a risk in the foam samples and phenanthrene poses a significant risk in all samples except the hose down sample. The highest HI for phenanthrene was in the foam samples and in the final burn sample.

Table 7. Hazard indices of contaminants in the St Mary's fire-water samples to protect highly disturbed environments

Analyte	Foam 1	Foam 2	HP 1	Hose down	LP2	Final
Cyanide[1]	2.22	1.11	7.67	0.39	0.56	2.56
As III[1]	0.19	0.17	0.11	0.02	0.17	0.22
As V[1]	0.50	0.43	0.29	0.05	0.43	0.57
Cd[1]	81.4	118	22	26.1	70.6	3
Cu[1]	50.8	44	44.8	11.6	44.4	16.8
Ni[1]	1.53	2.53	1.06	0.31	0.65	0.06
Pb[1]	105	596	134	309	1713	163
Zn[1]	59.7	147	79.4	153	323	99
Naphthalene[1]	5.41	0.59	<LD	<LD	<LD	0.24
Phenanthrene	NV	NV	NV	NV	NV	NV

[1] Trigger value protective of 80% species (suitable protection level for a highly disturbed environment) ANZECC/ARMCANZ 2000
<LD is below limit of detection
NV is no guideline value available

Table 8. Hazard indices of contaminants in the St Mary's fire-water samples to protect slightly to moderately disturbed environments

Analyte	Foam 1	Foam 2	HP 1	Hose down	LP2	Final
Cyanide[1]	5.71	2.86	19.7	1.00	1.43	6.57
As III[1]	2.92	2.50	1.67	0.29	2.50	3.33
As V[1]	5.38	4.62	3.08	0.54	4.62	6.15
Cd[1]	326	471	88	105	283	12
Cu[1]	91	79	80	20.7	79.3	30
Ni[1]	2.36	3.91	1.64	0.47	1.0	0.1
Pb[1]	291	1647	371	853	4735	450
Zn[1]	231	568	308	594	1250	384
Naphthalene[1]	28.8	3.13	<LD	<LD	<LD	1.25
Phenanthrene[2]	2525	358	123	100	<LD	335

[1] Trigger value protective of 95% species (suitable protection level for a slightly to moderately disturbed environment) ANZECC/ARMCANZ 2000
[2] Interim Canadian Environmental Quality Guideline: a long-term no-effect concentration (CCME 2002)
<LD is below limit of detection

Based on the 80% trigger value the Waiuku fire-water samples pose a high risk to aquatic life from cyanide, especially from the bedroom and lounge samples (Table 9). The risk from arsenic is low to moderate, but all the other metals do pose a high to very high risk to aquatic life. Lead and zinc pose a consistently very high risk across all three rooms, while cadmium, copper and nickel pose the highest risk from the bathroom sample. Copper from the bathroom sample has the highest risk of all the metals (3224 times the guideline value). Phenanthrene poses a high risk in the lounge sample based on the 95% trigger level (Table 10).

Table 9. Hazard indices of contaminants in the unfiltered Waiuku fire fire-water samples to protect highly disturbed environments

Analyte	Bedroom	Bathroom	Lounge
Cyanide[1]	21.39	<LD	32.83
As III[1]	1.41	2.00	0.31
As V[1]	3.61	5.14	0.79
Cd[1]	1.54	406	35
Cu[1]	59	3224	169
Ni[1]	3.36	35	2.29
Pb[1]	328	352	143
Zn[1]	39	748	147
Naphthalene[1]	0.00	0.82	0.35
Phenanthrene	NV	NV	NV

[1] Trigger value protective of 80% species (suitable protection level for a highly disturbed environment) ANZECC/ARMCANZ 2000
<LD is below limit of detection
NV is no guideline value available

Table 10. Hazard indices of contaminants in the unfiltered Waiuku fire fire-water samples to protect slightly to moderately disturbed environments

Analyte	Bedroom	Bathroom	Lounge
Cyanide[1]	55	<LD	84
As III[1]	21	30	4.58
As V[1]	39	55	8.49
Cd[1]	6.15	1625	140
Cu[1]	105	5757	302
Ni[1]	5.20	54	3.55
Pb[1]	906	974	394
Zn[1]	151	2900	570
Naphthalene[1]	0.00	4.38	1.86
Phenanthrene	1.25	0.00	75

[1] Trigger value protective of 95% species (suitable protection level for a slightly to moderately disturbed environment) ANZECC/ARMCANZ 2000
[2] Interim Canadian Environmental Quality Guideline: a long-term no-effect concentration (CCME 2002)
<LD is below limit of detection

Aquatic toxicity tests

Although comparing the concentrations of contaminants with water quality criteria can give an indication of the potential toxicity due to single contaminants, direct toxicity testing (DTA) is a more robust and preferred method of assessing sample toxicity because it takes into account the bioavailability of the contaminants as well as the effects of chemical interactions and any mixture toxicity.

For the St Mary's School fire-water samples, mayflies exposed to the fire hose control water, the diluted foam water control and the deionised water control showed some mortality over the duration of the experiment, indicating experimental stress (Fig. 3). However, there were no differences between the control treatments. The three foam samples (samples 1 – 3) had to be considerably diluted (100 fold) to stop them frothing too much in the toxicity test system. This diluted the contaminants present in the foam samples used to manage the first two fires (samples 2 and 3) and consequently mortality in both of the fire-water foam samples was no different from controls (Fig. 3).

Burns 3 and 4, which were managed using water from a high-pressure hose, produced highly toxic fire-water that resulted in almost 100% mortality in mayfly larvae within their first 24 hr of exposure, and it is highly likely that mortality occurred at a much earlier time point (Fig. 3). The first burn (burn 5) to be managed with water from a low pressure hose yielded no fire-water for testing as it evaporated on interaction with the fire; the building was therefore hosed out afterward to provide some water for toxicity testing. Mayflies showed moderate toxicity to this sample after 48 hr exposure, indicating toxic material remains after a fire is extinguished (Fig. 3). This material was washed off and subsequently discharged into the environment.

Burn 6 was also managed using a low-pressure hose and fortunately sufficient water was collected for toxicity testing. Like the fire-water collected from the fire extinguished using a high-pressure hose, the burn managed with a low-pressure hose yielded equally toxic fire-water (Fig. 3). In the final burn, a tremendous amount of water was used to protect surrounding buildings from catching alight during the intentional destruction of the St. Mary's tennis shed. Fire-water was collected from a nearby stormwater drain (approximately 100 metres from the tennis shed site) and although the water was significantly discoloured, it was not acutely toxic to mayfly larvae.

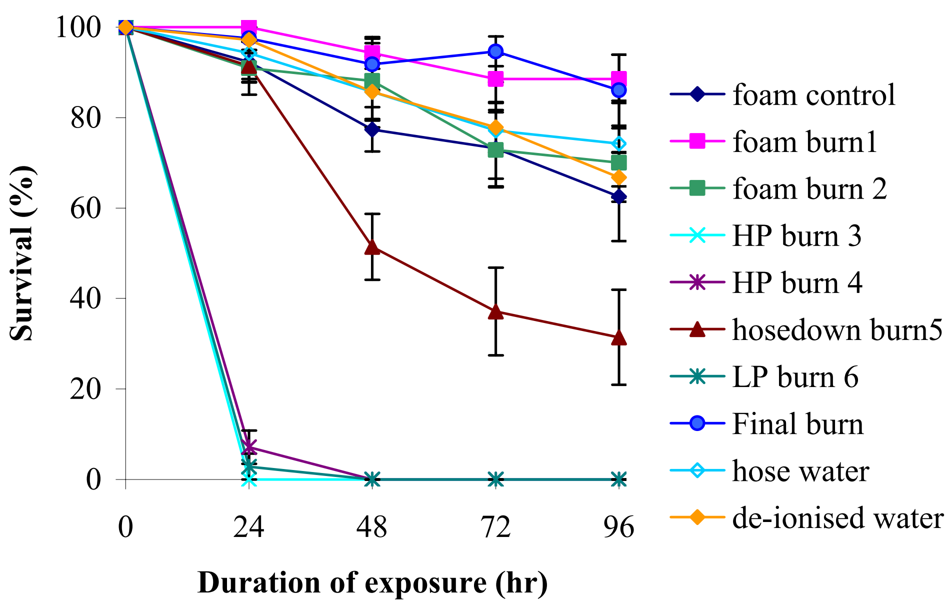

Fig. 3. Survival of mayflies exposed to fire-water from St Mary's School for up to 96 hr.

For the Waiuku fire-water samples, control mortality was very low, with only 1 mayfly dying out of the 60 used (Fig. 4). However, the fire-water samples all proved very toxic, with only 4 mayflies out of the 180 tested surviving at 96 hr. There was no obvious difference in mortality between animals exposed to filtered or unfiltered samples. The samples from the bathroom and lounge fires were very toxic with total mortality within 24 hr, while the bedroom fire sample showed gradual, but still 100% (or almost) mortality within 96 hr.

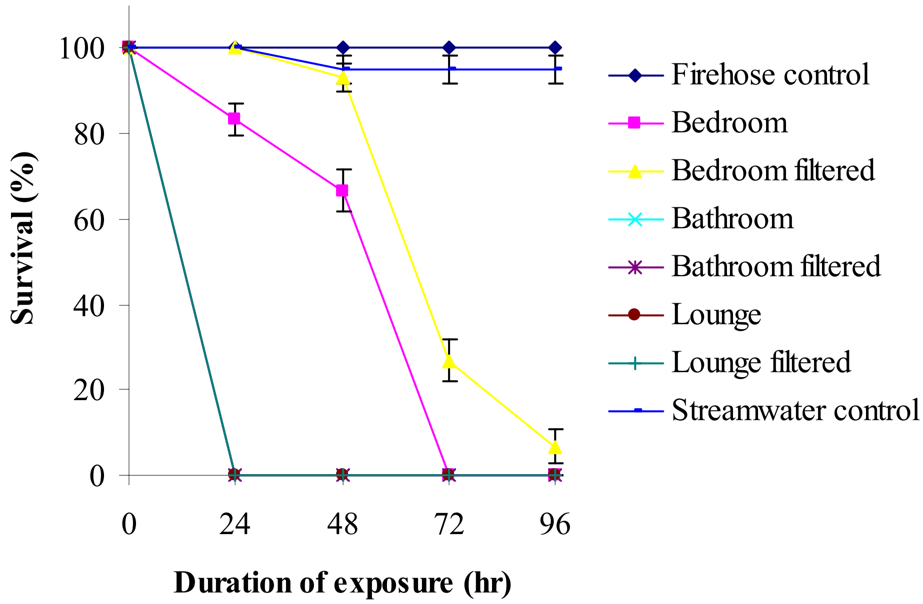

Fig. 4. Survival of mayflies exposed to fire-water from the Waiuku fire-water samples for up to 96 hr.

In vitro toxicity test

The dioxin level of the St Mary's filtered samples used in the toxicity tests was assessed using an *in vitro* cell-mediated assay. Exposures of rat hepatoma cell line to the fire-water samples is given as 'dioxin (TCDD)-equivalents' in Table 11.

Table 11. Dioxin equivalents as calculated using the H4IIE- EROD assay

Sample	Sample Label	TCDD Equiv. (ug TCDD/L)	SEM
1	Foam control	0.0081	0.0036
2	Foam burn 1	0.6962	0.0529
3	Foam burn 2	0.0958*	0.0106
4	H.P. burn 3	0.0184*	0.0031
5	H.P. burn 4	0.1364*	0.0125
6	Hose down	0.0096*	0.0028
7	L.P. burn 6	0.0219	0.0041
8	Final burn	0.0012	0.0002
9	Fire hose control water	0.0006	0.0001

SEM = standard error of the mean, * sample was cytotoxic to the H4IIE cells.

It is worth noting that some of the samples extracted contained ultrafine particulates (this was most likely in samples 2 and 3) that were not removed by coarse filtering. The dioxin equivalents stated here may therefore have been artificially increased due to bound contaminants on these particles (normally binding causes a reduced bioavailability) being removed during the extraction process. Cytotoxicity was seen in many samples. The sample containing the most TCDD equivalents was the fire-water collected after the initial burn that was managed with foam. This sample contained almost 0.696 µg TCDD/mL, compared to between 0.0012 to 0.136 µg TCDD/mL in the other fire-water samples. Fire-hose control water, hose down water and storm water from the final burn had relatively insignificant TCDD concentrations. The TCDD concentration in the first foam-controlled sample compared with the second could be indicative of the material that was burnt. It is noted that this first fire caught alight very dramatically, indicating highly flammable material. When comparing the TCDD equivalents in each fire-water sample with toxicity to mayflies it is evident there is a good correlation between toxicity and dioxin (Fig. 5).

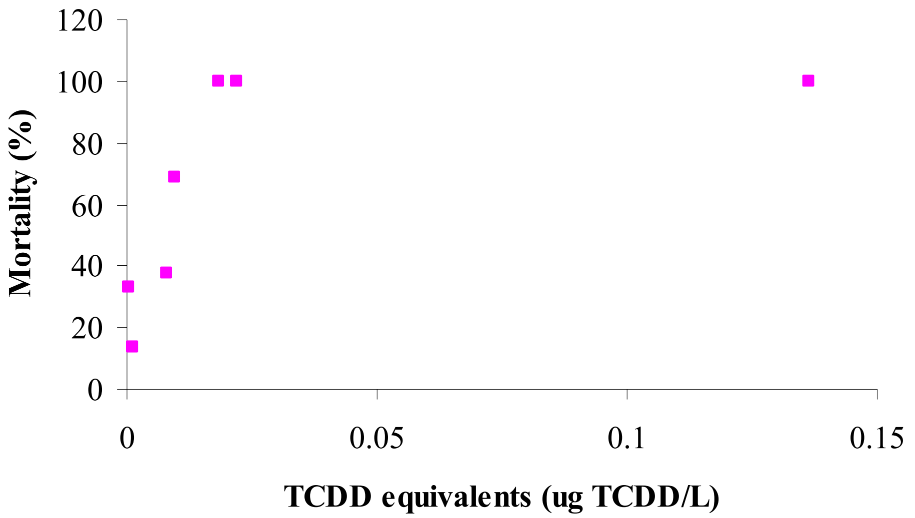

Fig. 5. Correlation of dioxin equivalents as calculated using the H4IIE- EROD assay with toxicity to mayflies.

5.3. Mapping the distribution of important fish species at risk of fire-water pollution

This project has dealt primarily with the discharge of contaminated fire-water to urban stormwater systems and their receiving waters. Pollutants carried by fire-water into stormwater drains have featured in numerous Regional Council pollution investigations, especially in the Auckland Region. Most councils recognise that urban streams (the most likely recipients of fire-water discharges) can support important aquatic biota and are often the subject of high public interest. Regional councils and some city and district councils monitor the state of watercourses in their area, and typically have policy statements or plans stating their intention to maintain or enhance the quality of freshwater and coastal habitats.

Some councils collect records of the locations of important habitats of indigenous (and sometimes introduced) biota, and councils can obtain significant amounts of data from the NIWA National Freshwater Fish Database. This database collates records contributed by many organisations including local government, Department of Conservation, Fish and Game councils, tertiary institutions, and environmental consultants.

Much of the data on the National Freshwater Fish Database was collected during assessments of the effects of proposed or existing developments on the environment to help process resource consents by regional councils. For this reason there are often clusters of fish data points around the fringes of urban areas where development is proposed, or where recent development has occurred. Fish data points also tend to be clustered around areas of easy access such as road bridges and streamside parks. Central city areas that became urbanised a long time ago, such as central Auckland City, may be relatively lacking in fish data, in part because streams in these areas may have been piped.

Councils set rules designed to avoid, remedy or mitigate the adverse effects of human activities on watercourses, and they often have officers trained to respond to pollution incidents, and to take necessary actions to minimise adverse effects of pollution incidents on the environment. The scale of council pollution response to a particular event may be affected by council knowledge of a watercourse, for example, a stream may be a poor quality ephemeral habitat unable to support significant fish communities, while other streams may be known to support rare native species or fish spawning sites. Given that the Fire Service is usually first on the scene of events where fire-water could carry contaminants to stormwater systems, it could be beneficial for the Fire Service to have access to simple summary information indicating the likelihood of the receiving environment supporting important freshwater fish communities as indicators of environmental quality. Fire service units could carry maps of their territories showing stormwater catchment areas, and whether important fish species are known (or likely) to occur in their receiving waters.

Even without data on past fish records for specific streams or catchments, there are general species-habitat relationships that can indicate a likelihood of particular fish species, or mixtures of species occurring in a given section of a stream or catchment, for example:

- coastal reaches of streams tend to support the most diverse fish communities, in part because they are used by numerous native species that have a seawater or estuarine stage during their lifecycle;
- lowland, low-gradient stream communities are also likely to support more diverse communities because they are less likely to have barriers capable of preventing migration to and from the sea (particularly for non-climbing species such as inanga and smelt);
- for the above two reasons lowland, coastal streams are the most likely habitats for the relatively rare giant kokopu;
- grassy reaches of coastal streams flooded by backed-up freshwater during spring high tides, could be important inanga and giant kokopu (whitebait) spawning sites;
- low-lying floodplains that are often submerged by minor floods and covered by dense groundcover vegetation, could be spawning habitats for banded kokopu (including many small, inland streams around Auckland);
- inland, high-gradient streams tend to be dominated by species with strong migratory instincts and climbing abilities such as longfinned eels, shortfinned eels and banded kokopu (including many inland streams around Auckland);
- areas upstream of hydroelectric dams or significant waterfalls may support only those native species capable of establishing land-locked populations such as Cran's bullies, certain galaxiids in the South Island (some of which are endangered), and if there is a lake, common bullies and koaro;
- clean, gravelly streams south of the Auckland region could be important trout spawning habitats, and in the South Island, trout or salmon spawning habitats;
- steams and rivers feeding into lakes may be important spawning habitats for trout (e.g., streams feeding into Lake Taupo) or salmon (in the South Island);
- small streams and drains in low gradient or swampy areas, including those that almost dry up during summer, are often habitats for banded kokopu (especially around Auckland) and they could be habitats for threatened mudfish (especially around Hamilton and Christchurch);
- streams with steep upper reaches and/or with native bush cover may be important habitats for the shortjawed kokopu and longfinned eels (both species in decline), lamprey (uncommon) and koaro;
- large rivers and the main stems of any coastal streams are migratory routes and habitats for many fish species; however, the risks of contamination from fire-water are reduced as dilution increases.

While it is possible for experienced biologists to list fish species likely to occur in an area based on location, species-habitat associations and nearby fish records, it is often not possible to predict fish community composition accurately. Many habitats apparently suitable for particular species may lack those species, and migratory fish species often appear in unexpected places. It is also important to note that the fish database may contain little or no data from a particular stream or catchment, and where there are species lists from particular streams, such lists cannot be assumed to be complete. There are few records of giant kokopu in the Auckland area, in part because this is a relatively rare species, but probably also because of the difficulty of sampling many of the coastal stream habitats likely to be occupied by this species.

The NIWA fish database provides a basic mapping facility where the locations of fish records for all species, or for selected species, can be illustrated for a given area, catchment, or subcatchment. While the maps created by the fish database facility are useful for a quick reference of fish distribution (Fig. 6), they provide very little detail on streams, roads, or other site-specific layers that could assist someone looking at a particular spot (such as a fire scene).

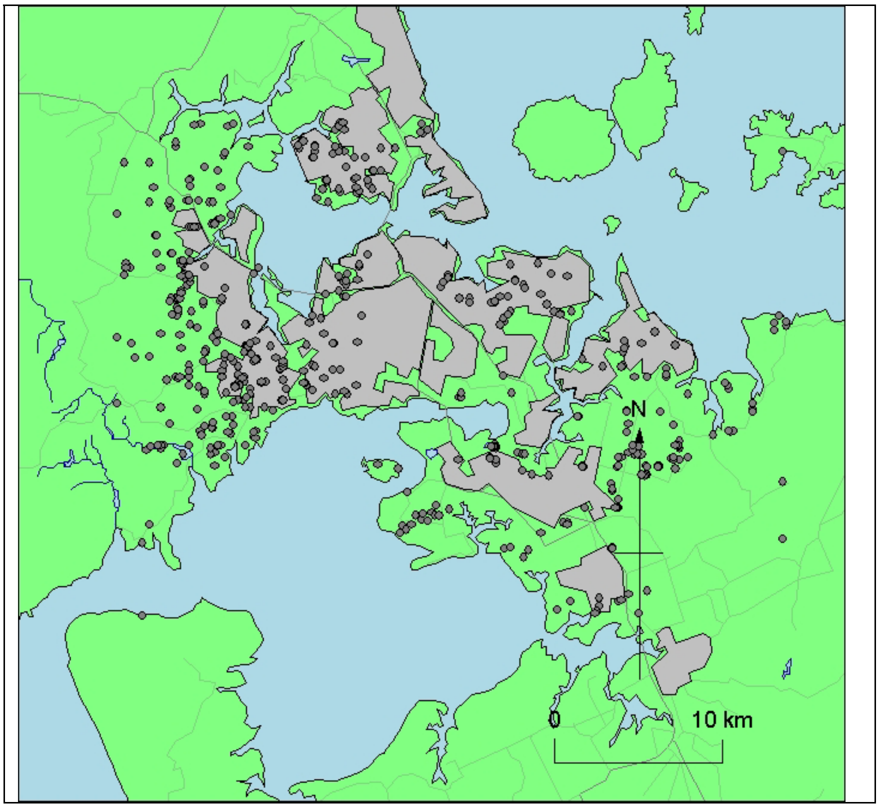

Fig. 6: Auckland freshwater fish distribution (all species from map NZMS260 R11). Map generated using the NIWA National Freshwater Fish Database programme.

Maps showing the distribution of important freshwater fish, including native species classified as "nationally endangered", "in decline" or "sparse" (Department of Conservation 2002) and introduced trout and salmon (which are given special status under the RMA and protected by Fish and Game regulations) would be of greater relevance to the Fire Service or local council when deciding on the sensitivity of the receiving environment and the importance of minimising the discharge of pollutants in particular areas. GIS can be used to plot the locations of particular species, or habitats considered to be of particular importance. In the Auckland area, habitats known to support populations of the relatively rare giant kokopu should be considered among the higher priority sites for protection (Fig. 7). Other cities and towns around New Zealand will have streams supporting different native species of conservation interest, and urban streams south of the Auckland region may support trout and (in the South Island) salmon.

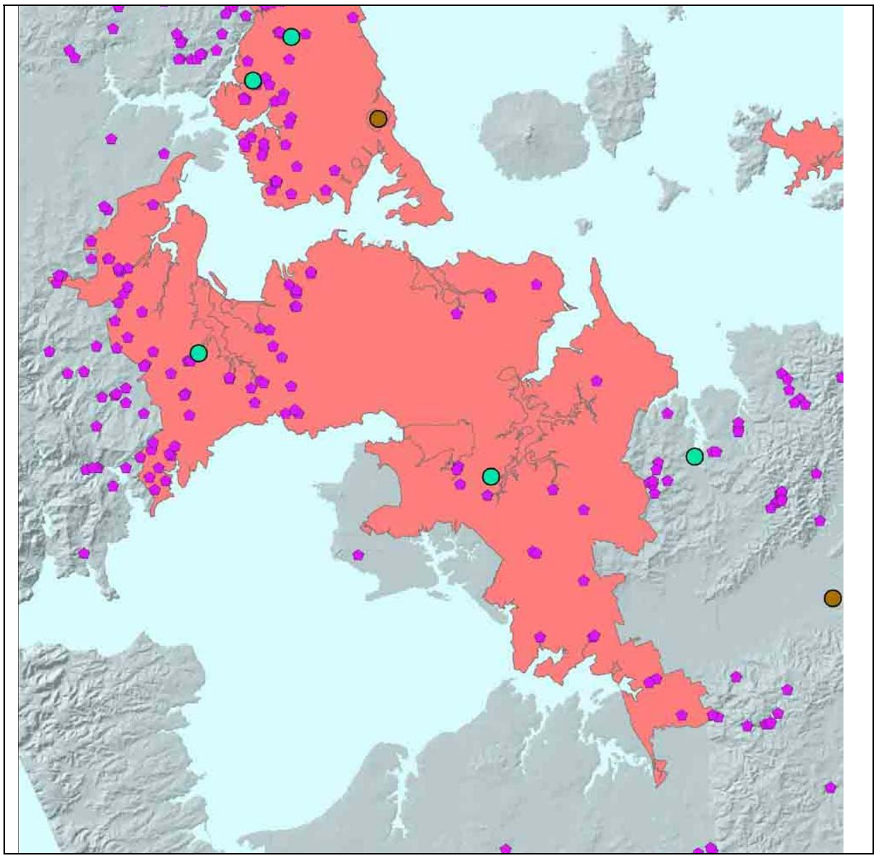

Fig. 7. Use of GIS to plot Auckland freshwater fish species (from map NZMS260 R11) given the threat classification of "gradual decline" by the Department of Conservation (green = giant kokopu, purple = longfinned eels) or given RMA and Fish and Game protection (brown = rainbow trout).

Maps showing records of important fish species in areas as large as entire NZMS260 topographic maps (Fig. 7) can be useful for providing an idea of the scarcity of particular fish species in a region, but more site-specific and detailed information would be required by the Fire Service or council to determine if important fish species have been recorded from a specific catchment. Fish locations from the database need to be placed onto maps of fine enough scale to show layouts of streets and watercourses, again using GIS software. Maps at city scale (Fig. 8 showing Waitakere City) or suburb or subcatchment scale (Fig. 9 showing the Glen Eden area) allow greater amounts of information to be displayed, including the locations of all fish records, with species information for every site.

Maps showing areas zoned by the city or district council as "commercial" or "industrial" (Figs 8 and 9) would provide additional information relating to the possible severity of pollution risk. It is generally recognised that residential house fires carry relatively less risk of fire-water-carried pollution compared with commercial/industrial property fires (Peter Wilding, Waitakere City District Deputy Chief Fire Officer, pers, comm.). All the ARC fire-water pollution incidents detailed in section 5.1 of this report involved commercial/industrial properties.

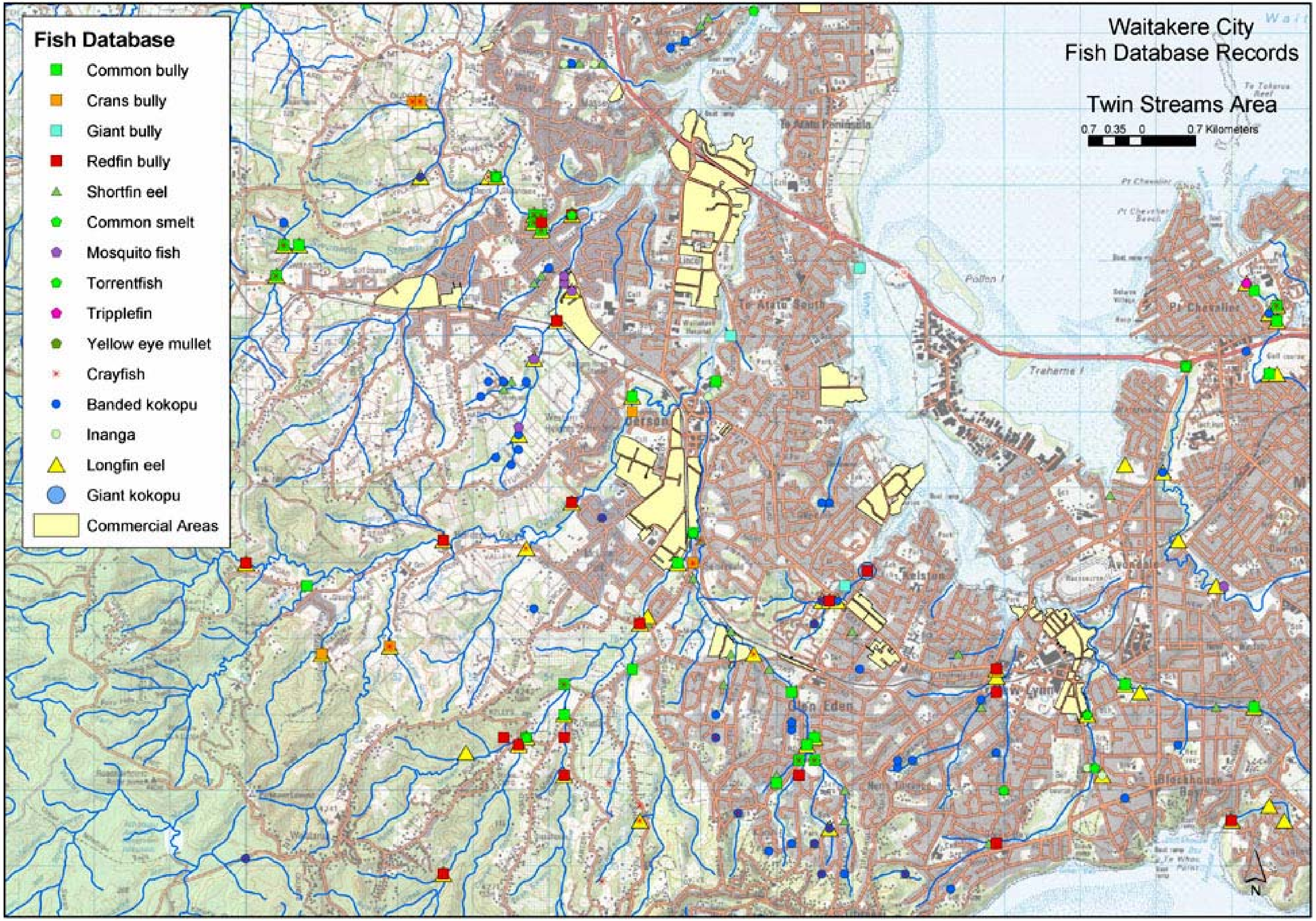

Fig. 8. Waitakere City freshwater fish distribution, showing examples of species recorded at all sites listed on the NIWA National Freshwater Fish Database, plotted with GIS. Commercial/industrial zone information from Waitakere City Council. Road, topography and stream detail obtained from map NZMS260 R11 (stream detail has been enhanced).

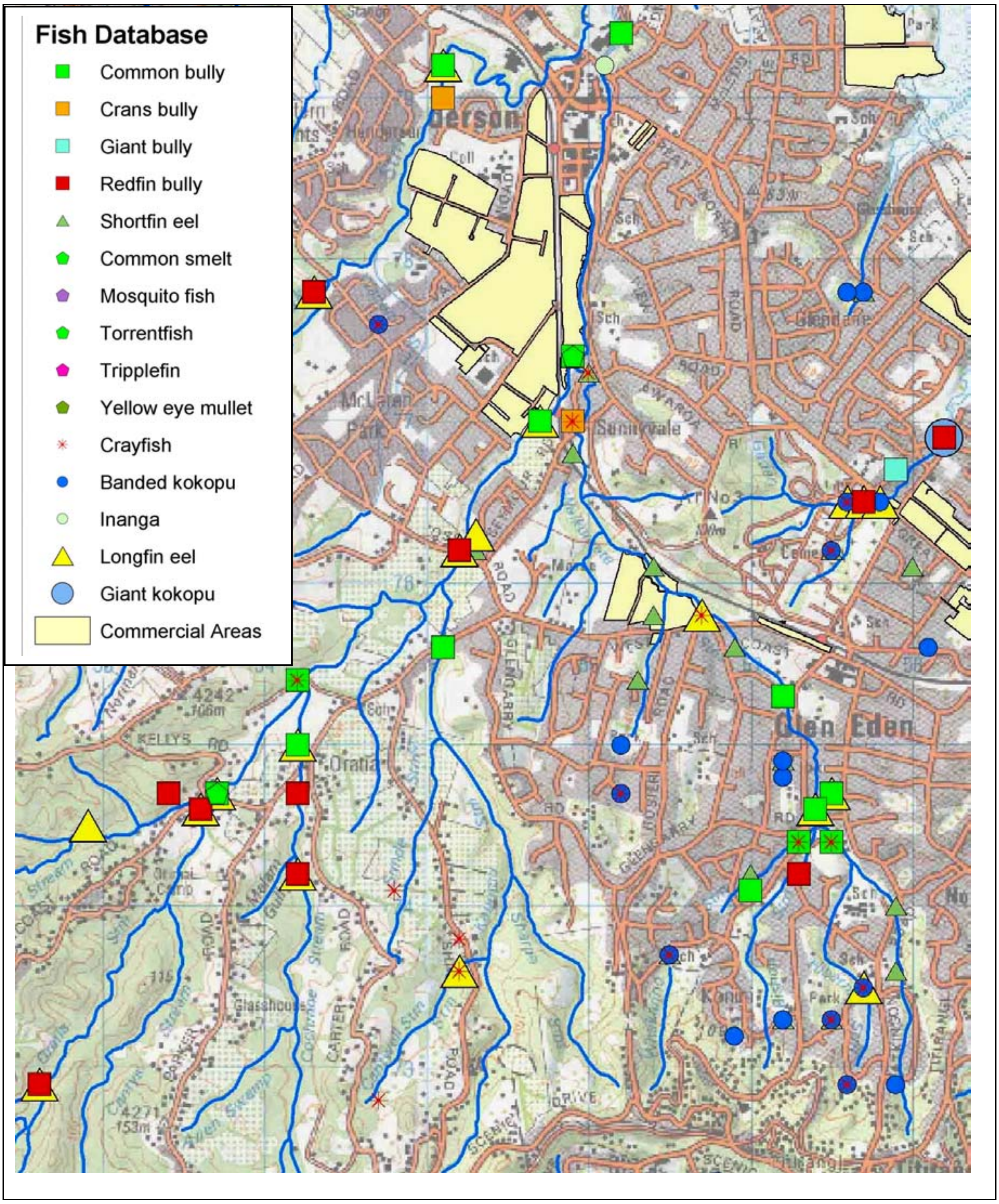

Fig. 9. Oratia and Waikumete Stream (Glen Eden area, Waitakere City) fish distribution, showing examples of species recorded at all sites listed on the NIWA National Freshwater Fish Database, plotted with GIS. Commercial/industrial zone information from Waitakere City Council. Road, topography and stream detail obtained from map NZMS260 R11 (stream detail has been enhanced).

Several organisations could help the Fire Service map watercourses supporting important fish habitats, either to compile a database for referral in future fire incidents, or when more information is needed about a receiving water below a particular fire scene. Stream resource priority lists have been prepared by some organisations, for example:

- the Otago Regional Council prepared lists of valuable streams (for human use and for biological reasons) during the preparation of their regional water plan;

- the Auckland Regional Council propose to give extra protection to perennial streams (permanent or "Category 1" habitats);
- some organisations keep records of the locations of important native fish spawning sites (e.g., Wellington Regional Council and Otago Department of Conservation);
- Fish and Game offices around the country may have priority lists of streams of importance to anglers or for trout and salmon spawning.

Such information sources could provide important data not found on the NIWA fish database, and therefore maps similar to Fig. 9 could display additional layers of information such as spawning sites gathered from these organisations.

In many areas, Council stormwater drainage plans can be obtained by the Fire Service or council pollution control officers and these can be used to track the likely flow path of fire-water. These plans show the layout of underground stormwater pipes, and where these pipes enter the receiving water body. Once the receiving water is confirmed, the relevant fish database records can be obtained.

Stormwater drainage plans may show opportunities to intercept fire-water if it is thought to carry serious pollutants, as illustrated in the ARC files on the Rentokil Initial Ltd fire response (Section 5.1). In the example shown in Fig. 10, the Waitakere City Council stormwater network map for an urban area near Henderson in Waitakere City clearly shows the stormwater pathway from the site of a hypothetical fire in Monroe Road. Among the potential interception points are manholes, surface drains and treatment ponds where there may be opportunities to bring in sucker trucks to pump out contaminated water. In the Monroe Road example, the plans indicate two ponds downstream of the fire scene, one above and one below Lucienne Drive. Ponds could provide suitable locations for the deployment of booms and absorbent materials to intercept contaminants, as well as easy access for sucker trucks to intercept contaminated fire-water. Pond outlets can sometimes be temporarily blocked (a tactic used in the Carter Holt Harvey ponds, section 5.1) to allow extra time for sucker trucks to remove contaminants.

The eventual receiving water for the Monroe Road site is the Paremuka Stream, and there are fish database records of longfinned eels (a species classified as being in decline) downstream of the stormwater outlet (Fig. 10). While longfinned eels are listed as being in decline, Fig. 7 suggests they are much more common than giant kokopu in the Auckland region. If the database had shown a giant kokopu record in the Paremuka Stream below the stormwater outfall, the ARC and Department of Conservation would probably have been particularly concerned about any contaminants being carried into the stream by fire-water.

The limited amount of fish data from the Paremuka Stream will be in part due to the limited number of fish surveys carried out in the stream. This is often the case because there are thousands of urban streams in New Zealand, and relatively few organisations carrying out fish surveys. A lack of records of species other than eels does not necessarily mean there are no other species in the stream.

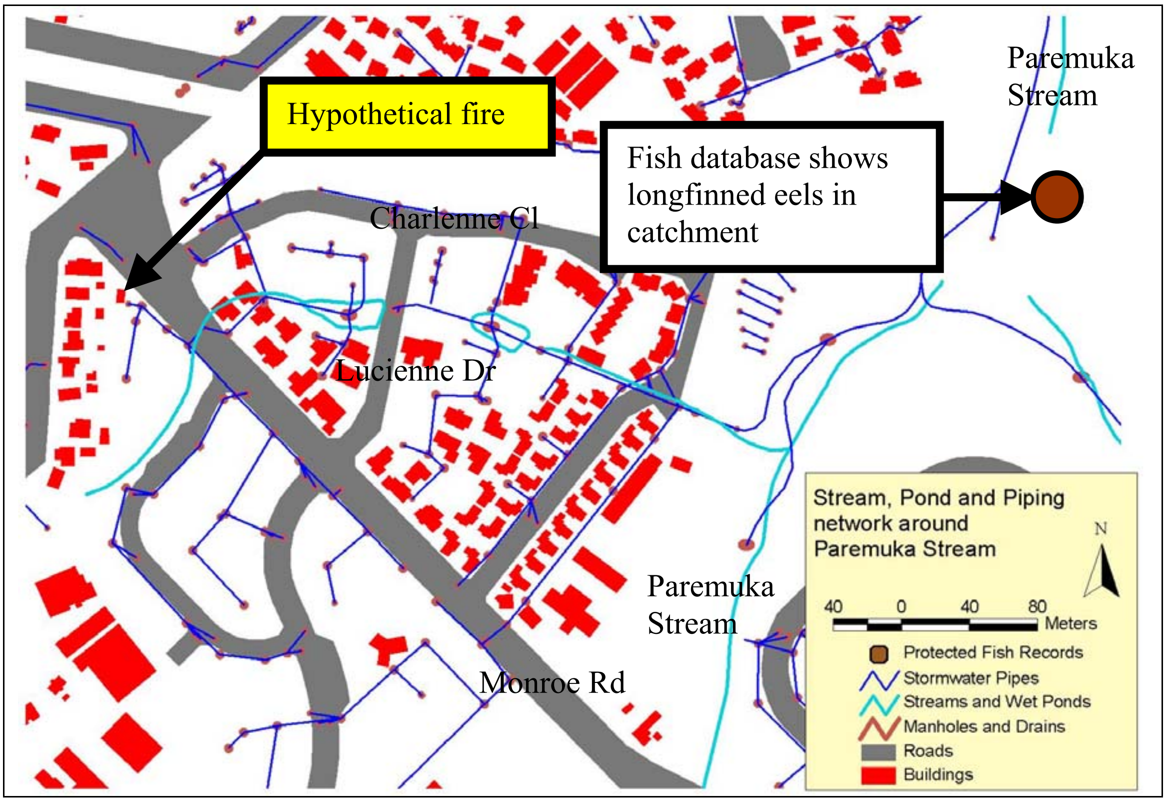

Fig. 10. Use of GIS to show the site of a hypothetical fire, in relation to roads, buildings, stormwater drainage layout, receiving water (Paremuka Stream) and fish database records. Map generated primarily using Waitakere City Council data, with fish data from the NIWA National Freshwater Fish Database.

Some fish species given threat classifications by the Department of Conservation are known to occur in or near many urban areas. Longfinned eels and giant kokopu are given the category of "gradual decline" and lamprey are given the category of "sparse" but these species have been recorded in or near most New Zealand cities. The introduced brown and/or rainbow trout, (protected by Fish and Game regulations), also appear on the fish database in or near all cities (though rarely around Auckland). Other species given some threat classification or Fish and Game protection occur in or near urban areas in different parts of the country, for example:

- streams in or near most North Island cities may support shortjawed and/or giant kokopu;
- streams in or near Hamilton may support black mudfish;
- streams in or near Palmerston North may support brown mudfish;
- streams in or near Wellington may support brown mudfish, or dwarf galaxias;
- streams in or near Christchurch may support Canterbury mudfish, or salmon;
- streams in or near Dunedin/Mosgiel may support Eldon's galaxiid, or salmon.

6. Conclusions

6.1. Review of past fire-water pollution incidents

Regional council records of fire-related pollution incidents concentrate on those from industrial complexes where other contaminants occur on site. There were none that recognised that fire-water from fires of non-industrial buildings can also carry significant levels of toxic compounds as shown by our analyses of fire-water collected from controlled burns.

The case studies located reflect the wide diversity of contaminants that can be carried by fire-water from industrial complexes or vehicles, into stormwater systems and eventually to streams. Fire-water can flood chemical storage containers and flush spilt contaminants or burnt material into stormwater systems. Most of the fire-water pollution incident files obtained during this study described fire-water discharges that quickly reached small streams, although some of these receiving waters were close to the confluence with much larger rivers or estuaries, reflecting the close proximity of Auckland urban areas to estuaries.

Fire-water could be hazardous even without any contaminants because of the potential heat of water draining from a fire scene. The potential for fire-water heat and toxicity to cause problems in receiving waters will relate to the concentrations of contaminants and the temperature of water leaving the fire scene, the duration of fire-water discharge, any dilution from other stormwater or groundwater sources, and the dilution provided by the receiving waters. The sensitivity of the receiving environment will also vary from place to place, depending on the quality of the habitat and the types of aquatic species present.

Observations made in the regional council pollution files, and by us during Fire Service Exercises, highlight where the Fire Service could modify their activities to minimise the potential for adverse effects on the environment. High-pressure water delivery can extinguish some fires with such a small amount of water that there is almost no fire-water discharge from the scene. The diversion of fire-water over land, to safe storage areas (allowing pumping to waster trucks) or to sewer lines (with permission of the relevant wastewater management authority) should be considered if site conditions permit. In some cases temporary and specially designed filtration devices could be fitted into stormwater collection areas or sumps to reduce contaminant levels in water escaping to the environment.

The case studies show the importance of speed in pollution control responses therefore we recommend on-going liaison between the Fire Service and regional council and city/district council personnel, to ensure the Fire Service has all necessary contact details for council staff, sucker truck operators, and suppliers of potential bunding materials such as sand, sawdust or soil. Because the Fire Service is likely to be on the scene before council pollution control officers, it could be beneficial for Fire Service vehicles to carry some contaminant-soaking, non-reactive apparatus such as oil/chemical absorbent pads/pillows.

6.2. The nature of fire-water collected from control burns

Fire-water collected from both control burns had levels of toxic compounds and heavy metals much higher than those previously reported for house fires in New Zealand and higher than freshwater quality criteria. This suggests that fire-water from house fires should be prevented from entering stormwater systems whenever possible.

The management of the St Mary's School lounge-room scenarios was very toxic to mayflies in an undiluted form, causing significant mortality within 24 hrs. We could not properly assess the aquatic toxicity of the three foam samples due to the concentration of detergent remaining in the fire-water causing significant foaming in the toxicity test (however, Adams and Simmons (1999) suggest foams are toxic in aquatic ecosystems). Although contaminant levels varied, there were no distinguishable differences in aquatic toxicity of fire-water generated from either low or high-pressure hoses. At a higher dilution it may have been possible to distinguish differences between the treatments; however, since each lounge-room scenario was unique, any differences in toxicity of the resulting fire-water would be driven by the materials that were burnt and the dilution (i.e. the quantity of fire-water remaining as surface water. The water collected from the hose down following burn 5 was less toxic, presumably due to a dilution effect of the hose down water. The water collected from the final burn was very dilute, and did not cause acute toxicity in the mayfly tests.

All three samples from the Waiuku fires were highly toxic to mayflies, with samples from the bathroom and lounge fires causing 100% mortality within 24 hr, while the bedroom fire sample showed gradual, but still 100% (or almost) mortality within 96 hr. Filtering the samples had no effect on mortality.

All the St Mary's School samples contained mainly metals, except for the low pressure burn sample, which also contained phenolic compounds. The only compounds that possibly occurred in higher concentrations in the more toxic samples were copper and nickel, but no other metals showed any particular trend. Only very low concentrations of PAHs were found in any of these samples, suggesting toxicity was more likely due to the metal levels in the samples rather than to the organic contaminants. This is further supported by the lack of toxicity observed in the final burn sample, despite it containing a large array of PAHs, including phenanthrene, which had an HI of 335.

When comparing the Waiuku fire-water samples with the St Mary's School fire-water samples it was evident that the Waiuku fire-water samples contained much higher levels of metals than were found in the St Mary's fire-water samples. However, for the organics this was not the case, except for the phenolic compounds, which were the highest in the bathroom sample. Despite the lounge sample containing a huge array of organic compounds, in most cases these were at lower concentrations than those found in the final burn sample from St Mary's School. The presence of the large array of chemicals is likely due to it being essentially a final burn sample, i.e. it was collected by flushing out the house after the final fire was put out.

6.3. Mapping the distribution of important fish species at risk of fire-water pollution

This report has shown how maps can be created with sufficient urban detail to help the Fire Service pinpoint a fire scene in relation to stormwater networks and likely fish habitat values. The Fire Service and Council pollution control officers can use such maps to assess the likely significance of fish populations affected by a discharge, and to locate opportunities to intercept contaminants.

7. Recommendations

- Because of the likelihood fire-water will contain toxic compounds, it Fire-water should be prevented from entering stormwater systems whenever possible. This also includes fire-water that might be generated after the fire is extinguished and during post-fire site cleanup.

- As chemical foam fire suppressants can be toxic in aquatic ecosystems (Adams & Simmons 1999), fire-water containing foam should be prevented from reaching waterways.
- Techniques to achieve these outcomes might include the following:
    a. divert fire-water from stormwater systems and pond fire-water to allow removal by sucker trucks or discharge to tradewaste;
    b. use oil/chemical absorbent pads, booms, sand, sawdust, zeolite, etc., capable of soaking up spillages, and hay bales as temporary filters;
    c. use stormwater network maps to identify possibilities to intercept and remove contaminants;
    d. give higher priority to preventing the discharge of contaminated fire-water to receiving waters that offer little dilution;
    e. use of earth dams (in serious cases, and with regional council approval) in streams to retain significant pollutants for removal by sucker trucks.
- Further research should be directed at the following:
    a. determining levels of contamination occurring under smoke plumes from fires;
    b. determining levels and persistence of soil contamination at the fire scene;
    c. designing filtration devices that could be placed in stormwater drains immediately Fire Service personnel arrive at a fire scene;
    d. developing effective systems or means to inform Fire Service personnel when a fire scene connects to a stream network of high environmental sensitivity;
    e. more detailed studies of the effect of fire suppressant foams and fire retardants on New Zealand ecosystems would be warranted if enhanced use of these technologies gains favour.

8. Acknowledgements

We thank Simon Davis and Jonathan Shelley from the New Zealand Fire Service for their assistance with the project and particularly with the controlled burns. We also thank Veronica McLeod, Denise Jones, Katherine Trought and Marcos Garcia for technical assistance in the laboratory.

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Appendix 1a. Concentrations (mg/L) of chemical analytes in fire-water samples from St Mary's School.

Analyte	Foam control*	Foam 1*	Foam 2*	High Pressure	Hose down after Low Pressure 1	Low Pressure 2	Final burn	Tap water Control
Ammoniacal-N	<LD (0.11)	0.16 (16.1)	0.182 (18.2)	8.82	1.51	21.6	2.97	0.02
Cyanide	<LD	<LD (0.04)	<LD (0.02)	0.138	0.007	0.01	0.046	0.001
Arsenic	<LD	<LD (0.07)	<LD (0.06)	0.04	0.007	0.06	0.08	<LD
Cadmium	<LD (0.0017)	0.0007 (0.07)	0.0009(0.094)	0.0176	0.0209	0.0565	0.0024	<LD
Copper	<LD (0.0067)	0.001 (0.127)	0.0011 (0.11)	0.112	0.029	0.111	0.042	0.0036
Nickel	<LD (0.0006)	<LD (0.026)	<LD (0.043)	0.018	0.0052	0.011	0.0011	<LD
Lead	<LD (0.002)	0.01 (0.991)	0.056 (5.6)	1.26	2.9	16.1	1.53	0.0008
Zinc	<LD (0.049)	0.0185 (1.85)	0.0454 (4.54)	2.46	4.75	10	3.07	0.15
Naphthalene	<LD	<LD (0.46)	<LD (0.05)	<LD	<LD	<LD	0.02	<LD
2-methylnaphthalene	<LD	<LD (0.027)	<LD	<LD	<LD	<LD	<LD	<LD
Acenaphthylene	<LD	<LD (0.436)	<LD (0.044)	<LD	<LD	<LD	0.023	<LD
Dibenzofuran	<LD	<LD (0.09)	<LD (0.01)	<LD	<LD	<LD	<LD	<LD
Fluorene	<LD	<LD (0.108)	<LD (0.015)	<LD	<LD	<LD	0.008	<LD
Phenanthrene	<LD	0.010 (1.01)	<LD (0.143)	0.049	0.04	<LD	0.134	<LD
Anthracene	<LD	<LD (0.238)	<LD (0.028)	<LD	0.006	<LD	0.03	<LD
Fluoranthene	<LD	<LD (0.342)	<LD (0.047)	0.025	0.016	0.008	0.157	<LD
Pyrene	<LD	<LD (0.331)	<LD (0.043)	0.021	0.016	0.006	0.172	<LD
Benzo[a]anthracene	<LD	<LD (0.043)	<LD	0.009	<LD	<LD	0.033	<LD
Chrysene	<LD	<LD (0.035)	<LD	0.007	<LD	<LD	0.029	<LD
Benzo[b]fluoranthene	<LD	<LD (0.035)	<LD	0.009	0.006	<LD	0.043	<LD
Benzo[k]fluoranthene	<LD	<LD (0.007)	<LD	<LD	<LD	<LD	0.013	<LD
Benzo[a]pyrene	<LD	<LD (0.026)	<LD	0.006	<LD	<LD	0.049	<LD
Indeno(1,2,3-c,d)pyrene	<LD	<LD (0.018)	<LD	0.005	<LD	<LD	0.042	<LD
Benzo[g,h,i]perylene	<LD	<LD (0.015)	<LD	<LD	<LD	<LD	0.053	<LD
Di-n-butylphthalate	<LD	<LD (0.03)	<LD	<LD	<LD	<LD	<LD	<LD

Phenol	<LD	0.082 (8.2)	0.028 (2.8)	1.46	0.62	1.9	0.33	<LD
2-methylphenol	<LD	<LD (0.39)	<LD (0.23)	0.13	0.13	0.44	0.09	<LD
3&4-methylphenol	<LD	<LD (0.49)	<LD (0.15)	0.29	0.22	0.83	0.08	<LD
2,4-dimethylphenol	<LD	<LD	<LD	<LD	<LD	0.21	0.05	<LD

* analyte concentration in diluted sample used in toxicity tests (concentration in undiluted sample given in brackets)
<LD = below detection limit

Appendix 1b. Concentrations (mg/L) of chemical analytes in fire-water samples from the Waiuku fire.

Analyte	Fire hose control	Bedroom (unfiltered)	Bedroom (filtered)	Bathroom (unfiltered)	Bathroom (filtered)	Lounge (unfiltered)	Lounge (unfiltered)
Ammoniacal N	0.02	2.39	2.85	44.7	43.7	11.9	13.1
Cyanide	0.04	0.385	0.233	<LD	0.002	0.591	0.496
Arsenic	<LD	0.506	0.297	0.72	0.548	0.11	0.1
Cadmium	<LD	0.00123	0.00011	0.325	0.257	0.0279	0.0225
Copper	0.0104	0.147	0.0512	8.06	5.49	0.423	0.334
Nickel	0.0037	0.0572	0.017	0.598	0.477	0.039	0.0361
Lead	0.002	3.08	0.0573	3.31	1.71	1.34	0.863
Zinc	0.016	1.21	0.02	23.2	19.3	4.56	4.4
Naphthalene	<LD	<LD	<LD	0.07	0.024	0.0298	0.0106
2-methylnaphthalene	<LD	<LD	<LD	<LD	0.03	0.0014	<LD
Acenaphthylene	<LD	0.0004	<LD	0.05	0.023	0.023	0.0065
Acenaphthene	<LD	<LD	<LD	<LD	<LD	0.0005	<LD
Dibenzofuran	<LD	<LD	<LD	<LD	<LD	0.0032	<LD
Fluorene	<LD	<LD	<LD	<LD	<LD	0.0041	0.0009
Phenanthrene	<LD	0.0005	<LD	<LD	0.006	0.03	0.0135
Anthracene	<LD	<LD	<LD	<LD	<LD	0.0044	0.0024
Fluoranthene	<LD	<LD	<LD	<LD	<LD	0.0107	0.0036
Pyrene	<LD	<LD	<LD	<LD	<LD	0.0079	0.0025
Benzo[a]anthracene	<LD	<LD	<LD	<LD	<LD	0.0012	<LD
Chrysene	<LD	<LD	<LD	<LD	<LD	0.0012	<LD

Benzo[b]fluoranthene	<LD	<LD	<LD	<LD	<LD	0.0008	<LD
Benzo[k]fluoranthene	<LD	<LD	<LD	<LD	<LD	<LD	<LD
Benzo[a]pyrene	<LD	<LD	<LD	<LD	<LD	0.0006	<LD
Indeno(1,2,3-c,d)pyrene	<LD	<LD	<LD	<LD	<LD	0.0004	<LD
Benzo[g,h,i]perylene	<LD	<LD	<LD	<LD	<LD	0.0003	<LD
Dimethylphthalate	<LD	<LD	<LD	<LD	<LD	0.001	<LD
Diethylphthalate	<LD	<LD	<LD	<LD	0.02	0.004	<LD
Di-n-butylpthalate	<LD	<LD	0.005	<LD	<LD	0.01	0.043
Bis(2-ethylhexyl)phthalate	<LD	<LD	<LD	<LD	<LD	0.013	<LD
Butylbenzylphthalate	<LD	<LD	<LD	<LD	0.02	0.022	<LD
Phenol	<LD	0.238	0.266	6.1	4.48	2.17	0.0219
2-chlorophenol	<LD	<LD	<LD	<LD	0.02	0.01	0.91
2-methylphenol	<LD	0.012	0.03	1.3	0.86	0.11	0.094
3&4-methylphenol	<LD	0.017	0.046	2.3	1.51	0.2	0.1
2,4-dimethylphenol	<LD	0.005	<LD	0.6	0.44	0.008	0.0254

<LD = below detection limit

Appendix 2: Photos of controlled burns and case studies

a. St Mary's School Controlled Burn

Figure 1: Preparation for fire exercises at St Mary's School. Left: Second-hand furniture items ready for six simulated living room fires. Right: Mock living room set up for the first burn.

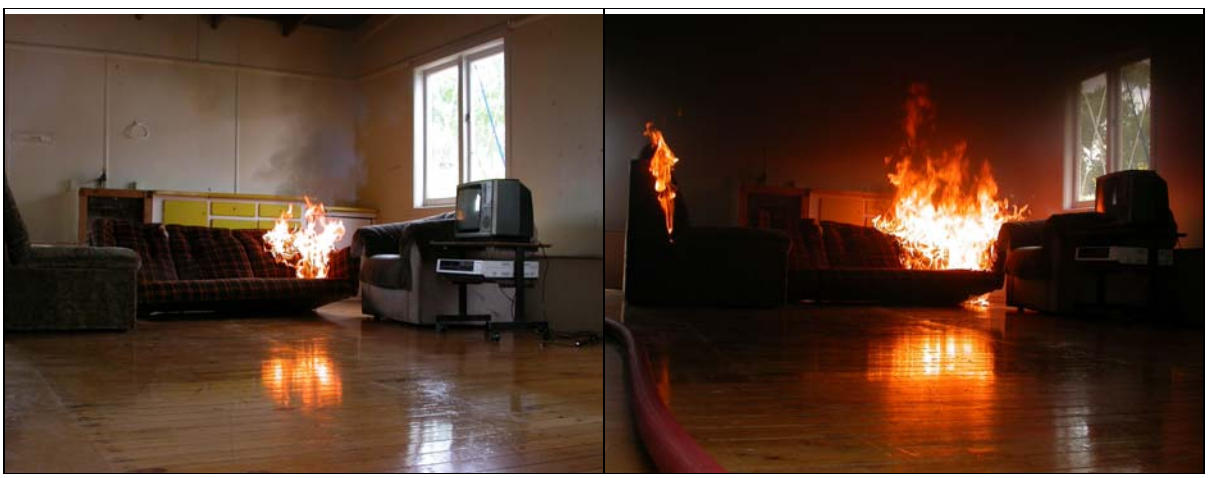

Figure 2: Mimicking a typical house fire using the St Mary's School tennis shed. Left: Fires were set to mimic a typical couch fire. Right: Mid-way through the first fire exercise, approximately one minute before this fire was extinguished.

Figure 3: Fire-water collection below the St Mary's School tennis shed. Left: Holes cut into the floor allowed collection of fire-water beneath the shed. Right: Fire-water draining into plastic bins placed below the drainage holes.

Figure 4: Fire-water collection from the St Mary's School tennis shed. Left: Fire-water flowing overland to tennis court stormwater drain (bottom right of photo). Right: Fire-water being bottled for contaminant analysis and toxicity testing.

Figure 5: St Mary’s School tennis shed burn, 22 January 2005. Left: Significant smoke plume developing during the final burn. Right: Steam and smoke generated during the latter stages of the final burn.

Figure 6: Fire-water path from the St Mary’s School tennis shed burn, 22 January 2005. Left: Fire-water flowing overland to car park stormwater system (the brown solid matter is wood chips from around the shed. Right: Final stormwater discharge to the lower Onepoto Stream, approximately 500 m downstream of the fire scene.

Figure 7: The Onepoto Stream was the receiving water for discharges of fire-water from the St Mary's School tennis shed burn, 22 January 2005. Left: Onepoto Stream at Lake Road upstream of the point where fire-water reached the stream. Right: Onepoto Stream downstream of the fire-water discharge (via the stormwater drain shown in Fig. 4).

Figure 8: The Onepoto Stream downstream of discharges of fire-water from the St Mary's School tennis shed burn, 22 January 2005. Left; Soot visible in backwaters. Right: Net used to collect fish fleeing downstream during the period of fire-water discharge.

Figure 9: Native fish caught fleeing downstream during the fire-water discharge in the Onepoto Stream, 22 January 2005. Left: Live common bullies. Right: Juvenile bullies that died shortly after being removed from the stream.

b. Waiuku Controlled Burn

Figure 10: Left: House at 68c Marae O Rehia Rd, Waiuku used for the second controlled burn. Right: Plastic bins placed under the bedroom to collect fire-water.

Figure 11: Left: Interior scene of bedroom fire. Right: Exterior scene of bedroom fire.

Figure 12: Left: Exterior scene of bathroom fire. Right: Controlling the final burn.

Figure 13: Left: Final burn progressing. Right: Towards the end of the final burn.

c. Case studies of pollution incidents involving fire water

Figure 14: Carter Holt Harvey Pulp & Paper fire, Penrose, 26 Dec 2003. Left: Waterlogged paper and fire-water. Right: Waterlogged paper and ash carried by fire-water to stormwater drains. (Photos: Auckland Regional Council).

Figure 15: Carter Holt Harvey Pulp & Paper fire, Penrose, Dec 2003 to January 2004. Left: Stormwater treatment ponds filled with waterlogged paper and ash. Right: Twelve days later the stormwater ponds had become anaerobic (black). (Photos: Auckland Regional Council).

Figure 16: Carter Holt Harvey Pulp & Paper stormwater ponds, after the December 2003 fire. Left: Pond filled with decomposing paper, 12 January. Right: Pond after paper sludge removed, 19 January. (Photos: Auckland Regional Council).

Figure 17: Duffett Doors, Papatoetoe, 21-Dec-03. Left: Oil drums damaged by fire. Right: Oil from leaking drums running overland. (Photos: Auckland Regional Council).

Figure 18: Duffett Doors, Papatoetoe, December 2003. Left: Oil running into a stormwater drain (leading to the Puhinui Stream). Right: White and pink absorbent pads and pillows used to soak up oil from below the stormwater outfall into a tributary just above the confluence with the Puhinui Stream. (Photos: Auckland Regional Council).

Figure 19: Colourplus paint manufacturers, Mt Roskill, 24 – 25 Jan 2002. Left: Paint manufacturing building damaged by fire. Right: Interior of building showing spilt paint likely to be flushed by fire-water. (Photos: Auckland Regional Council).

Figure 20: Colourplus paint manufacturers, Mt Roskill, 24 – 25 Jan 2002. Left: Fire-water running down driveway towards the stormwater system and stream. Right: The slow, weedy stream (a natural filter) meant the front of the fire-water travelled only 450m from the site in 18 hours. (Photos: Auckland Regional Council).

Figure 21: Otahuhu Chromeplaters Ltd, 7 – 8 May 2000. Left: Sand used as a bund and to absorb chromic acid displaced from acid baths by fire-water. Right: Stream coloured yellow by chromic acid due to the fire-water discharge (before sand bunding). (Photos: Auckland Regional Council).

Figure 22: Otahuhu Chromeplaters Ltd, 7 – 8 May 2000. Left: Construction of an earth dam in the stream to intercept contaminated fire-water. Right: Completed earth dam retaining fire-water, allowing removal of contaminated water by Chemwaste sucker trucks. (Photos: Auckland Regional Council).

Figure 23: Pacer Car Clean Products, Otahuhu, 21 March 2004. Left: Fire-water washed from the car clean property to the stormwater system leading to the Tamaki River. Right: Ash carried by fire-water to the tidally flushed Tamaki River was considered unlikely to cause significant adverse environmental effects (only aesthetic effects). (Photos: Auckland Regional Council).

Figure 24: Rentokil Initial Ltd, Onehunga, 12 June 2000. Left: Fire-water contaminated by pesticide chemicals and dye, which reached the stormwater system feeding into the Manukau Harbour. Right: Fire-water was pumped by Chemwaste from a loading bay and from the reticulated stormwater system. (Photos: Auckland Regional Council).

Figure 25: Cobham Drive, Hamilton, chemical truck fire, 23 Sept 2002. Left and right: The truck fire resulted in the spillage of a range of toxic chemicals, which entered this tributary of the Waikato River, causing a fish kill. The colour was mostly rhodamine dye (used in paints and markers for animal health products). (Photos: Environment Waikato).