Fire Research Report

The Ecotoxicity of Fire-Water Runoff
Part III: Proposed Framework for Risk Management

ESR

August 2001

Water runoff from fire scenes is generally acutely toxic to aquatic ecosystems. The magnitude of the hazards posed by different types of buildings and facilities varies substantially, depending on the size of the structure, the extent of the burn, and the materials contained within it.

The literature review for this project found that fire runoff was responsible for significant damage to surface water ecosystems in a number of overseas fires, especially those occurring at chemical manufacturing plants or storage warehouses located near rivers and streams. In-the-field sampling of common house and small business fires conducted in this project represented a significant but comparatively lower acute toxic hazard.

The literature review and field sampling of runoff in the current study are consistent with one another and assist in the setting of hazard ranking priorities for an *Ecotoxicology Risk Management Framework*. The key elements involved in the prioritisation of these hazards and risks are described in this report. The framework generally consists of the following key elements: • Hazard ranking (for facilities), • Sensitive resource identification (for ecosystems), • Risk ranking (based on geographic overlap of the above) and • Pollution prevention plans implemented for high risk sites

A wide consultation with appropriate local authorities and ecological resource managers is encouraged to form this Framework. An important aspect that would facilitate implementation of a risk management framework is the use of computer based spatial analytical tools (i.e. Geographic Information Systems) to locate critical areas for ensuring that prevention and management plans are in place.

Jefferson Fowles, Ph.D.

New Zealand Fire Service Commission Research Report Number 19
ISBN Number 0-908920-62-8

The Ecotoxic Effects of Fire-Water Runoff

Part III: Proposed Framework for Risk Management

A Report to the New Zealand Fire Service

July 2001

Jefferson Fowles, Ph.D.
Toxicologist, Population and
Environmental Health Programme, ESR

Acknowledgements

This report was prepared by ESR and the research has been funded by the New Zealand Fire Service.

ESR would like to thank Paula Beever, Bill Butzbach, Tony Haggarty, and Chris Napier of the New Zealand Fire Service, and Campbell Sturrock and Rebecca Kemp of the Auckland Regional Council. ESR also thanks the Fire Service library for their co-operation and input of information which has been valuable throughout this project.

Disclaimer

TABLE OF CONTENTS

SUMMARY

Water runoff from fire scenes is generally acutely toxic to aquatic ecosystems. The magnitude of the hazards posed by different types of buildings and facilities varies substantially, depending on the size of the structure, the extent of the burn, and the materials contained within it. A general method for identifying and prioritising hazards and risks from these events would facilitate the effective use of resources to prevent future catastrophic events occurring near sensitive aquatic areas.

The literature review for this project found that fire runoff was responsible for significant damage to surface water ecosystems in a number of overseas fires, especially those occurring at chemical manufacturing plants or storage warehouses located near rivers and streams.

The existence of agrichemicals was reported to greatly increase the hazard potential of a facility to nearby aquatic ecosystems (ESR, 2000). However, even in the absence of agrichemicals, significant toxic hazards exist for fire water run-off from all cases studied.

In the field sampling of fires conducted in this project, common house and small business fires represented a significant but comparatively lower acute toxic hazard. All five fires with runoff sampled in the course of this project were acutely toxic to aquatic life. The house fire sampled represented the lowest hazard potential in terms of the contaminants involved and the dilution factor needed to bring the chemical exposures within acceptable ranges. In all cases, the concentrations of copper and zinc were of primary concern for acute ecotoxicity. Polyaromatic hydrocarbons (PAHs) and toluene were the major contributors to the acute toxicity in specific cases. An autoshop fire contained very high levels of PAHs in addition to copper and zinc, and the volume of water needed to dilute this runoff to acceptable levels was considerable.

The literature review and field sampling of runoff in the current study are consistent with one another and assist in the setting of hazard ranking priorities for an *Ecotoxicology Risk Management Framework.*

The key elements involved in the prioritisation of these hazards and risks are described in this report, drawing upon a literature review and field sampling results in the two previous reports.

The framework generally consists of the following key elements:

- Hazard ranking (for facilities)
- Sensitive resource identification (for ecosystems)
- Risk ranking (based on geographic overlap of the above)
- Pollution prevention plans implemented for high risk sites

A wide consultation with appropriate local authorities and ecological resource managers is encouraged to form this Framework. An important aspect that would facilitate implementation of a risk management framework is the use of computer based spatial analytical tools (i.e. Geographic Information Systems) to locate critical areas for ensuring that prevention and management plans are in place.

1. PURPOSE OF THIS REPORT

This report provides a synthesis of international literature reviewed and data collected through field sampling, with a goal of forming a general framework for the management of ecological risks and hazards from fire water run-off. This report is the third in a series that includes a literature review and background to ecotoxicity concerns about fire run-off internationally, and a report of the chemicals found in run-off from five sampled fires in the Auckland area.

2. INTRODUCTION

Hundreds of structural fires occur in New Zealand every year, and many of these fires contribute some amount of contaminated water run-off that ends up in storm water or sewerage drains, and some run-off may flow directly into surface waters. The aggregate ecological damage from this run-off has not been assessed, but it is clear from case studies in the international literature, and from the field studies conducted in this project, that run-off can be an important source of acute pollution for aquatic ecosystems (ESR 2000; ESR 2001). To manage this risk, a framework is presented to help guide decision making that prioritises hazards and risks and focuses resources on preventative measures (fire safety and contingency plans). The risks need also to be assessed in the context of nearby ecosystem receptors and their susceptibility to damage from a run-off event.

The elements that would be needed for a comprehensive risk management framework are described in general terms in this report. Successful management of these types of hazards and risks would likely require the co-operation of multiple agencies as well as property owners.

Fire fighters are unlikely to have a great deal of latitude in deciding how a given fire is to be fought in ways that would reduce ecological impact. Therefore, a focus on preventative measures and emergency preparedness within each facility seems to be a much more practical solution for reducing these impacts.

Five fire scenes were sampled in the current study. While this is not a sample size that allows for a large amount of generalisation, there were some common patterns found. Field sampling of run-off from the different types of fires showed that all run-offs sampled represented an acute aquatic ecological hazard, often driven by high concentrations of copper and zinc, both being acutely ecotoxic and bioaccumulative metals. Concentrations of other chemicals in the sampled run-off from the five fires were highly specific to the type of fire. For example, polyaromatic hydrocarbons (PAHs) may drive the risk assessment concerns if petroleum-based oil material is contained in the run-off.

3. FACTORS INFLUENCING ECOTOXIC RISK

3.1 IDENTIFYING HAZARDS

There are a number of factors contributing to the assessment of ecological hazards. In general, the hazards that need to be considered are:

Structures and Facilities

- Type of facility
- Size of facility
- Safety procedures in place
- Contingency plans

Materials Contained in a Facility

- Chemical types
- Quantities
- Turnover activity

3.1.1 Structure and Facility Hazards

Some generalisations can be drawn from the field sampling of run-off in this project. It appears that in terms of facility type, small business venues pose a greater ecological risk than common house fires, and that copper and zinc are ubiquitous contaminants in fire runoff that drive the ecological risks in many cases. International case studies reviewed in Part I of this report show that, as might be expected, heavy industries, chemical industries, and large stores of plastics, tyres, and other organic materials can pose a serious threat to neighbouring waterways in the event of run-off. Chemical hazards in these facilities can include materials that are not toxic under normal conditions. The case of a fire in a large plastics storage area is an example of 'non-toxic' materials becoming an ecological hazard upon combustion and drainage of runoff into waterways (see Allied Colloids fire described in Part I of this report). There were no fires from these high-risk types of facilities sampled in the current field studies.

The hazard associated with the facility will also be a function of facility size. Larger facilities will generally require greater volumes of water and contribute more chemical material into the runoff.

The presence of up-to-date fire prevention materials (e.g. sprinkler systems, etc) and contingency plans for management of a fire significantly contribute to the reduction of ecotoxic hazard potential of the facility.

Field sampling showed that the order of hazard from five fires in various structures and venues was the following (in descending order):

Table 1. Facility Hazards from Field Sampling

Hazard Rank	Fire Scene	Key Contaminants
1	Autoshop	(PAHs, copper, zinc)
2	Fruit shop	(copper, zinc, PAHs)
3	Sports store	(copper, zinc)
4	House fire	(copper, zinc)
5	Car fire	(toluene, copper, zinc)

The provisional ranking of these facilities is based on the volume of clean water that would be required to dilute the run-off to achieve acceptable levels for all contaminants according to water quality criteria from the U.S. Environmental Protection Agency, or from Environment Canada, for acute aquatic ecotoxicity. In general, the literature review and field sampling support the ranking of hazards from structural fires in the following way:

Generalised ranking by facility type:

1 **Heavy industry**, especially agrichemical storage areas, but also including shipyards, metalworks, petroleum refineries, plastics or organic polymer manufacturing, agrichemical manufacturers, and chemical manufacturing or storage units.

2 **Light industry**, large businesses and warehouses for storage of solid materials, especially plastics

3 **Small businesses**, such as autoshops, dairies, fruit shops, and sports stores

4 **Common house fires**

5 **Vehicular fires** (vehicles transporting hazardous materials require separate consideration and would probably fall under the highest priority)

This list can be used to very broadly set priorities for fire hazards, recognising that within each general category of facility, there is a significant degree of variability in the types and magnitudes of chemical hazards that may be present. The field sampling from the current project covered fires from the three lowest hazard categories, which are also the most common in terms of total number of fires.

There are likely to be cases of high contamination risk, in which the fire should be treated and managed as a chemical incident rather than strictly as a fire. The ICI Riverview chemical store fire in Auckland in 1984 was one such example occurring in New

Zealand. Although the exposure concerns and risks following the ICI fire were, at the time, focused on human health impacts, the ecological consequences would also have been extremely high, due to the presence of agrichemicals, solvents, and other various chemicals (Elias et al,. 1990).

3.1.2 Chemical Hazards

The types of chemicals of particular concern for runoff, based on water quality criteria and acute aquatic ecotoxicity data, include the following:

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

- **Sources of cyanide**, or chemicals that can react to form cyanide (e.g. nitriles, thiocyanates).

- **Sources of metals**, especially mercuricals, but also lead, copper, zinc, and cadmium. Copper and zinc, as determined through field sampling, are fairly ubiquitous contaminants in run-off from structures, and have comparatively high ecotoxicity in aquatic systems, while their toxicity to humans is low. Copper and zinc levels may be a function of facility size.

- **Chemicals strongly affecting pH** (capable of making the pH of runoff less than 6 or greater than 9.5). This is more of a concern for chronic pollutants, but could still be damaging in an acute exposure situation.

- Sources of **ammonia**. Ammonia is highly toxic to most aquatic life.

- **Petroleum derivatives** and petroleum oils

- **Halogenated organics** (like PVC or chlorobenzenes) capable of forming halogenated dioxins and furans upon combustion.

It is important to note that although the metals, copper and zinc, in the field sampling largely drove the risk estimates for aquatic ecosystems in the current study, it may not be possible to mitigate these as hazards through safety planning (i.e. storage of materials, etc) or through controls. This is due to the ubiquitous nature of these metals in the structural materials of facilities, such as corrugated roofing.

In addition, copper and zinc, though highly acutely toxic to aquatic ecosystems, are unlikely to be 100% bioavailable, as is assumed in the water quality criteria values. Therefore, the criteria provide a conservative estimate of the true exposure and risk from these metals.

In short, it is not feasible for a facility to have a contingency plan that would eliminate or specifically reduce the presence of these particular metals in run-off. The hazards posed by these metals will generally increase as a function of the size of the structural fire. Therefore, large structures of any kind should be prioritised in some way.

Contaminants such as biocides and plastics stores are more likely to be amenable to identification and targeted intervention through reviews of storage practices and volume limits on site, compared with copper and zinc. It is recommended that prioritisation efforts concentrate on such materials and facilities initially.

3.2 FIRE SAFETY PREPAREDNESS AND CONTINGENCY PLANS

A key part of the risk management framework will include the precautions taken by a given facility to reduce risk of a fire occurring on site, and to have early warning systems in place in the event of a fire. A complete review of fire safety planning for facilities is beyond the scope of this report, but some additional information can be found in Part 1 of this report. Generally speaking, a high risk facility should have in place the following:

1. Adequate **Fire-safety systems** (sprinklers, water supplies, alarms, proper containment and storage of materials, etc).

2. **Hazard management plan** in place (runoff collection, drainage considerations, emergency management materials e.g. sandbags, booms, drain seals). If the risk assessment shows that fire-water runoff is likely to cause serious harm to the nearby environment, measures can be taken to reduce this potential impact before a fire occurs. It may be necessary to build structures that will contain the runoff, where it can then be transferred and disposed of without harm to the environment. The facility should consider if any of the following could be employed effectively to control runoff from a fire.

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

Sites posing a particularly high risk in the event of a fire-water runoff event should have sufficient plans and procedures in place to contain runoff and prevent it from flowing off-site and into a sensitive ecosystem.

3.3 Geography of the Site

Distance from the site to the waterway is an important consideration for the risk assessment. Some criterion for high vs low risk distance should be developed.

The location of the facility and geological features such as **slope** or **storm drains**, that may influence how and where the runoff drains need to be considered.

3.4 Ecological Susceptibility

Ecotoxicological risk is a function of hazard, exposure, and susceptibility of the exposed system. There are several factors that influence an aquatic ecosystem's vulnerability to harm from contaminants:

1. The **flow rate and volume** of the waterway determine the ability of the ecosystem to dilute the contamination to acceptable levels. Streams with low flow rates and volumes are particularly susceptible

2. The presence of **threatened or endangered species** is of critical importance.

3. An assessment of **existing contaminant loads**/inputs into the ecosystem should be done. Heavily impacted systems may be particularly vulnerable to damage from an acute pollution event. Alternatively, more **pristine areas** may require protection as unique resources and multiple use areas.

4. **Sediment type** and ability to adsorb contaminants. Sediment high in organic matter will tend to adsorb more organic contaminants and result in a lower bioavailability of these chemicals for exposure to aquatic life. Similarly, a high sediment clay content may indicate greater binding of ionic forms of some elements and reduce availability. Sandy sediments are likely to be the most sensitive to runoff impacts.

It is important to include consideration of ecosystem sensitivity in the implementation of a risk management strategy for runoff. It is recommended that consultation with local authorities and resource agencies, including the Department of Conservation, be included when identifying vulnerable resources.

4. USE OF FIRE FIGHTING FOAMS AND RETARDANTS

Most toxicological tests carried out on foams and retardants to date indicate little potential for long term harm (Adams and Simmons, 1999). However, both foams and retardants would be expected to have acute toxic effects on aquatic ecosystems if dilution factors are not large. There are therefore ecological and financial costs to the use of these materials, the latter of which would be expected to limit their use to only where it is necessary to control a situation for which water alone would not be sufficient. It is not expected that these materials would contribute significantly to the ecological risks of run-off.

5. A REGULATORY FRAMEWORK FOR RUNOFF MANAGEMENT

A management and planning framework could be implemented through a step by step process. This process includes fire safety considerations, ecotoxicology, and ecology. Consultations with industries, industry groups such as the Chemical Industry Council (CIC), and various agencies including Regional Councils (RC), the Department of Conservation (DOC), and the Ministry for the Environment would be necessary components of this management process. The general steps in this management scheme are illustrated below:

Figure 1. A Framework for Assessment and Management of Ecological Risks from Fire Water Run-off.

Develop Criteria
For Hazardous Facilities

Consideration of size and type of facilities, type and volume of substances present, turn-over of materials and activity at the site, and if fire safety plans are in place.

↓

Identify High Hazard Facilities

Consultation with RC*, CIC*, companies.

↓

Identify Highly Susceptible Resources

Focus on rivers, lakes, coastal habitat, and estuaries. Consult with RC and DOC*. Obtain GIS maps of these resource features.

↓

Develop a **Spatial Map** of Overlap Between Critical Hazards and Susceptible Ecosystems

Use geographic information system software to map and analyse the most high risk areas for fire safety/contingency plan inspections.

↓

Management Options

A) Notify High Risk Facilities
Encourage/require Preventative Actions
B) Develop Set of Actions to be Taken at the Scene
1. if contingency plans have been put in place to safeguard against ecological damage from run-off
2. if no contingency plan has been implemented

C) Develop set of remedial actions to be taken following the incident

Identify sites requiring inspections. Determine needs for contingency plans for each facility.

Determine if and how the fire should be fought in order to minimise collateral damage to the Ecosystem.

Document procedures for incidents. Identify any needs for environmental sampling.

Table 2. Considerations for Ranking Ecological Risks from Fire Run-off

Risk Level	*General condition*	*Specific considerations or examples*
High	Large or medium sized facilities with a lack of fire safety systems or contingency plans.	Includes chemical manufacturing or storage plants, metalworks, shipyards, industrial storage warehouses. Absence of sprinklers, alarms, proper storage plans. No pollution prevention plans.
	Facilities with high volumes of chemical storage or turnover.	e.g. over 1 tonne per week – risk varies with chemical type.
	Presence of high risk chemicals for any size facility or vehicle	agrichemicals, plastics, tyres, caustics, metals, cyanide, ammonia, petroleum products.
	Large or medium sized facilities in close proximity or that drain to waterways.	e.g. less than 100 meters from site or drain
	Any facilities near to particularly sensitive waterways.	e.g. within 100 m from a particularly sensitive waterway.
Medium	Small businesses with some fire safety systems and contingency plans.	Fruit shops, sports stores, auto shops, with old fire safety systems and no plans to contain runoff
	Small to medium sized facilities with a low turnover of chemicals/materials.	e.g. less than 200 kg per week
	Small facilities or businesses close to waterways.	Less than 100 meters from site or drain.
Low	Domestic houses close to waterways.	
	Large facilities beyond critical distance from sensitive areas.	e.g. over 100 meters from site or drain
	Large facilities with extensive contingency plans and fire safety systems.	Presence of containment systems, bunds, etc. Modern fire safety systems.
	Car fires	

6. CONCLUSIONS

Based upon what is known about the ecotoxicity of chemical contaminants and of fire incidents where ecological impacts have been identified, it may be concluded that fire-water runoff can pose a threat to nearby aquatic environments. In cases of large industrial fires, it has been shown that rivers, streams, and lakes near to large fires bear the brunt of the ecological impact, and can sustain long-lasting damage. For most common house fires, this threat is comparatively minor. However, there is a real threat to aquatic systems from industrial fires and some fires from small businesses can also produce highly toxic runoff.

The type and magnitude of damage that occurs from fire runoff is a complex product of the size and type of facility, the emergency planning measures in place, and the location of the fire with respect to susceptible ecological resources.

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

The use of GIS software to spatially analyse the overlap between facility hazards and sensitive ecosystems is likely to be the most efficient and systematic way to implement the risk assessment/prioritisation process.

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

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

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

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

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

There is clearly a need for industries themselves to actively manage these risks, and for authorities to ensure that the highest-risk facilities are prioritised and made aware of the risks involved.

7. REFERENCES

Adams R and Simmons D. 1999. Ecological effects of fire fighting foams and retardants. Paper presented at Bushfire ’99 conference Albury, Australia. July 1999.

Elias S, Bandaranayake DR, Edwards IR, and Glass WI. 1990. The Health Consequences of the ICI Fire. New Zealand Department of Health. Wellington.

Institute of Environmental Science and Research (ESR). 2000. The ecotoxic effects of fire-water runoff: Part 1 – Review of the literature. A report for the New Zealand Fire Service. October 2000.

Institute of Environmental Science and Research (ESR). 2001. The ecotoxic effects of fire-water runoff: Part 2 – Analytical results. A report for the New Zealand Fire Service. March 2001.