Fire Fighting Water:  
A Review of Fire Fighting Water Requirements  
A New Zealand Perspective

by
Simon Davis

Supervised by
Dr Charley Fleischmann

Fire Engineering Research Report 00/3  
March 2000

This report was presented as a project report as part of the  
M.E. (Fire) degree at the University of Canterbury

School of Engineering  
University of Canterbury  
Private Bag 4800  
Christchurch, New Zealand

Phone 643 364-2250  
Fax  643 364-2758  
www.civil.canterbury.ac.nz
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School of Engineering
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Private Bag 4800
Christchurch, New Zealand
Phone 643 366 7001
Fax 643 364 2758
ABSTRACT

This paper seeks to identify a linkage between the requirements for fire fighting water and building design. This paper reviews existing methods to calculate fire fighting water requirements and comments on their applicability in the context of fire service tactics.

Defining what constitutes an adequate supply of water for fire fighting is also central to planning fire service operations.

The provision of water for fire fighting operations is a significant infrastructure cost borne by the community as the fire fighting requirements dominates the sizing of the network elements.

This paper reviews work undertaken to date and seeks to offer a methodology that supports the fire engineering approach being adopted in performance based building codes.
ACKNOWLEDGEMENTS

I would like to thank the following people who have assisted in the gathering of information for this report and those who have assisted me in completing my second part time Masters course.

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- Pat Roddick at the University of Canterbury Engineering Library.

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- To my fellow part time students in Auckland who despite holding down a full time job and family made the last four years very interesting and stimulating.

- And finally my wife Janet, and children Catherine, Timothy and Emma who have put up with me burying my nose in a textbook for the last seven years.
# Table of Contents

ABSTRACT...................................................................................................................................... i
ACKNOWLEDGEMENTS ................................................................................................................... iii
Table of Contents ............................................................................................................................ iv
List of Figures .................................................................................................................................... vi
List of Tables ..................................................................................................................................... vi

## CHAPTER 1 INTRODUCTION

1.1 Overview ................................................................................................................................... 1
1.2 Implications of Determining Fire Fighting Water Requirements .............................................. 1

## CHAPTER 2 WATER SUPPLIES

2.1 Introduction .............................................................................................................................. 3
2.1.1 Cost ........................................................................................................................................ 3
2.1.2 Reliability ............................................................................................................................. 4
2.1.3 Quality .................................................................................................................................. 4
2.1.4 Water Demand .................................................................................................................... 5
2.1.5 Access ................................................................................................................................... 7
2.2 Historical development ............................................................................................................ 8
2.3 Non Reticulated Water Supplies .............................................................................................. 9
2.3.1 Water Shuttle Vs pumped relays ....................................................................................... 10
2.3.2 Cisterns ................................................................................................................................ 10
2.4 Water Supply Classification ..................................................................................................... 10
2.4.1 American Water Works Association .................................................................................. 10

## CHAPTER 3 LEGISLATION

3.1 Introduction .............................................................................................................................. 11
3.2 Fire Service Act 1975 ............................................................................................................... 11
3.3 Building Act ........................................................................................................................... 12
3.4 Resource Management Act .................................................................................................. 14
3.5 Local Government Legislation and NZ Standards ................................................................. 15

## CHAPTER 4 EXTINGUISHING MECHANISM OF WATER

4.1 Introduction .............................................................................................................................. 17
4.2 Extinguishment Mechanisms ................................................................................................ 18
4.2.1 Fuel Surface Cooling ......................................................................................................... 21
4.2.2 Flame Zone Cooling .......................................................................................................... 21
4.2.3 Inerting ................................................................................................................................ 22

## CHAPTER 5 METHODOLOGY

5.1 Introduction .............................................................................................................................. 23
5.1.1 Fire Engineering Methodology ......................................................................................... 23

## CHAPTER 6 FIRE SIZE DETERMINATION

6.1 Introduction .............................................................................................................................. 25
6.2 Background ............................................................................................................................ 26
6.3 Fire Modeling .......................................................................................................................... 29
6.3.1 Introduction ....................................................................................................................... 29
6.3.2 t^2 growth fires ............................................................................................................... 30
6.3.3 Other Fire Models ............................................................................................................ 31
6.4 Firecell Size Limitation .......................................................................................................... 35
6.5 Large Single Story buildings ................................................................................................ 37
6.5.1 Veg Pak ............................................................................................................................ 38
6.5.2 ATCO .................................................................................................................................. 38
6.5.3 New Zealand Safety ......................................................................................................... 39

## CHAPTER 7 FIRE SERVICE INTERVENTION

7.1 Introduction: Fire Brigade Response ..................................................................................... 40
7.2 Planning ................................................................................................................................... 40
7.3 Dispatch ................................................................................................................................... 42
7.4 Operations .............................................................................................................................. 43
7.4.1 Introduction ....................................................................................................................... 43
7.4.2 Operations - Historical .................................................................................................... 44
7.4.3 Tactics .................................................................................................................................. 45
7.4.3.1 Maneuverability .......................................................................................................... 46
List of Figures

Figure 2.1: Time all Fires Occur vs. Maximum Water Usage .......................................................... 6
Figure 4.1: Droplet surface area Vs droplet diameter ...................................................................... 17
Figure 4.2: Theoretical cooling power of water .................................................................................. 19
Figure 6.1: Typical fire progression (stylised) .................................................................................... 25
Figure 6.2: How fire service alerted .................................................................................................. 27
Figure 6.3: Heat release rate Vs ventilation factor .............................................................................. 35
Figure 8.1: Building floor area Vs Water flow requirements ............................................................ 58
Figure 8.2: Comparison of water flow Vs area (0–100 m²) ................................................................. 63
Figure 8.3: Comparison of water flow Vs area (100–2000 m²) ......................................................... 63
Figure 8.5: Types of property involved in fire .................................................................................... 70
Figure 8.6: Incidents handled by fire service ..................................................................................... 71
Figure 8.7: Fire incident breakdown .................................................................................................. 72
Figure 8.8: How structure fires extinguished ..................................................................................... 73
Figure 8.9: Water flow rates used to extinguish all fires .................................................................... 74
Figure 9.1: Comparison of Empirical Methods .................................................................................. 81
Table 9.1: $K_1$ Human Intervention ................................................................................................. 84
Table 9.2: $K_2$ Fire Safety features ...................................................................................................... 84

List of Tables

Table 2.1: Number and Location of where fires occur (Rural and Urban Fires) ............................... 6
Table 2.2: Fires in rural areas ............................................................................................................ 9
Table 3.1: Fire Damage due to Radiation Exposure onto Neighbouring property ............................. 14
Table 4.1: Variation of critical water application rate with fire surface area ...................................... 20
Table 6.1: Heat output from $t^2$ fires (MW) ..................................................................................... 31
Table 6.2: Heat output from $t^2$ fires (MW) ..................................................................................... 34
Table 6.3: Firecell Floor Area Limitations ......................................................................................... 36
Table 6.4: Fire Cell Floor Area Limitation (m²) .................................................................................. 37
Table 7.1: Water supply classification table ..................................................................................... 44
Table 7.2: Flow and Pressure characteristics of NZFS hose ............................................................. 49
Table 8.1: NZFS fire fighting water usage .......................................................................................... 53
Table 8.2: Number of fire streams per head of population ................................................................. 53
Table 8.3: ISO Grading Scale ............................................................................................................. 55
Table 8.4: Building Construction Factor ............................................................................................ 57
Table 8.5: Building Occupancy Factor .............................................................................................. 57
Table 8.6: Fire fighting resources based on water supply ................................................................. 60
Table 8.7: Maximum fire cell size based on water supply ................................................................. 61
Table 8.8: Correlation of fire data ...................................................................................................... 62
Table 8.9: Efficiency factors of varying fire service waterway equipment ........................................ 64
Table 8.10: Water Supply Coefficient – $K_1$ .................................................................................... 66
Table 8.11: Minimum Water Supply Flow Rates, Ontario Building Code ......................................... 66
Table 8.12: NZFS incident callouts .................................................................................................. 75
Table 8.13: Experimental suppression tests ....................................................................................... 76
Table 9.1: Water Classification Table ................................................................................................. 85
CHAPTER 1 INTRODUCTION

1.1 Overview

This report seeks to investigate the linkage between building type, the expected fire size within that building and the required water supply to extinguish that fire. From this a more definitive method for calculating fire fighting water requirement can be established.

Water is the most common fire-extinguishing agent used due to its abundance, low cost and effectiveness. In urban areas, water is usually provided via a reticulated underground pipe network. Hydrants are placed in this network to gain access for fire fighting purposes. The localised water quantity and flow associated with fire fighting far exceeds the water draw off required for other purposes. Thus the fire fighting requirements dictates the sizing of a reticulated supply. Rabash (1985) commented that fire authorities demands for water supplies were based on instinct, influenced by what could be made available rather than what was needed.

The move to performance based building codes provides the impetus to analyse the basis of many of the existing prescriptive methods for specifying water requirements for accuracy and applicability.

This review also looks at the legislative background in New Zealand with a view to the responsibilities and legal obligations of the various interested parties.

1.2 Implications of Determining Fire Fighting Water Requirements

The establishment of fire fighting water requirements is central to fire service operations as it underpins the selection and distribution of resources. For this reason a number of organisations and authors have addressed this subject and provided a variety of solutions. The provision of fire-fighting water is intimately linked to the tactics employed by the fire service and thus will be influenced by the introduction of new technology.
Because the fire fighting water requirements dominant the sizing of a reticulated network it is important that these requirements are defined as accurately as possible. Water supply utilities are also interested in fire fighting water requirements as they are required to plan and design their systems to cope with the high draw offs associated with fire-fighting. These draw offs can occur at any time.

This paper investigates the use of both reticulated water supplies and static supplies for fire fighting.

The provision of sufficient fire fighting water is to ensure the fire service can curtail and suppress a fire. This requires identification of the likely fire size at the point the Fire Service is able to apply water. The amount of fire fighting water needs to be specified by pressure, flow rate and total available quantity.

Having stated this requirement however it is clear from the research undertaken in the preparation of this paper that some buildings which, when they do catch fire, result in the total loss of the building. This occurs despite the best efforts of the fire brigade and sufficient water supply. The reasons for this outcome are investigated in more detail in the body of the report.

To develop a conclusion from the myriad variables that affect the development, discovery and suppression of a fire, this report reviews methods of extinguishment employed by the fire service and the opportunities that exist for quicker intervention. Quicker intervention will mean the fire size is smaller and will thus require less water to extinguish.
CHAPTER 2  WATER SUPPLIES

2.1  Introduction

The provision of fire fighting water requires consideration of a number of points. These are:

- Cost
- Reliability
- Quality of water
- Water demand i.e. flow rate, storage and available pressure
- Provision for access via fire hydrants

2.1.1  Cost

Although water is inexpensive and readily available, it’s processing and distribution carries a significant cost in terms of infrastructure cost. The main component of this cost is in the capital works required to filter and sterilise the raw water supply and produce a potable water supply. The reticulation cost is also significant in terms of the initial investment and ongoing maintenance required. The cost of providing a water reticulation supply to meet the needs of fire fighting over and above a potable supply was evaluated in a study undertaken by the National Research Council Canada (NRCC 1997). This study concluded that it was more cost effective to provide a tanker supply for fire fighting rather than increasing the size of the water processing and reticulation system.

Anecdotal evidence indicates that 30% of the cost of the water supply infrastructure is to cope with the requirements for fire fighting water. Narayanan (1998) indicates that the total cost of the national infrastructure is 3 Billion New Zealand Dollars. The Auckland Regional Council Lifelines Project (1999) identified that the capital cost of the primary reticulation system in Auckland exceeds $ 1,000 million. As this represents about 30% of the population, the orders of magnitude seem correct.

Thus $ 900,000,000 of the water supply infrastructure is cost that can be attributed to comply with the needs for fire fighting. In comparison the cost of the New Zealand
annual fire losses is approximately $120 million (Gravestock, 1999). In this respect the investment in the fire fighting water supply infrastructure greatly exceeds the annual insured property losses.

The Auckland network serves a residential area of 270 km$^2$ which represents 80% of the total system. Thus the greatest savings are to be made in the reticulation to residential areas.

### 2.1.2 Reliability

The Auckland Life lines project also identified that the existing water system is delivered via a number of single node elements such as filter stations etc. These elements are susceptible to damage from seismic activity and would take a long time to reinstate. This reinforces the need to be able to access alternative water sources for fire fighting.

The use of alternative supplies such as ponds, streams and swimming pools is common in rural areas where reticulated supplies do not exist. A project undertaken by the New South Wales Fire Brigade in Australia (Covey 1999) specifically set out to identify these alternative sources. This was prompted by their experience of reticulated water shortages during bush fires on the urban-rural interface. The provision of alternative static water supplies has an added benefit for New Zealand. Botting (1998), in his study on the impact of post earthquake fire, recommended as a mitigation priority the provision of alternative water supplies.

### 2.1.3 Quality

The quality of water required for fire-fighting purposes is much lower than that required for human consumption and hence it is appropriate to consider other alternative water supplies to supplement large reticulated supplies. With the development of rainwater storage and “grey water” storage the ability exists to make this supply available for fire fighting purposes. Rainwater retention tanks are also becoming more common due to Resource Management Act requirements to minimise site runoff.

Another potential source of fire fighting water is from the runoff collection tanks required by the Dangerous Goods Act and it’s replacement, the Hazardous Substances
& New Organisms Act. This possibility identifies the need to define what is a suitable water quality for fire fighting purposes.

The quality of water required for fire fighting has never been adequately defined but an obvious requirement is the need to limit the concentration of suspended material to a size that will pass through the various constrictions and orifices found in fire service pumping equipment. The presence of corrosion products and debris in reticulated supplies is one of the main causes of fire service pump failure (Prestige Diesel, 1999) in the Auckland region. The potential exists for runoff water to be contaminated with chemicals. These chemicals must either be below a certain concentration or alternatively separated from the fire fighting water supply if this source is to be considered suitable.

The requirement for a more sophisticated filtering or screening device on fire service pumps is one possible solution. New Zealand Fire Service (NZFS) pumps are currently fitted with a strainer on the inlet and between the first and second stage, but these devices have a coarse mesh. Any filter or strainer device will create a pressure drop that will reduce the pumps ability to lift water from static supplies. To minimise this effect requires the filter to be adequately sized. It must also be mounted on the vehicle unobtrusively but in a position they can be easily and quickly unblocked. Any increase in pressure loss through the intake system would predispose the use of either pressurized or flooded supplies i.e. supplies that have some measure of positive head so as to compensate for the loss of capacity due to a filtering device.

Fire Service pumps are capable of drafting water, but this requires the use of a special rigid suction pipe that does not collapse under the effects of negative pressure. The pump is required to be close to the water supply as only a few lengths of the suction pipe are carried on an appliance. These aspects together with the rapid fall off in pump performance with increasing drafting depth conspire to limit the opportunities to draw water from static supplies.

2.1.4 Water Demand

A comparison of the times of day when fires occur with the maximum draw off of water reveals that occur almost simultaneously (refer figure 2.1).
This emphasis’s the need to calculate the fire fighting water requirements in addition to the normal potable water demands.

Most structure fires occur within residential properties. On average, 25 % of residential fires occur in kitchens due to cooking activities (refer table 2.1). This provides an indication of why these demands occur at similar times.

Table 2.1: Number and Location of where fires occur (Rural and Urban Fires)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All Fires</td>
<td>18242</td>
<td>20951</td>
<td>24664</td>
</tr>
<tr>
<td>Structural Fires</td>
<td>6558</td>
<td>7345</td>
<td>7310</td>
</tr>
<tr>
<td>Residential Fires</td>
<td>4472</td>
<td>4839</td>
<td>4906</td>
</tr>
<tr>
<td>Kitchen Fires</td>
<td>1059</td>
<td>1186</td>
<td>1342</td>
</tr>
</tbody>
</table>

The New Zealand Code of practise for Urban Subdivision NZS 4404 specifies that the fire fighting requirements determine the pipe sizes. This is demonstrated by comparing the typical water flows in a domestic situation to the fire fighting water requirements. The average peak water usage in a residential home is approximately 1 litre per second (l/s). This compares with a minimum fire fighting water flow of 3.5 l/s for a single high-pressure branch or the current New Zealand Fire Service (NZFS) domestic fire fighting water requirement of 25 l/s.

A review of various existing fire fighting codes reveals reserve storage times varying from 6 hours to 10 hours. When this is compared with the maximum fire resistance rating of a structure it is evident that these times have been based on the assumption that multiple fires will occur. Any single structure will have been destroyed within this period. With the introduction of more detection and suppression systems into these large buildings together with fire resistant separations, the probability of simultaneous fires within an area served by the same reservoir must be negligible.

The use of this quantity of water must also be questioned in terms of the environmental damage it causes and the net benefit that accrues from it use. Extinguishing a fire within a building with millions of litres of water that subsequently is written off emphasis's the need for the proper fire fighting tactics to be employed.

Most fire brigade equipment has the capability of pumping water in excess of the ability of a reticulated supply system to supply. This can produce low pressures within the pipe work that results in backflow. In the long established urban areas where the pipe network is reaching the end of its life, the possibility of drawing in contaminated ground water is real. For these reasons fire service personal must be careful not to go below an agreed minimum pressure. In an undulating area, where the water is drawn at the bottom of the hill this may result in negative pressures at the top, hence this minimum pressure may be more than the generally accepted figure of 100 kPa.

2.1.5 Access

The normal method of gaining access to a reticulated supply is via in ground hydrants. These are spaced at regular intervals along public roads in accordance with either a spacing or area requirement. In New Zealand hydrants are spaced at two distances...
depending on area. These distances are 90 m and 135 m giving a maximum distance to travel of either 45 m or 67.5 m. Each appliance carries 140 to 200 m of 90 mm Ø hose and two hydrant waterway stands. This indicates a mismatch in the spacing distances, which should be investigated.

2.2 Historical development

The development of fire fighting water requirements in New Zealand was reviewed by Edwards (1985) in his report, prepared for the last major revision of the NZFS fire fighting water Code of Practice.

Prior to the development of this code circa 1978, municipal water supplies were graded for fire fighting adequacy by the New Zealand Insurance Council (ICONZ). Premiums for fire insurance were based on the water supply grading. This penalised owners of property where the local supply authority was deemed inadequate. The methodology employed by ICONZ is unstated but appears to be based on the USA Insurance Standards Office (ISO) method.

This approach has been superseded by the introduction of the NZFS Code of Practice. Changes in risk management have also occurred as the insurance industry has become more competitive. For residential property, insurance companies divide residential properties into those in reticulated areas and those in non-reticulated areas.

Commercial properties are considered on an individual basis, with some insurance companies undertaking a comprehensive inspection and scoring various aspects according to the companies procedures. These aspects include fire and the building owner is made aware of what improvements are required to reduce the risk and hence lower the premium. However at the other end of the spectrum are insurers who insure a portfolio of buildings without consideration of the individual risk posed by an individual building’s within the portfolio. Walker (1998) considered essential that mitigation of loss is associated with premium, otherwise there is no real incentive. In the past, owners where required to comply with prescriptive building legislation that required a structure to have fire protection. With the move to performance based legal requirements that only require a designer to protect neighbours property, the onus for protecting ones own property falls onto the owner and indirectly, his insurer. This aspect does not seem to have been appreciated by the insurance fraternity.
2.3 Non Reticulated Water Supplies

A review of fire incidents reveals that 18% of fires occur in non-reticulated areas (refer table 2.2). For larger fires within these areas, that require water supplies exceeding that carried on fire service appliances, fire fighters must utilise alternative water sources.

Table 2.2: Fires in rural areas

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All Fires</td>
<td>18242</td>
<td>20951</td>
<td>24664</td>
</tr>
<tr>
<td>Rural Fires</td>
<td>3369</td>
<td>3727</td>
<td>4584</td>
</tr>
<tr>
<td>% Rural fires of All Fires</td>
<td>18.5</td>
<td>18</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Source: NZFS emergency incident statistics 1995-98

To access these water sources quickly and efficiently requires them to be documented so that responding units can locate the sources and know how to draw from them.

Covey (1999) reports that the Australian New South Wales Fire Brigade has instigated a project to identify and document static water sources in their urban-rural interface. Experience and post incident studies have indicated that the reticulated supply is unable to cope with bush fires. To overcome this the Brigade has surveyed the interface area for water sources that they can use in addition to the reticulated supply. Studies have shown that fire fighters supported by suitable trained residents can save homes by controlling the small fires that occur due to flying burning brands.

Fire fighting water requirements must recognise alternative non-reticulated supplies if they can be accessed and must be factored into the calculations when assessing requirements. For these sources to be suitable, consideration must be given to the provision of fire service couplings on tanked supplies, preferable flooded. For ponds, lakes and dam supplies, draughting pipes are necessary. The vehicular access to the connection points must be suitable for the size of vehicle used. It is preferable to have pickup points that the vehicle can drive through so that it does not need to turn round or perform time delaying manoeuvres.

The effective use of any non-reticulated supply requires detailed preplanning. As already mentioned Botting (1998), in his study on the impact of post earthquake fire, recommended as a mitigation priority the provision of alternative water supplies. It
has been the experience that an earthquake of any magnitude will result in the failure of the reticulated supply. This is best alleviated by the provision of distributed static water supplies.

2.3.1 Water Shuttle Vs pumped relays

The distance between fire risks and water supplies will dictate the choice between either shuttling or relaying water. Many fire brigades utilise tankers and hose layers. The tanker shuttle usually involves the use of collapsible tanks to provide the water source at the fire ground. Tankers require a quick pickup and fast dump mechanism to minimise turn around time.

2.3.2 Cisterns

The use of cisterns, especially in areas of low rainfall or low surface water is essential. A US brigade in Arizona work in a very arid region and has overcome this by the strategic placement of rainfall cisterns. These cisterns are complemented by a drive through facility complete with fast fill pumps and an overhead chute, much like railway steam engines used to rely on. In this way the brigade can quickly replenish their tankers without the need to establish suction hose and prime pumps.

2.4 Water Supply Classification

2.4.1 American Water Works Association

The American Water Works Association have produced a manual (1998) that proposes three methods for calculating fire fighting water requirements. These methods are:

- Insurance Services Office (ISO)
- Illinois Institute of Technology Research Institute (IITRI)
- Iowa State University (ISU)

Each of these methods has already been defined above. The AWWA manual provides a comparison of these three calculation methods. This is considered further in a later section of this report.
CHAPTER 3 LEGISLATION

3.1 Introduction

The legal obligation to supply fire-fighting water within urban New Zealand is implicitly required under the Local Government Act 1975. This requirement is very general and the legal requirement has become more obscure with the establishment of private water companies. Although the Act requires water to be present i.e. "Council shall at all times keep (the system) charged with water", it is silent on specific flow or volume requirements.

Many Local Territorial Authorities (LTA) have adopted the Model General Bylaw, New Zealand Standard (NZS) 9201. This standard includes a disclaimer that states that the authority is not able to guarantee an uninterrupted water supply and hence is not liable for any compensation arising from deficiencies in water supply.

The general public have an expectation that the provision of adequate fire fighting water is the responsibility of the local territorial authority. This expectation is reinforced by the attention the LTA apply to the fire safety aspects of building consent applications.

However a number of LTA are requesting building developers to demonstrate that the available water supply around a proposed development is adequate for the development given its construction, occupancy and fire load. This raises questions as to where the responsibility for an adequate water supply lies. Some observers (Edwards, 1985) have concluded that this issue will require case law to enable clarification.

3.2 Fire Service Act 1975

The Fire Service Act 1975, Section 30 provides for the New Zealand Fire Service (NZFS) to gain access to water from a variety of sources for the primary purpose of fighting fires. Typically, for urban brigades operating within a Gazetted Fire District, this is a reticulated water supply available via in-ground hydrant valves. A similar provision exists in the Forestry and Rural Fires Act 1977, section 36. This section provides for Principle Fire Officers to have access to water sources.
The Act also requires the National Commander of the New Zealand Fire Service to publish a Code of Practise (1992) specifying standards for fire fighting water in terms of supply volume and pressure. The last revision of this Code occurred in 1992. This revision was based on the prescriptive town planning and building legislation in force at the time. Both items of legislation have been replaced by performance-based legislation.

This code of practise is not mandatory and hence is considered as a recommended best practise.

Section 30(2) of this Act empowers the National Commander to perform checks as to the adequacy of the water supply. These checks also relate to the water supply required for the effective operation of fire protection systems. The Fire Service as part of its routine operations, test water supplies by conducting flow tests from reticulated water mains. The number of hydrants flowed simultaneously is based on the water classification zone the hydrants fall within.

### 3.3 Building Act

New Zealand was one of the first countries in the world to introduce a performance based building control system. This system is based on the Building Act (BA), introduced in 1991 and is underpinned by the Building Regulations introduced in the following year. The New Zealand Building Code (NZBC) is a schedule to the Building Regulations. The NZBC contains the performance based mandatory provisions. These provisions consist of 37 performance clauses of which four refer directly to fire. Approved solutions to many of the performance clauses are provided in the fire safety annex and are referred to as “Acceptable Solutions”. These Acceptable Solutions are published by the Building Industry Authority in a document called the Building Industry Authority (1992) New Zealand Building Code Handbook. The Acceptable Solutions are deemed to comply with the Building Regulations i.e. are approved documents.
Clause C3 “Spread of Fire” of the Building Regulation states in performance clause C3.3.9 that:

“The fire safety systems installed shall facilitate the specific needs of fire service personnel to:

➢ • Carry out rescue operations, and
➢ • Control the spread of fire.”

In this regard, fire safety systems are defined as:

“The combination of all methods used in a building to warn people of an emergency, provide for safe evacuation, and restrict the spread of fire, and includes both active and passive protection”.

Similar performance requirements appear in the other C clauses of the Code. In this respect the provision of water is required not only for manual fire suppression by fire service personnel, but also that sufficient water is provided for the successful operation of the buildings fire safety systems such as fire hose reels, building hydrant system and automatic sprinkler system.

The Building Act makes the distinction between owner’s property and neighbours property and indicates that the emphasis is given in this legislation to the fire protection of ones neighbours’ property rather than the owner’s own property. This is at variance to the Fire Service Act, which considers the protection of all property equally. Water supplies outside the building envelope do not come into the orbit of the Building Act legislation.

Comments in the approved documents and the waiver of separation distances for residential properties infers that the approved documents assume the intervention of the NZFS in stopping fire spread. This intervention is assumed to occur prior to significant damage to a neighbour’s property. A review of the available data from the fire information system (FIRS) indicates this assumption is accurate for a large majority of fires (refer table 3.1).
Table 3.1: Fire Damage due to Radiation Exposure onto Neighbouring property.

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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Structure fires</td>
<td>4097</td>
<td>3933</td>
<td>3608</td>
<td>6558</td>
<td>7345</td>
<td>7310</td>
</tr>
<tr>
<td>Exposure: Structure to</td>
<td>61</td>
<td>68</td>
<td>70</td>
<td>109</td>
<td>115</td>
<td>88</td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure: Structure to</td>
<td>58</td>
<td>43</td>
<td>33</td>
<td>44</td>
<td>46</td>
<td>55</td>
</tr>
<tr>
<td>other Property</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure: Varied to</td>
<td>33</td>
<td>54</td>
<td>99</td>
<td>53</td>
<td>105</td>
<td>110</td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Exposure damage</td>
<td>152</td>
<td>165</td>
<td>202</td>
<td>206</td>
<td>266</td>
<td>253</td>
</tr>
<tr>
<td>% of Total Fires</td>
<td>3.7</td>
<td>4.2</td>
<td>5.6</td>
<td>3.1</td>
<td>3.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>


The trend appears constant although this can be expected to trend up to reflect the increasing density of urban housing and the greater use of low melting point building materials such as UPVC guttering and cladding. An allowance must therefore be made when assessing water supplies to take cognisance of the water required for the control of radiation exposure.

### 3.4 Resource Management Act

The Resource Management Act requires TLA (section 14(3)(e)) to allow the Fire Service free use of water. It also requires TLA, in approving new subdivisions that adequate provision is made for fire fighting water. A number of Territorial Authorities have conducted preliminary studies to categorise fire fighting water supplies in accordance with the Town Planning designation for a given area. Traditionally TLA have largely taken the approach of using the District Scheme, formulated to meet the requirements of the Town and Country Planning Act 1977. These schemes devised for town planning purposes were used to match geographical areas with a water quantity based on the NZFS Code of Practise for fire fighting water.

In this fashion a given geographical area will allow a certain type of development and would thus require a certain water supply. This approach requires that fire-fighting water supplies be matched to the designated classification of the District Plan. The difficulty with this approach is the large variation in a buildings “fire risk” that can occur within a given zone.

With the advent of the Resource Management Act the concept of zoning has become outdated. Planning in terms of the Resource Management Act for an area does not
specifically analyse the effect of a proposed development with respect to fire. To compensate for this deficiency, some Territorial Authorities are requesting that the NZFS comment on the suitability of a water supply in an existing area for a proposed new development.

The Resource Management Act requires building developers to apply to the Territorial Authority for permission to undertake an intended development. TLA’s are requiring that this application must include a document indicating the suitability of the development with respect to the available fire fighting water supply and for access by fire fighters to undertake rescue and suppression operations. The introduction of this requirement has been created by the recognition that the traditional zoning of activities that occurred in terms of town planning regulations is now defunct. Territorial Authorities are requiring the Fire Service to provide written confirmation that the available water supply is sufficient for fire fighting when compared with the fire risk of the proposed development.

If a water supply were deemed inadequate by the NZFS for a proposed development, the TLA seems to expect the developer to propose an alternative means for achieving compliance.

3.5 Local Government Legislation and NZ Standards

Local bodies are governed by the Local Government Act 1974. Many sections of this Act have been rescinded. However Sections 647 & 648 of this Act still require Territorial Authorities to keep reticulated supplies charged with water, provide hydrants at regular distances and to mark and maintain hydrants to an acceptable standard.

A number of Territorial Authorities have formed water supply companies and the contractual link between these two entities varies. The status of private sector management of parts of the water network will further erode the existing tenuous legal obligations.

The NZFS code of practise is referred to in New Zealand Standard NZS 9201:1974. This Standard is titled the Model General Bylaw of which TLA are at liberty to adopt.
Chapter 7 deals with water supply and is used for new subdivisions and as such
nominates the NZFS Code of Practise as the benchmark for water supply.

The Water Supply Protection Regulations (1961) requires the water reticulation
system to be designed to meet the requirements of fire fighting but does not provide
any detail.

The Town and Country Planning Act 1977 established geographic zones called
districts to control the particular types of development in that district. This was
promulgated in accordance with the second schedule of the Act. The District Scheme
subdivided the urban area into zones where similar types of development would take
place. The District Scheme took into account land usage and the necessary amenities
required to support these uses but did not consider the necessary utilities required.
However most utilities were in the control of the public and hence the utility providers
planned their future developments around the District Scheme.

The requirements of the Town and Country Planning Act have been incorporated into
the Resource Management Act.

New Zealand Standard NZS 4404 is entitled Code of Practise for Urban Land
Subdivision. This standard was prepared so as to assist Territorial Authorities to
comply with the requirements of the Local Government Act. The adoption of this
Standard is voluntary and the Standard also recognises that it may be modified by a
Local Authority to suit its individual requirements. Part 5 of this Standard deals with
water supply and with regards fire fighting water supply refers to the NZFS code of
practise. This Standard provides more detail regarding the classification of fire risks
and provides the following examples:

Detached or semi-detached dwellings in suburban areas 25 l/s
Schools, local suburban shopping centres etc 50 l/s
Suburban industrial areas 100 l/s

A typical hydrant will flow 30 l/s and is required to run at no less than a minimum of
100 kPa pressure.
CHAPTER 4 EXTINGUISHING MECHANISM OF WATER

4.1 Introduction

Water is the most common fire-extinguishing agent used. This is because it possesses a range of physical and chemical properties that make it a very effective medium.

The theoretical water quantities required for actual extinguishment are very low when supplied in an efficient manner. Recent studies of water mist application indicate that droplets smaller than .03 mm are optimal. Reducing the droplet size improves the surface to weight ratio and hence allows a greater amount of energy absorption from the combustion process. This is evident when one calculates the surface area for one litre of water in droplet form (refer figure 4.1).

Figure 4.1: Droplet surface area Vs droplet diameter

However the lighter the droplet the more susceptible the droplet is to the buoyancy effects of the plume. These studies also demonstrate the effectiveness in applying the water indirectly to surfaces surrounding the fire. However containment of the water mist is essential and usually does not occur at the fires attended by a fire brigade.
The pressures required to produce the size of water droplets utilised in water mist applications are also beyond the equipment currently used by most brigades. Water pressures of 60 to 100 bar are discussed. This would require the introduction of a specialised pump and hose similar to the current high-pressure delivery. This 'ultra' high-pressure system would require the introduction of a smaller diameter hose and a special branch.

Water is also used for other aspects of fire fighting operations such as the protection of exposures, protection of fire brigade personnel and damping down smouldering material. Studies have shown that smaller water droplets are better at attenuating the radiation associated with a flame.

Rosander and Gisellson (1984) give water quantity figures for protecting radiation exposures of between 1 to 10 litre/m²/minute, dependant on the impinging radiation levels. These figures can be utilised to calculate the amount of additional water required to protect adjacent buildings. In this regard the amounts must be in multiples of the existing devices used by a brigade. This must also take account of the maximum throw that can be achieved with these devices.

4.2 Extinguishment Mechanisms

The most common fires fought by the fire service are termed class A fires. This type of fire is defined in the British/European Standard BS EN 2:1992 as:

"fires involving solid material normally of an organic nature, in which combustion occurs to form glowing embers".

This Standard recognises that the most common and effective extinguishing agent is water in the form of a jet or spray.

Water is a very efficient extinguishing agent for a variety of reasons. It is non-toxic, plentiful and cheap in comparison with other liquids. Because of its unique chemical composition it possesses a high sensible heat and latent heat of vaporisation. (Refer figure 4.2)
This is due to the ‘polar’ character of the water molecule, which means the molecule possesses an attractive force. This force binds the water molecules together and explains phenomena such as its surface tension. This also leads to one of the disadvantages of water in that it conducts electricity. The surface tension of water also means that fuel surfaces are not as readily “wetted”. This can be overcome however by the inclusion of small quantities of additives.

The high bonding between water molecules also explains the higher power requirements of water pumps and the need for higher pressures to produce small droplets. A typical low-pressure branch runs between five to ten bar water pressure and produces water droplets in the 250 to 350 μ (1 x 10^-6 m).

Water vaporises at 100° C, which is well below the typical temperatures associated with the production of gaseous volatiles (pyrolyzates) of around 300° C to 400° C. Contrary to this water freezes at 0° C and when it freezes it expands slightly. This can be a major problem, especially in areas where static water supplies are utilised. The expansion of water when it turns to ice can rupture equipment if this expansion is not compensated for.
The study by Rabash (1985) on diffusion flames indicates that removal of between 30 to 35% of the released energy is sufficient to extinguish the flame. This can be explained by examining the typical combustion process associated with a class A fire. The combustion process is a gaseous phase exothermic oxidation reaction that occurs above the fuel surface. An ignition source produces sufficient gaseous volatiles to sustain the combustion process. The production of these volatiles is principally achieved by the radiation energy transfer from the luminous flame above. Most of the energy from the combustion process is convected away in the plume and in preheating the oxygen used in the combustion process. The proportion of combustion energy that is converted to electromagnetic radiation (typically 30%) is transmitted in all directions to the surroundings. About 12% reaches the fuel surface and typically 40% of this amount is reradiated by the fuel surface. Thus only 7% of the available combustion energy is utilised in the production of more gaseous volatiles. In this regard only enough water is theoretically required to be applied to remove or absorb this energy to extinguish the combustion process.

Stolp (1976) reviewed this aspect and discussed how the critical application rate of water varied with the size of the fire. This data is reproduced below.

Table 4.1: Variation of critical water application rate with fire surface area

<table>
<thead>
<tr>
<th>Fire Surface Area: M²</th>
<th>Critical Rate of Application for Extinguishment L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UK</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
</tr>
<tr>
<td>100</td>
<td>~2000</td>
</tr>
<tr>
<td>1000</td>
<td>&gt;6000</td>
</tr>
</tbody>
</table>

Source: Stolp:1976

The measurements of water quantities taken by Stolp indicated that the energy required to vaporise the water only amounted to ~2% of the heat produced by the fire. It was stated that for free burning fires, the criterion for extinguishment expressed as a ratio of the heat release rate defined as $\Delta R$ and the abstraction rate $\Delta W$ i.e. $\Delta R/\Delta W$~9-10%. For a confined crib fire this ratio went down to ~5-6 indicating a higher critical application rate. When comparing this result with the introduced coefficients utilised by authors who propose using the heat release rate, the efficiency coefficient goes down as low as .01.
Mawhinney et al. (1994) discusses a number of extinguishment methods such as flame inerting, dilution and chemical inhibition. However the application of water to a Class A compartment fire achieves extinguishment by a combination of mainly three mechanisms. The influence of each mechanism in the overall extinguishment of the fire is dependent on the method of delivery of the water. These mechanisms are defined below.

4.2.1 Fuel Surface Cooling

The impingement of water on the solid fuel surface reduces the rate of pyrolysis by the cooling of the surface. This reduces the rate at which the pyrozlates are generated and thus reduces the heat release rate. As less material burns, the flame size is reduced and the thermal feedback to the fuel is reduced. This further reduces the production of gaseous volatiles. The combustion process produces a buoyant plume. This inhibits the penetration of small droplets of water to the fuel surface. Thus wetting of the fuel surface is most effectively achieved by the application of a solid stream of water.

4.2.2 Flame Zone Cooling

Water resident in the flame zone absorbs the heat from combustion by the convection cooling of the flame. Experiments performed (Sversor & Lundstrom, 1999) reveal that this convection process is either natural or forced dependent on the size of the water droplet.

The removal of the heat of combustion reduces the heat available to initiate further combustion and thus slows the heat release rate. The water droplets also interfere with the concentration of free radicals within the combustion zone and inhibit the complex chain branching reaction that occurs during combustion (Grant et al., 1996). Optimum flame zone cooling is produced by the introduction of fine water mist. The small droplets maximise surface area per unit mass and thus absorb more energy per unit mass.

Given that the residence time within the flame zone is small this factor is very important.
4.2.3 Inerting

The introduction of water onto a hot fuel surface or flame will invariably produce steam. The conversion of water from its liquid to gaseous state is accompanied by a large increase in volume (water expands approximately 1700 times when converting from a liquid to gaseous state). This volume increase reduces the oxygen partial pressure and hence inert's the combustion process by the exclusion of oxygen. This effect is most pronounced in enclosures and is the principal suppression mechanism associated with water mist systems.
CHAPTER 5 METHODOLOGY

5.1 Introduction

The linkage sought in this paper is between building type, expected maximum fire size and required fire fighting water supply. A knowledge of this linkage will allow allocation of manpower, equipment and pumping capability. This information can then be utilised to undertake accurate pre-incident planning.

5.1.1 Fire Engineering Methodology

A fire engineering approach is required so that the expected fire within a given building can be predicted and correlated to an acceptable fire-fighting water supply. This approach requires the definition and identification of a number of aspects. This report investigates existing methodologies for assessing expected building fire size and how these have been related to fire fighting water requirements. In determining the expected fire size we must consider which relevant parameter we are seeking. A number of authors have sought linkages between the buildings size and the fire fighting water required. Other authors have utilised the heat release rate.

It follows that the identification of water quantity also then defines the other resources required in fighting the fire i.e. equipment, pumping capacity and manpower.

This report considers the following aspects:

- Classifications of buildings in terms of fire size i.e. the expected fire size within a building type at the time of fire service intervention.
- Fire Brigade response model i.e. time to intervention
- Required water supply to extinguish the expected fire size.

In regard to fire fighting water the determination of fire starts or the likelihood of a fire occurring is irrelevant. Fire risk can be defined as providing a quantitative measure of a fire occurring and the consequences of that fire (NZS 4360:1999). The existing NZFS fire fighting Code of Practise refers to “risk classification” in an attempt to take into account the nature of the buildings fire risk and yet it does not consider the number of people, their activity, and the active and passive fire protection systems located within the structure. The sizing of an adequate water supply must
exclude the consideration of fire starts and hence assume that all buildings will be subject to fire.

The number of fire starts are only relevant if one wishes to consider an economic model in terms of comparing cost vs. benefit. In this case the probability of a fire occurring, the subsequent loss and the cost of providing a fixed supply in comparison with the cost of providing fire service cover would need consideration. An accurate comparison of the cost of the reticulation infrastructure dedicated to fire fighting water compared with the cost of domestic sprinklers would be of great interest.

The elapsed time between ignition of a fire in an urban structure till the arrival of the fire service is in the order of five plus minutes. The American National Institute of Standards & Testing (NIST) standard calls for a 7 minute response time. As discussed elsewhere the New Zealand Fire Service has an Emergency Response Guidelines. These guidelines are incorporated into the purchase agreement between the Government and the NZFS for the provision of fire cover. This currently requires a seven minute response to 90% of all calls.
CHAPTER 6  FIRE SIZE DETERMINATION

6.1 Introduction

The resolution of fire size is central to many questions in fire engineering. In this instance we are interested in the spectrum of compartment fires.

The transitional nature of fire within a compartment can be separated into five phases or events. Not all these phases may occur in a given fire. These are:

- Ignition
- Smouldering
- Flaming growth
- Fully developed - Flashover
- Fully developed - Non-flashover
- Decay

Figure 6.1: Typical fire progression (stylised)

When comparing these stages against a timeline and plotting physical intervention by fire fighters, it is evident that fire fighting will start, in a worse case scenario, during the fully developed phase of the fire.
The parameters dictating the growth and size of a fire within a compartment are:

Fuel:

- Distribution
  - Geometry
  - Flammability
  - Calorific value

Ventilation:

  Vertical openings
  - Horizontal openings

Compartment:

  Size (surface area)
  - Thermal properties of surfaces

The above parameters combine in a complex relationship to produce a range of outcomes. The fire may either only involve the item first ignited or alternatively spread to the remainder of the compartment. At full development this fire will either be a fuel or ventilation controlled fire.

6.2 Background

Much of the current research in fire development and suppression is concerned with fire growth at the incipient stage, as an input into design of fixed detection and suppression systems. However fire fighters are usually confronted with fully developed fires, at least in the compartment of fire origin. In this respect this area of interest is more akin to the structural fire engineer who is interested in the life of the fully developed fire through to decay. These fires are usually post flashover, given the time between fire ignition and arrival of the brigade.
Earlier detection of a fire requires the presence of automatic detection devices or an alert human presence in the vicinity of the fire. The human detection of fire is still the most common as reflected in how the NZFS is alerted. The NZFS is turned out to 92% of the incidents it attends by telephone call (refer Figure 6.2). Automatic alarm systems only account for 2% of the incidents the fire service respond to.

Figure 6.2: How fire service alerted

In New Zealand and Australia the success rate of automatic sprinkler systems is above 96%. Maryatt’s (1988) analysis of sprinkler-controlled fires indicates that a few sprinkler heads control most fires. This success rate must be acknowledged when considering the fire safety of a building. The chance of a big fire within sprinkler-protected buildings could be considered to be negligible and thus a sprinkler-protected building will require a smaller fire fighting water supply than the same building without a sprinkler system.

The Acceptable Solution to NZBC Clause C4 assumes that an automatic fire sprinkler system will operate, as it allows for the halving of the structural fire endurance rating. This assumes the sprinkler system will operate, suppress the fire and avoid the
collapse of the building. In recognition of the success sprinkler systems enjoy, buildings fitted with complying automatic sprinkler systems should be given a lower risk classification.

In non-protected buildings a worst-case scenario applies and hence it must be assumed that a fire will occur and grow, and thus the probability of fire starts is irrelevant.

Fire growth is stopped by either the introduction of firecells to limit spread of fire, intervention by the Fire Service or the activation of an automatic suppression system. The approved documents to the New Zealand Building Code introduce a limitation on firecell size in Clause C3, for non-sprinkled buildings (refer Figure 5). However for single storied buildings with no ceilings, the fire cell size is allowed to be unlimited, if provision is made for smoke and heat venting.

However these types of buildings usually have large fires that result in the total loss of the building and release vast quantities of pollution into the air and waterways.

It is the Author’s contention that a limitation on firecell size must be introduced in line with the maximum fire size that the fire service would be able to control with the available water supply. The only other alternative is to recognise that in the event of a fire whilst the building is unoccupied the most probable outcome will be a total loss. This outcome contravenes the moral and legal requirement to minimise damage to the environment.

Where large fire load energy densities combine with large firecells it can be demonstrated that the fire size quickly exceeds the capability of the fire service to extinguish. If no mitigating actions are put in place the fire service are left with no alternative but to revert from an offensive operation to a defensive one. This means the fire exposures are protected but that the fire itself is allowed to burn out. The addition of water to the fire achieves little and is usually detrimental due to the high quantities of contaminated runoff water.

Firecell limitations are also imposed by the physical limitations of the fire fighting equipment in terms of the reach or throw of water jets.
The prospect of a total loss of the building and its contents is a very good argument for limiting firecell sizes or alternatively, the installation of automatic suppression systems.

The number of building occupants is relevant if rescue operations are carried out. However most commercial buildings are either sprinkler protected or are required to have an operational evacuation scheme. The evacuation scheme requires that the building occupants self evacuate and thus do not require the resources of the fire service.

6.3 Fire Modeling

6.3.1 Introduction

The types of fires of interest to fire fighters are mainly compartment fires. This type of fire is usually ventilation controlled and heavily influenced by the amount and type of fuel.

Either physical or mathematical models can achieve the modelling of a buildings performance in fire. The physical modelling of fire is expensive and hence only used for the more exotic buildings.

Mathematical models can be either of the deterministic or probabilistic type. The probabilistic model requires the fire to be broken up into a sequence of events and a probability applied to each event. At present insufficient information is available for this approach to be effective.

Deterministic models are based on a mixture of algebraic equations that are becoming more sophisticated with the advent of faster and more powerful computers.

The more sophisticated programs utilise computational fluid dynamics (CFD). This approach divides the compartment up into a myriad number of small volumes. Each element is treated individually and the effects of the elements surrounding it are determined via a series of mathematical relationships based on the conservation of mass, species, energy and momentum. These equations are applied over small increments in time and to each element. This then involves many iterations and hence huge numbers of computations. Setting up and running a CFD analysis is very time
consuming and hence limits its application to very sophisticated projects and research institutes.

Typically deterministic models split the volume or space of interest into a small number of zones and apply a number of simplifying assumptions. The same mathematical relationships based on the conservation of mass, species, energy and momentum are utilised.

A number of computer based analytical models have been developed recognising the influence that the fire load, ventilation and type of building structure have on the growth of a fire to its fully developed stage. These models then could be utilised in a similar fashion to define the requirements for fire fighting water in a specific building.

### 6.3.2 $t^2$ growth fires

A simple model utilised by many fire engineers is the $t^2$ growth fire. The fire growth is applicable to the fuel surface controlled fire that is not influenced by the compartment.

These fires are defined by the formulae:

$$Q = (\alpha t / 1200)^2$$

Equation 6.1

Where

- $Q$ equals the heat release rate
- $\alpha$ equals the growth rate coefficient
- $t$ is the time in seconds

Utilising this formula and inputting the expected times for fire service intervention provides a typical fire size (refer Table 6.1).
Table 6.1: Heat output from $t^2$ fires (MW)

<table>
<thead>
<tr>
<th>Speed</th>
<th>$\alpha$</th>
<th>Time to 1 MW</th>
<th>Time in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>2</td>
<td>600</td>
<td>1</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td>Fast</td>
<td>8</td>
<td>150</td>
<td>16</td>
</tr>
<tr>
<td>Ultrafast</td>
<td>16</td>
<td>75</td>
<td>64</td>
</tr>
</tbody>
</table>

The $t^2$ fire model has its origins in the design of detectors and thus was only intended to model fires of a few hundred kilowatts in size (Babrauskas, 1996). The use of $t^2$ fire models have been used for comparisons with furniture calorimeter tests where by judicious choice of a constant, the modeller arrives at a growth curve roughly approximating the heat release rate from the test. This approach however ignores the major compartment effects due to reradiation and that the fact that the ventilation may be constrained. Both have significant effects on the heat release rate. In this respect the use of this model for fires reaching typically hundreds of Megawatts cannot be recommended.

6.3.3 Other Fire Models

Most models require a heat release rate to be inputted or alternatively only provide the $t^2$ fire model as an input. Janssens (1992) undertook a comprehensive review of the current post-flashover fire models and concluded that the COMPF2 model was the most applicable model.

The original work on determining heat release rates from compartment fires was undertaken by Kawagoe. The model proposed by Kawagoe was aimed at predicting the temperature within a post flashover fire so as to predict the fire resistance required by structural building elements.

The gas temperatures were calculated by considering the energy balance of the heat generated by the fire being equal to the heat lost from the compartment. He noted an empirical relationship between the ventilation of a compartment and the energy released by the fire.
He defined the heat release rate from a compartment fire as follows:

Equation 6.2

\[ M = 0.09 \ A \sqrt{h} \]

Where

- \( M \) = pyrolysis rate (kg/s)
- \( A \) = Area of opening (M\(^2\))
- \( h \) = height of vertical opening

The mass loss rate is utilised to calculate the heat release rate by multiplying by the calorific value of the fuel.

Equation 6.3

\[ Q = m \ \Delta h \]

Where \( Q \) = quantity of heat released per unit time (MJ/s or MW)
And \( \Delta h \) = calorific value of the fuel (MJ/kg)

Kawagoe’s work was based on wood crib fires within small compartments and we now know that wood crib fires have special burning characteristics. The pyrolysis coefficient is modified in the COMPF2 program from .09 to .12. Babrauskas presumes this increase by 30% is to account for the reradiation within the compartment and vitiation of the fire. The reradiation enhances the pyrolysis rate and hence increases the heat release rate. However the energy release is reduced by the incomplete combustion of the fuel and the loss of energy that occurs through venting to the outside of unburnt pyrolates. To account for these losses, Babrauskas proposed that the calorific value of the fuel be taken as 12 MJ/kg.

Equation 6.4.

\[ M = 0.12A \sqrt{h} \]

For multiple vertical and horizontal openings, the approximation proposed by Buchanan can be utilised to determine a single ventilation factor.
Equation 6.5

\[ A\sqrt{H} = 2.33A_h\sqrt{h} + A_v\sqrt{H} \]

Where \( A_h \) = Horizontal opening area
\( h = \) Horizontal opening height
\( A_v = \) Vertical opening area
\( H = \) Vertical opening height

This correlation is only valid where

Equation 6.6

\[ 0.3 \leq (A_h\sqrt{h} \ast A_v\sqrt{H}) \leq 1.0 \]

Utilising the Babrauskas formulae for a variety of fuels of different calorific values at different ventilation factors gives the following: refer table 6.2
Table 6.2: Heat output from a ventilation controlled fire for varying calorific values of fuel

<table>
<thead>
<tr>
<th>Ventilation Function</th>
<th>Fuel Type : Calorific value : MJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>12</td>
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<td>70</td>
<td>14</td>
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<td>80</td>
<td>16</td>
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<tr>
<td>90</td>
<td>18</td>
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<td>100</td>
<td>20</td>
</tr>
<tr>
<td>110</td>
<td>22</td>
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<tr>
<td>120</td>
<td>24</td>
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<tr>
<td>130</td>
<td>26</td>
</tr>
<tr>
<td>140</td>
<td>28</td>
</tr>
<tr>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>160</td>
<td>32</td>
</tr>
<tr>
<td>170</td>
<td>34</td>
</tr>
<tr>
<td>180</td>
<td>36</td>
</tr>
<tr>
<td>190</td>
<td>38</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>210</td>
<td>42</td>
</tr>
<tr>
<td>220</td>
<td>44</td>
</tr>
<tr>
<td>230</td>
<td>46</td>
</tr>
<tr>
<td>240</td>
<td>48</td>
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<tr>
<td>250</td>
<td>50</td>
</tr>
<tr>
<td>260</td>
<td>52</td>
</tr>
<tr>
<td>270</td>
<td>54</td>
</tr>
<tr>
<td>280</td>
<td>56</td>
</tr>
<tr>
<td>290</td>
<td>58</td>
</tr>
<tr>
<td>300</td>
<td>60</td>
</tr>
</tbody>
</table>
If these figures are plotted on a graph we get four lines (refer Figure 6.3)

Figure 6.3: Heat release rate Vs ventilation factor

6.4 Firecell Size Limitation

From an analysis of the property damaged in a fire it is evident that a small number of fires create the majority of property loss. These are usually the large unsprinklered industrial properties. This outcome indicates that a fire can be too big for the fire service to extinguish. When this occurs, the fire service must adopt a defensive fire
fighting methodology. This stops the fire from spreading to other property but results in the loss of the building.

Fontana et al. (1997) discovered as part of their 10-year study of Swiss fires that 2% of the fires resulted in 75% of the total insurance compensation. New Zealand insurance sources (Gravestock, 1999) indicate that although the majority of fires occur in residential dwellings (35% of all fires and 67% of all structural fires, refer to Table 8.14) 62% of the insurance paid out for fire loss is for commercial losses.

A review of large fires indicates the use of large quantities of fire-fighting water with minimal change to the outcome of the fire. The building is still totally destroyed. These buildings are usually large floor area, single fire cell and single storey with minimal fire protection systems.

In these instances it is more effective to adopt a defensive tactic rather than an offensive one. This should result in less water runoff into waterways and hence less water borne pollution. Both the Resource Management Act and the Building Act requires the effect on the environment to be minimised.

The approved documents produced by the Building Industry Authority, and thus deemed to comply with the Building Act, provides for a maximum firecell size. (refer to Table 6.3)

Table 6.3: Firecell Floor Area Limitations

<table>
<thead>
<tr>
<th>Fire Load Energy Density MJ/M²</th>
<th>Fire Hazard Category</th>
<th>Maximum Firecell Floor Area M²</th>
<th>Total Fire load MJ</th>
<th>F Rating (acceptable solutions) Minutes</th>
<th>Average Heat Release Rate R (1000)</th>
<th>Theoretical Water Capacity l/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>1</td>
<td>5000</td>
<td>2,000,000</td>
<td>90</td>
<td>370</td>
<td>431</td>
</tr>
<tr>
<td>800</td>
<td>2</td>
<td>2500</td>
<td>2,000,000</td>
<td>180</td>
<td>185</td>
<td>215</td>
</tr>
<tr>
<td>1200</td>
<td>3</td>
<td>1500</td>
<td>1,800,000</td>
<td>240</td>
<td>139</td>
<td>161</td>
</tr>
<tr>
<td>1600</td>
<td>4</td>
<td>[1250]¹</td>
<td>[2,000,000]</td>
<td>300</td>
<td>111</td>
<td>129</td>
</tr>
<tr>
<td>2000</td>
<td>4</td>
<td>[1000]¹</td>
<td>[2,000,000]</td>
<td>300</td>
<td>111</td>
<td>129</td>
</tr>
<tr>
<td>2400</td>
<td>4</td>
<td>[833]¹</td>
<td>[2,000,000]</td>
<td>300</td>
<td>111</td>
<td>129</td>
</tr>
</tbody>
</table>

Source: Building Industry Authority NZBC acceptable solutions C3/AS1 Clause 3.7.1

* acceptable solutions requires specific fire engineering solution

However in the construction of large single storey buildings the acceptable solutions allow unlimited firecell sizes on the proviso that the building is provided with smoke and heat ventilation. This is usually achieved by the installation of clear plastic
roofing over 15% of the roof area. This is assumed to melt and allow the fire to vent. This venting of the fire is intended to avoid the build-up of heat that will lead to structural collapse and also allow fire fighters to advance into the building below the smoke and heat layer.

These buildings are intended to contain very large quantities (fire loads) of combustible products and yet are not required to be equipped with either a fire detection or suppression system. When a fire occurs in these buildings while the building is unoccupied, the fire will grow to a substantial size before visual detection by a passer by. The common result due to the late detection of the fire is the complete destruction of the building, severe damage to the environment and usually substantial economic loss.

This problem has been recognised by the U.K. Loss Prevention Council (LPC), which has produced a design guide for the fire protection of buildings. For large single storey buildings the design guide recommends a limitation on the firecell floor area (refer table 6.4).

Table 6.4: Fire Cell Floor Area Limitation (m²)

<table>
<thead>
<tr>
<th>Occupancy Type</th>
<th>Unsprinklered</th>
<th>Sprinklered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shop &amp; Commercial</td>
<td>4000</td>
<td>8000</td>
</tr>
<tr>
<td>Industrial</td>
<td>7000</td>
<td>14000</td>
</tr>
<tr>
<td>Storage</td>
<td>4000</td>
<td>8000</td>
</tr>
</tbody>
</table>


A similar approach has been adopted in the U.S.A. with the introduction and ratification of the International Building Code. The Code introduces the “fire area concept”. This concept establishes the maximum allowable floor areas for non-sprinklered buildings. A limitation of total floor area, individual floor area and building height is established for each occupancy classification. The limitation imposed for a single storey residential building is 1115 m².

6.5 Large Single Story buildings

Rimen (1990) conducted a number of studies on behalf of UK brigades to appraise the efficiency of fire service branches. He noted that relatively few incidents attended by the UK brigades required the use of non hose reel branches, although where used these fires accounted for a substantial proportion of fire losses.
This emphasis’s the need to recognise when a fire is too large and hence why the maximum flow rate should be capped.

A review of the large fires that have occurred in the Auckland region over the last few years reveal this same trend. These fires are discussed in more detail below.

6.5.1 Veg Pak

A review of the fire that occurred in the packing shed of Veg Pak on 11 December 1998 emphasised the need for pre-incident planning.

The shed was located in a rural area and was not served with a reticulated supply. The building was a large (floor area=8000 M$^2$) single storey shed used for the storage of vegetables in wooden bins.

The first arriving units were required to jury rig a non-standard connection to the bore water supply. This was not effective. The bore water pump was driven by an electric motor fed from the mains. The mains power was isolated by the power supply company resulting in the loss of bore water.

A water relay was established from a static supply 1000m away. It is estimated that this only provided a flow of 24L/S. Because of the lack of water the fire operation was mainly defensive with most of the water from the four low-pressure branches used to protect exposures. The building was a total loss. (*Operation analysis, NZFS 11/12/98)

Similar conclusions have been reached about a number of large building fires in that incorrect firemanship techniques have been utilised.

6.5.2 ATCO

The ATCO fire, which resulted in a total building loss, also utilised large quantities of water. At the fire’s peak it is estimated that 256 L/S of water was flowing and that a total of 1.2 million litres of water would have become run off into the local storm water system. Firefighters applied their residential tactics to this fire by injecting high-pressure water mist into the upper layer. The use of high-pressure fog is inappropriate in large firecells, or those compartments that have been vented.
This type of fire requires the application of solid jets of water to the base of the fire. Water mist in this application is ineffective as the water is carried away in the strong buoyant plumes or evaporated before it can reach the fire fuel. Ground based monitors are effective for reaching the fuel source.

The application of water to the base of a fire in a large building is sometimes impossible without entering the building. This is fraught with danger due to the unknown condition of the structure especially the roof. Some brigades are experimenting with robots to overcome this problem.

6.5.3 New Zealand Safety

The building was a large single storey warehouse constructed in 1994. The building was extensively damaged by fire in 1997. The building was fitted with heat detectors, which did activate an automatic alarm. However, by the time the Fire Service arrived the building was well involved in fire.

An internal attack was mounted initially but due to the fear of structural collapse this reverted to an external fire attack. The use of external monitors and aerial appliances is questionable, as the effect on the fire seems to have been minimal. The end result was that 90 per cent of the building was damaged.
CHAPTER 7  FIRE SERVICE INTERVENTION

7.1 Introduction: Fire Brigade Response

A fire brigade response model allows the computation of an expected time for the fire service to receive the alarm, respond, set up and apply water to the fire. This has been a subject of a number of studies both in Australia (AFAC, 1997) and Europe (BSI DD240, 1997).

The Australian model under development by AFAC is called the Fire Brigade Intervention Model (FBIM). This model not only estimates the time of arrival of the fire service in the enclosure of fire origin but also takes into account the effect trapped or incapacitated occupants have on this time.

The New Zealand Fire Service as part of its purchase agreement with the Government undertakes to meet operational guidelines. These guidelines in respect to response to a fire emergency are called Emergency Response Resourcing Guideline (ERRG) and were proposed as follows:

- Respond to 90% of structure fire incidents within 7 minutes
- Respond to 99% of structure fire incidents within 10 minutes

As a first approximation these times could be used to determine fire service intervention.

7.2 Planning

The New Zealand Fire Service is required by Section 27A of the Fire Service Act 1975 to develop operational procedures. These operational procedures are outlined in the NZFS manual of operations (FSM8) (NZFS, 1999). Each urban fire district is divided into zones and specific turnout procedures have been specified for each of the various incidents that may occur in that zone.

At present these procedures always produce a predetermined response to a reported incident within a given zone. Ideally, for each zone, the resources dispatched should match those required in a worst-case scenario. This would require an analysis of each and every risk within a zone. This has not occurred as yet, so instead incidents are categorised into one of eight classifications, as follows;
Vegetation
Structural
Rescue
Mobile Property
Hazardous material
Flammable liquid/gas
Natural disasters
Aviation disaster

The turnouts for each of these classifications can be escalated from the initial response of 1, up to a maximum of 5 for a significant fire. For example the initial response to a structural incident in a typical Central Business District (CBD) zone is four pumps, one platform and one ladder.

This gives a theoretical pumping capacity of 330 l/s for a first alarm turnout. This flow rate exceeds the 200 l/s required for the most onerous risk classification required by the NZFS Code of Practice for Fire Fighting Water. It is recognised that these turnouts are driven by the manpower requirements and this indicates a mismatch of equipment and manning resources.

If the alarm is escalated to a second alarm, an additional three pumps, a platform and the command unit are responded to the incident.

In addition to the predetermined response to an incident, the Chief Fire Officer of a Fire District is required to develop risk plans for specific buildings so as to provide information to the responding units.

The information required includes the following:

- Building size
- Building location
- Access to Building
- Type of occupancy
- Water Supply
- Building Fire Safety features
The type of buildings that are required to have risk plans include the following:

- Boarding houses, hotels and other licensed apartments
- Motels and apartment buildings
- Rest houses
- Hospitals and psychiatric care institutions
- Prisons and places of lawful restraint
- Public assembly
- Multi storey buildings
- LPG/CNG installations
- Special risk industrial and commercial premises

The Fire Service undertake building inspections to gather this information and also as part of the process when approving evacuation schemes. Evacuation schemes are required by the Fire Safety and Evacuation of Building Regulations (FSEB Regulations). The buildings requiring evacuation schemes include those listed as requiring risk plans and hence this opportunity can be utilised to establish the fire fighting water requirements.

A NZFS project is underway currently to investigate the feasibility of providing this information on a computer located in the responding vehicle.

7.3 Dispatch

Operational appliances are despatched to incidents by the NZFS Communication Centres. There are three inter-linked centres in New Zealand at Auckland, Wellington and Christchurch.

The Communication Centres are alerted of incidents by a variety of means but the predominant method is still by the telephone system (Refer Figure 6.2) The Communications Centre operator determines the location of the incident and inputs this information into a computerised dispatch system. The computer then identifies the predetermined response. Radio and pagers pass this information to the selected NZFS personnel who are to be responded to the incident. On full time manned stations, fire fighters are also alerted by voice over the station loudspeaker system connected to the radio.
7.4 Operations

7.4.1 Introduction

The supply of fire-fighting water should be balanced with the fire service pumping capacity responded to a fire incident.

Currently in New Zealand the flow-rate and quantity of fire-fighting water is determined by a Code of Practise issued by the NZFS (NZFS, 1992). This code of practice adopts a prescriptive approach to the classification of fire risk and applies it to a geographical area. With the demise of the Town and Country Planning regulations and its replacement with the Resource Management Act, this is no longer a valid methodology to equate fire risk and fire fighting water usage.

The main drawback in the classification of “fire risk” by a geographical area is that this does not recognise the large variety of buildings, and hence fire risk, that may occur in a given area. These buildings, dependant on age, use and building fire safety features will vary widely in “fire risk”. For this reason it is the authors contention that a definition of fire risk can only be associated with a specific building and not a geographical area.

The definition of fire risk in the current code of practice is only based on urban zones and precludes other risks such as fires in open areas or special risks such as marinas or isolated industrial complexes. Any identification of fire risk must be applicable to a broader range of “risk”.

The current code of practice specifies the required water supply in terms of water flow, pressure and reserve storage. The code provides a table showing the required reticulated flow, the number of hydrants this flow is to be available from (within a 270 m radius) and the water storage capacity of the system.

The fire risk for a given geographical area is categorised into five classes. These classes are described by building type and geographic location.

This approach is prescriptive, arbitrary and has not been revised to take cognisance of the introduction of performance-based design. The background to these water
quantities is given in Edwards report (1985). These studies factored in various facets of a building to come up with the water requirements given in the code.

With regards to fire fighting water requirements the urban fire districts have been divided up into areas and classified according to a “fire risk classification”. This fire risk classification is defined using a general descriptor based on the location of the area. (refer table 7.1).

Table 7.1: Water supply classification table

<table>
<thead>
<tr>
<th>CLASS</th>
<th>FIRE RISK CLASSIFICATION</th>
<th>WATER FLOW L/S</th>
<th>NUMBER OF HYDRANTS</th>
<th>MAXIMUM SPACING M</th>
<th>RESERVE STORAGE M³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>City CBD</td>
<td>200</td>
<td>8</td>
<td>90</td>
<td>4,320</td>
</tr>
<tr>
<td>B</td>
<td>Large city Industrial &amp; Commercial</td>
<td>200</td>
<td>8</td>
<td>90</td>
<td>2,880</td>
</tr>
<tr>
<td>C</td>
<td>Built up areas</td>
<td>100</td>
<td>4</td>
<td>90</td>
<td>1,080</td>
</tr>
<tr>
<td>D</td>
<td>Secondary Towns CBD</td>
<td>50</td>
<td>3</td>
<td>135</td>
<td>360</td>
</tr>
<tr>
<td>E</td>
<td>Residential</td>
<td>25</td>
<td>2</td>
<td>135</td>
<td>90</td>
</tr>
</tbody>
</table>

Source: NZFS Code of Practice for Fire fighting Water Supplies (1992)

7.4.2 Operations - Historical

The Romans are credited with the formation of organised fire fighting with the introduction of *Vigiles*. These men were tasked with checking and preventing fires. The firefighting tools employed by the vigiles were buckets and axes. This methodology remained substantially unchanged until the invention of hand operated pumps. The introduction, by insurance companies, of pumps coupled with dedicated teams of fire fighters reduced fire loses through the increased flow rate and more effective projection of water.

The most radical improvement to fire fighting methods came with the invention and introduction of the steam engine and it’s coupling to a water pump. As the motive systems have become more sophisticated so has the ability to pump larger quantities of water at higher pressures. This has the allowed the change from branches producing solid jets of water to nozzles that produce a range of water streams varying from jet streams to fine water mist.

Dr Charles Oyston in 1863 (Clark,1995) is credited with patenting the first spray nozzle. Oyston recognised that the more finely divided the water the more surface
area the water droplets possessed. This allowed the water to absorb more energy, thus making water use more effective and economical. Oyston's device was a smooth bore nozzle modified by the addition of fingers that could be slid into the jet stream. The fingers broke up the stream into a spray and thus produced droplets. The device must have reduced the throw of the water stream thus requiring fire fighters to be closer to the fire. These types of branches enjoyed some popularity in the later half of the 1800's (Linder, 1997).

7.4.3 Tactics

A review of fire fighting water requirements would be incomplete without considering the type of tactics employed to fight a given fire. The first task on arrival at a fire is for the fire officer to ascertain if there are persons trapped inside the structure and if so to then attempt a rescue. To begin suppression requires the officer to "size up" the fire and adopt a particular tactic. This is a subjective process requiring experience and training. Tactics can be divided into two categories. These are:

- **Defensive**
- **Offensive**

A defensive operation recognises that the fire has reached such a size that insufficient resource's can be mustered to extinguish the fire. This requires the fire fighters contain the fire so that it can burn itself out without affecting neighbouring property. The protection of adjacent property is achieved by projecting water onto the exposed surfaces so as to keep them cool and hence below their ignition point. If airborne burning brands are being produced, a competent officer will distribute resources downwind to combat potential spot fires. The quantity of water required will be a function of the exposed area and the equipment available to project water onto these exposures. This quantity of water will invariably be less than that required to extinguish the fire.

Offensive tactics rely heavily on the equipment employed. Considerable debate still continues regarding the sizes of hoses and nozzles and about the pros and cons of high-pressure fog nozzles vs. smooth bore. The use of specific hose and nozzle size is based on a variety of criteria. These factors are:
7.4.3.1 Maneuverability

The size and more specifically the weight of fire appliances require that these vehicles are not driven off public roads. This limitation may require long lays of hose to reach a fire. Typically the lay between the hydrant and the pump is a straight run and hence most brigades place flaked lay flat large diameter hose in a rear facing compartment that can be drawn off. Tactics vary as to how the hydrant is reached with the hose. Hydrants at close centres usually involve a fire fighter running the hose out from the vehicle. A number of American brigades with longer distances between hydrants, "pick up" the hydrant and run the hose from off the moving truck.

The type of hose run out to the fire varies considerably between brigades and of course the fire size on arrival. Most American brigades utilise lay flat hose in diameters ranging from 1 1/2" to 2 3/4". These hoses are usually preconnected in 200 to 300 foot lengths and connected via a screw coupling to an outlet from the pump. The hoses are laid up in a variety of combinations and sizes both in transverse and cross lay formats. The European preference is for hose in rolls that are run out individually by the firefighter.

Long lengths of hose are suitable for direct in line run outs but become unmanageable when required to manoeuvre them around obstacles and corners. The larger the hose the heavier it is, once filled with water and hence the more difficult to move. More manpower is required to move the hose around obstacles.

7.4.3.2 Reaction force

Smooth bore nozzles produce less reaction force and are thus easier to control for a given flow. This is an important aspect when considering manpower availability. Less reaction force will require less manpower to manoeuvre and hold a hose.
7.4.3.3 Reach

A smooth bore nozzle will throw water a greater distance due to its more efficient conversion of potential energy to kinetic energy. The solid jet will also penetrate a hot fire plume and be less affected by winds or other induced air stream effects. The solid jet is thus more effective at reaching the fuel and cooling the surface. This also produces less steam, which obscures the compartment and scalds fire fighters. Solid jets also entrain less air and thus cause less disturbance of the fire. Fog nozzles however have the advantage of producing a curtain of water that can protect fire fighters when close to a high radiation output fire. Water screens are very effective at shielding thermal radiation.

Chief Laymen is credited (Fornell, 1991) with the introduction of fine water spray nozzles in the aftermath of World War 2. Layman was the commander of the US Coast Guard fire school during this war and he rediscovered the effectiveness of fine water spray on suppressing compartment fires. He experimented with this on returning to civilian urban fire fighting and authored a book describing his findings (Layman, 1952). The book was widely read by fire service personnel and re-established the use of water spray branches within urban brigades. Layman did specify the criteria for water spray to be effective. These are:

- Fire confined within a compartment
- Use of a nozzle/ branch producing a fine enough spray
- Hot enough surface (ceiling) to turn the water to steam
- No fire fighters or occupants within the compartment

The last aspect is very important and clearly recognises that the use of fine water sprays in combination with an aggressive interior attack is inappropriate and will result in injury to the fire fighter. Layman always intended this as an external attack device.

The Swedish have modified this procedure so as to utilise it as an interior attack weapon. The high-pressure fine water spray is directed at the ceiling (hot layer) in small bursts. This keeps the steam generated to manageable quantities, which do not scald the fire fighter, or obscure his vision and allows him to approach the seat of the
fire safely. Once close enough to the fire, the fire fighter reverts to a straight water jet and directs this at the seat of the fire. The net result is an economical use of water. However the application of this methodology safely requires skilled and experienced fire fighters. For this reason training is central to its successful deployment. To train their fire fighters in this technique, the Swedish brigades have introduced realistic fire training for all their fire fighters. Various brigades in the U.K., Australia and New Zealand are adopting this type of training.

7.4.4 NZFS Operations – Current

Most NZFS appliances are fitted with mid-ship Darley pumps that can only be run while the vehicle is stationery. The appliances carry between 1000 to 1800 litres of water. The vehicles are typically equipped with four low-pressure delivery (LPD) outlets and two high-pressure delivery hoses (HPD).

The LPD is stored internally inside lockers within the vehicle in a roll or flaked on trays. The hose comes in diameters (Ø) of 45, 70 and 90 mm. The hoses are coupled together via double lug instantaneous couplings. These deliveries must be extracted from the locker, unrolled or run-out and connected to the pump outlet. Typically the feed to the pump from the hydrant standpipe is laid in 90mm Ø hose and the individual low-pressure deliveries are run in 70mm Ø hose. Hose lays from the hydrant to the pump are from the rear locker where the hose is preconnected and flaked. The pump operator breaks this hose as required to connect to the pump.

The two HPD are mounted externally on either side of the vehicle on a reel. The delivery can be unrolled straight from the vehicle and are permanently connected to the pump. The HPD system can be quickly brought into action and are thus the first tool used in most residential fires. Fires in larger buildings are usually beyond the range of the fixed hose length of 90m. This type of fire requires the deployment of the low-pressure deliveries.

The low-pressure delivery is usually 70 mm Ø hose, in both flake and roll in a side locker. The low-pressure delivery is fitted with an Elkhart nozzle that has an adjustable flow that can be set at 8 l/s, 11 l/s or 16 l/s at 700 kPa (125, 175 or 250 GPM). The normal setting is the middle setting. The most common Elkhart nozzle (branch) used by the NZFS is the SF model. This unit, at 700 kPa is capable of
throwing water up to 37m on straight stream. The standard hose flow and pressure drops used for calculations are recorded below (refer table 7.2).

Table 7.2: Flow and Pressure characteristics of NZFS hose

<table>
<thead>
<tr>
<th>Hose Size Diameter: mm</th>
<th>Nominal Flow l/s</th>
<th>Pressure drop per length: kPa</th>
<th>Length of Hose M</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>30</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>70</td>
<td>10</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>45</td>
<td>10</td>
<td>200</td>
<td>30</td>
</tr>
</tbody>
</table>

A typical hydrant will flow 30 l/s but this highly dependant on the running pressure and what size pipe is connected to the hydrant. The standard appliance is capable of pumping 60 l/s and hence will need a feed from at least 2 hydrants. Most appliances carry 8 lengths of 90 mm hose in its rear locker, which means if 60 l/s of water is required they can be no more than 100 m, away.

The trend in modern fire fighting has been to higher-pressure delivery branches. These devices provide a fine water spray or stream projected at high velocity. It has long been understood that fine particles of water present a high surface area to a fire and thus enable the rapid uptake of heat from the fire.

This heat removal together with the expansion that occurs when water changes from liquid to vapour provides the two main mechanisms of fire extinguishment. In addition the velocity of the water is important so as to penetrate the buoyant fire plume and overcome the turbulence associated with a fire. However the velocity of the water has a negative impact in that air is entrained into the jet and this can cause a flare up of a vitiated fire by the mixing of oxygen with the pyrolyzates (gaseous volatile's produced by the energy from combustion) that have already been produced by the fire. Fornell (1991) states that a 6 l/s spray nozzle working at 700 kPa can induce 5 to 10 m³/s of air movement. This effect is employed by firefighters as a quick method to ventilate smoke logged buildings. The nozzle is directed outside through an opening and this induces the smoke laden air to be drawn out with the water stream. The production of steam is accompanied by a large increase in volume that displaces the oxygen. This expansion also produces variations in air pressure that can force flame into uninvolved areas.
Water spray is very effective as a radiation screen and as such is used to protect the fire fighter when advancing on a fire and to provide a water curtain to protect other structures from fire radiation.

Most high-rise building are fitted with internal hydrant riser complying with either the latest New Zealand Standard NZS 4510 or its predecessors. When working from a building hydrant system the riser kit taken aloft is usually a combination of 70 and 45mm Ø hose. Byrne (1998) in his technical review for this Standard stated that a generally accepted coverage area for one branch was 100 m².

The standard technique applied in small residential fires is the use of a high-pressure hose to inject bursts of water mist into the upper hot layer. This allows the firefighter to safely advance to the seat of the fire. The correct use of this technique ensures that the pyrolyzates in the upper layer are sufficiently cooled to inhibit combustion when the gases do reach oxygen. The water mist also reduces the downward radiation onto the firefighter from the hot gas layer.

This technique has been utilised since the introduction of high-pressure deliveries. The use of variable pattern branches allows the use of the branch in both a fog pattern and a straight jet. Once the seat of the fire is reached, water is applied in a jet onto the burning material. This technique utilises the various extinguishing mechanisms that water has to offer and maximises the effectiveness of the cooling power of water.

The disadvantage of this technique is the need for the firefighters to advance into the compartment on fire and to be judicious in the use of water. Too much water will result in large volumes of steam production, which will inhibit visibility, and cause steam burns. The potential also exists to force, due to the expansion of the steam, the fire into a non-involved area. If circumstances change such as additional ventilation due to a window breaking, the fire can intensify rapidly and trap the fire fighter in a flashover. These inherent disadvantages have spurred the NZFS to instigate the use of compressed air foam (CAF).
CHAPTER 8  FIRE FIGHTING WATER

8.1 Introduction

The sizing of fire-fighting water requirements needs to assume a worst-case fire scenario based on good fire engineering principles. Most authors studying this relationship have sought to relate the required water quantity to either compartment floor area or volume.

Most modern urban communities are serviced by a reticulated water supply. The service utility company makes water available for domestic potable, sanitary and other miscellaneous purposes and also to serve the additional commercial demands for process water.

Over and above these requirements are the needs of fire fighting. Water for fire fighting is required for the building fire safety features such as automatic sprinkler systems, fire hose reels and building riser system and the fire hydrants located on the public main.

The sizing of water processing and storage facilities is an important economic decision. Water usage is time dependent and these fluctuations in use are absorbed by the storage facilities. Bulk water metering has provided an opportunity to predict water flow rates. However a large fire or even comprehensive flow test, i.e. where 6 to 8 hydrants are flowed simultaneously, can result in large sustained draw offs that can significantly diminish water supplies and reduce water pressures.

If water is drawn off in significant quantities in a low-lying area, the reticulated pressure can fall to below zero at an elevated location. This will possibly result in backflow and lead to contaminated water being drawn into the system. Backflow preventers can stop this occurring from connected sources downstream of a preventer but will not stop water being drawn in through imperfections in the pipe system.
Other aspects require consideration besides the flow and pressure characteristics. These are:

- **Adequacy** – required fire flow for sufficient time
  Adequacy of water supply is considered in terms of sufficient water flow for the duration of a fire.

- **Reliability**
  Reliability is a function of the amount of redundancy in the system arising from multiple storage facilities, interconnection and the type of delivery system. The reliability of the system reflects the ability of the system to remain in service despite continued maintenance, breakage’s or equipment failure.

- **Type of delivery system. Gravity Vs pump**
  Gravity systems are inherently more reliable than pumped system unless redundancy or standby power is incorporated into mechanically pumped systems.

- **Storage capacity**
  Storage is a function of tanks, reservoirs and other static supplies and their degree of interconnection.

- **Interconnection**
  Interconnection must also include sufficient valving to allow for isolation in the event of failures or the need to cross connect systems.

- **Alternative static supplies**
  Alternative non-portable supplies combined with adequate fire service resources can provide sufficient fire-fighting water. Distance to the risks and accessibility are important factors.

- **Emergency supplies**
Currently no accurate records are kept of water use during a fire incident and this will need to be addressed when the NZFS Fire Incident Reporting system (FIRS) is updated. Some figures have been deduced from the existing version of FIRS but these figures cannot be considered very accurate. (Refer Table 8.1)

Table 8.1: NZFS fire fighting water usage

<table>
<thead>
<tr>
<th>Duration to Stop Arrival (Hrs)</th>
<th>Number of Incidents</th>
<th>% of Total</th>
<th>Estimated total water used: m³</th>
<th>Average total water used per incident: l</th>
<th>Average peak water flow rate: l/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>3880</td>
<td>89.5</td>
<td>39,684</td>
<td>10,228</td>
<td>2.8</td>
</tr>
<tr>
<td>1 - 2</td>
<td>344</td>
<td>7.9</td>
<td>25,065</td>
<td>72,864</td>
<td>20.2</td>
</tr>
<tr>
<td>2 - 3</td>
<td>69</td>
<td>1.6</td>
<td>12,063</td>
<td>174,823</td>
<td>48.3</td>
</tr>
<tr>
<td>3 - 4</td>
<td>18</td>
<td>0.4</td>
<td>2,900</td>
<td>161,117</td>
<td>44.8</td>
</tr>
<tr>
<td>4 - 5</td>
<td>8</td>
<td>0.2</td>
<td>2,973</td>
<td>371,633</td>
<td>103.2</td>
</tr>
<tr>
<td>5 - 6</td>
<td>5</td>
<td>0.1</td>
<td>1,552</td>
<td>310,344</td>
<td>86.2</td>
</tr>
<tr>
<td>6 - 7</td>
<td>4</td>
<td>0.1</td>
<td>935</td>
<td>233,700</td>
<td>64.9</td>
</tr>
<tr>
<td>&gt; 8</td>
<td>8</td>
<td>0.1</td>
<td>3,501</td>
<td>437,640</td>
<td>121.6</td>
</tr>
</tbody>
</table>

The recording of water consumption will only be possible by the introduction of measuring and recording devices on individual pumps. The new CAF capable fire appliances being introduced by the NZFS have a flow measuring capability. If this were connected to a recording device the collection of water flow data would be possible.

8.2 Historical

A number of water supply engineers in the last century examined the problem of determining what was an adequate fire-fighting water supply. Most of the earlier relationships were based on the number of hose streams per head of capita. (refer table 8.2)

Table 8.2: Number of fire streams per head of population

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Population (In thousands)</th>
<th>Fire stream Flow in L/S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>4000</td>
</tr>
<tr>
<td>Shedd</td>
<td>1889</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Fanning</td>
<td>1892</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Kuichling</td>
<td>1897</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Freeman</td>
<td>1892</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Source: Linder(1997)
Equation 8.1

\[
\text{Water flow} = 2.8 P^{1/2} \quad \text{(Kuichling formulae)}
\]

Where \( P \) = population in thousands

Freeman published a definitive study on the use of a reticulated water supply for fire fighting. In his study he noted the importance of a big bore pipe network in supplying the large flow rates required in fire-fighting. He calculated the typical pressure drops of hose and proposed that hydrants be spaced at 76 m intervals in the CBD and 122 m in residential areas.

His recommendations for pressure were to run the system between 450 and 550 kPa and never to drop below 100 kPa.

The precursor to the Insurance Standards Office (ISO) was the National Board of Fire Underwriters (NFBU). The NFBU promulgated the following formula for calculating fire flow for CBD areas and municipalities.

Equation 8.2

\[
G = 1020\sqrt{P} (1 - 0.01\sqrt{P})
\]

Where:
\( P \) = Population in thousands
\( G \) = Fire flow in gallons/minute (GPM)

Converting to a water flow measured in litre/second (l/s) gives:

Equation 8.3

\[
\text{Flow(l/s)} = 64.4\sqrt{P} (1 - 0.01\sqrt{P})
\]

8.3 Numerical Models

The approach by many authors investigating the requirements for fire fighting have sought or stated relationships between fire-fighting water flow and a building parameter, either the floor area or compartment volume. The linkage is obscure and this is reflected in the wide variance of data taken from the various sources.
8.3.1 Insurance Services Office: ISO

The ISO method is considered by Linder (1997) to be the most comprehensive and widely used method of calculating fire-fighting water flow requirements.

The grading schedule for municipal fire protection produced by the American Insurance Services offices includes a procedure for grading water supply. Included in this is a method for calculating fire-fighting water requirements.

The schedule is used as a means of developing fire insurance rates for buildings. The schedule considers four main aspects (refer Table 8.3) of which water supply is of interest to this study.

Table 8.3: ISO Grading Scale

<table>
<thead>
<tr>
<th>Feature</th>
<th>Points per Feature (total)</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Supply</td>
<td>1950</td>
<td>39</td>
</tr>
<tr>
<td>Fire Department</td>
<td>1950</td>
<td>39</td>
</tr>
<tr>
<td>Fire Service communications</td>
<td>450</td>
<td>9</td>
</tr>
<tr>
<td>Fire Safety Control</td>
<td>650</td>
<td>13</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5000</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

The required fire flow is determined for a risk by consideration of the following parameters

- Size
- Construction
- Occupancy
- Exposure to other buildings

The ISO code calls for water supplies varying from 31.5 l/s for two hours to 757 l/s for 10 hours. The ISO method describes the fire fighting water requirement as needed fire flow (NFF). The NFF is defined as the rate of water flow necessary to control a fire in a specific building. It is intended as an input into assessing an insurance rating and is not intended as a design criterion. Irrespective of this, the ISO methodology is utilised as a methodology for calculating fire-fighting water requirements. The NFF is calculated as follows:
Equation 8.3

\[ NFF_i = (C_i) (O_i) (X+P)_i \]

Where:

- NFF is measured in gallons/minute (.063 l/s)
- \( C_i \) = building construction
- \( O_i \) = occupancy
- \( X \) = adjacent building exposure
- \( P \) = communication paths

The subscripts indicate that a weighting or % can be attributed to differing characteristics in accordance with how representative that characteristic is of the building. The individual factors are defined as follows:

**Building Construction Factor: \( C_i \)**

The construction factor is calculated as follows:

Equation 8.5

\[ C_i = 18 F \sqrt{A_i} \]

Where

- \( F \) = Construction factor
- \( A_i \) = effective building area
  
  = \( k A_f \)
- \( K \) = Area coefficient
- \( A_f \) = Floor area of largest floor (ft²)

The floor area used in this calculation is that of the largest fire-cell (if fire rating exceeds 1 hour) and 50 % of the next largest fire-cell on the same floor i.e. \( k=1.5 \).

If the building does not have a 1-hour rating, the \( K \) factors listed in table 8.4 must be applied to all the other floors of the building.
Table 8.4: Building Construction Factor

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>F</th>
<th>K</th>
<th>(C_i) Min. l/s</th>
<th>(C_i) Max. l/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frame</td>
<td>1.5</td>
<td>1.5</td>
<td>32</td>
<td>505 **</td>
</tr>
<tr>
<td>2</td>
<td>Joisted Masonry</td>
<td>1.0</td>
<td>1.5</td>
<td>32</td>
<td>505 **</td>
</tr>
<tr>
<td>3</td>
<td>Non-combustible</td>
<td>0.8</td>
<td>1.5</td>
<td>32</td>
<td>378</td>
</tr>
<tr>
<td>4</td>
<td>Masonry</td>
<td>0.8</td>
<td>1.5</td>
<td>32</td>
<td>378</td>
</tr>
<tr>
<td>5</td>
<td>Modified fire resistant</td>
<td>0.6</td>
<td>1.25 *</td>
<td>32</td>
<td>378</td>
</tr>
<tr>
<td>6</td>
<td>Fire resistant</td>
<td>0.6</td>
<td>1.25 *</td>
<td>32</td>
<td>378</td>
</tr>
</tbody>
</table>

* K = 1.25 (not exceeding two largest floors) only if vertical opening are fire rated otherwise K = 1.5 (not exceeding eight floors).

** \(C_i\) for single storey buildings not required to exceed a maximum of 378.5 l/s

** Occupancy factor: \(O_i\)**

The Occupancy factor \(O_i\) reflects the influence the specific use of the building has on the combustibility of the building (refer table 8.5).

Table 8.5: Building Occupancy Factor

<table>
<thead>
<tr>
<th>Occupancy Class</th>
<th>Type of Occupancy</th>
<th>Example</th>
<th>(O_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C - 1</td>
<td>Non-combustible</td>
<td>Steel warehouse</td>
<td>.75</td>
</tr>
<tr>
<td>C - 2</td>
<td>Low combustible</td>
<td>Residential, accommodation, commercial &amp; public</td>
<td>.85</td>
</tr>
<tr>
<td>C - 3</td>
<td>Combustible</td>
<td>Industrial &amp; Retail</td>
<td>1.00</td>
</tr>
<tr>
<td>C - 4</td>
<td>Free burning</td>
<td>Commercial &amp; Industrial</td>
<td>1.15</td>
</tr>
<tr>
<td>C - 5</td>
<td>Highly combustible</td>
<td>Storage &amp; Industrial</td>
<td>1.25</td>
</tr>
</tbody>
</table>

** Exposure and Communication factors: \(X_i\) & \(P_i\)**

\(X_i\): Exposure Factor

This factor identifies the needed water flow to protect an adjacent building from the effects of a fire within the building being studied. This factor varies between 0 (for no exposure) to 0.25. This factor is relative to the type of construction, the size of the exposed wall and the distance apart.

\(P_i\): Communication factor

This factor accounts for the potential fire spread through an open or enclosed communicating passageways.

\(P_i\) varies from 0 (no openings) to .30
Equation 8.6

$$(X+P)i = 1.0 + \sum (X_i + P_i)$$

$$1 < (X+P)i < 1.50$$

Where a building has a wooden roof, 32 l/s is added to the NFF. Sprinklered buildings require the water flow to satisfy the sprinkler system to a minimum of 32 l/s.

A comparison of water flows, assuming no exposure is provided for a commercial office block of varying construction type and increasing floor area (refer Figure 8.1).

Figure 8.1: Building floor area Vs Water flow requirements
8.3.2 Illinois Institute of Technology Research Institute Method (IITRI)

This system was based on a study of 134 fires. The equations were obtained from a curve fitting exercise. Two equations have been defined as follows:

Equation 8.7

(A) Residential Occupancies

\[ Q = 9 \times 10^{-5} A^2 + 50 \times 10^{-2} A \]

Or in metric units

Flow rate (l/min) = 0.0395A^2 + 20.38 A

Equation 8.8

(B) Non-residential Occupancies

\[ Q = 9 \times 10^{-5} A^2 + 50 \times 10^{-2} A \]

Or in metric units

Flow rate (l/min) = -5.7 \times 10^{-3} A^2 + 17.12 A

Where:

\[ Q = \text{Flow rate in GPM} \]
\[ A = \text{Floor area of fire in ft}^2 \text{ or } \text{m}^2 \]

These formulas are based on empirical data

8.3.3 Barnett method

The Barnett methodology for calculating fire fighting water requirements has been proposed in the Fire Engineering Design Guide published by the Centre for Advanced Engineering (1994) and in more detail, in the MacBar design guide (1999).

A Windows™ based computer program called Firesys is also under development that utilises this methodology. Similar information has been published in other articles by the author.
The methodology is based by comparing the energy absorbed by the fire fighting water supply with the energy being released by the fire. The fire fighting water is assumed to have been heated from ambient temperature to 100 degrees Celsius and at boiling point to change phase from liquid to vapour (Figure 4.2). Thus a litre of water is assumed to absorb 2.6 MW of energy.

The required fire fighting water flow rate is given by

Equation 8.9

\[ \text{Flow rate (L/S)} = \frac{Q_f}{n_a} Q_w \]

Where:

- \( Q_f \) = The heat release of the fire: MW
- \( n_a \) = Cooling efficiency (defined in the Fire Engineering Design Guide as 0.1 and 0.32 in the Macbar design guide)
- \( Q_w \) = The theoretical absorption energy of water going from a liquid at ambient temperature to vapour at 100 degrees Celsius, equivalent to 2.6 MW of energy.

If this method is applied to the existing NZFS fire fighting water Code of Practise water flow rates and utilising the efficiency factors proposed, a maximum cooling rate is arrived at (refer table 8.6).

Table 8.6: Fire fighting resources based on water supply

<table>
<thead>
<tr>
<th>Water Flow: l/s</th>
<th>Fire Service Resources</th>
<th>Theoretical Cooling MW</th>
<th>Suppression Efficiency: ( C_1 )</th>
<th>Actual Cooling MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>26</td>
<td>0.32</td>
<td>8.3</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>65</td>
<td>0.32</td>
<td>20.8</td>
</tr>
<tr>
<td>50</td>
<td>3</td>
<td>130</td>
<td>0.32</td>
<td>41.6</td>
</tr>
<tr>
<td>100</td>
<td>7</td>
<td>260</td>
<td>0.32</td>
<td>83.2</td>
</tr>
<tr>
<td>150</td>
<td>10</td>
<td>390</td>
<td>0.32</td>
<td>48.0</td>
</tr>
<tr>
<td>200</td>
<td>14</td>
<td>521</td>
<td>0.32</td>
<td>166.7</td>
</tr>
</tbody>
</table>
Using this methodology he proposed maximum fire cell sizes based on the available fire fighting water quantity. (refer table 8.7)

Table 8.7: Maximum fire cell size based on water supply

<table>
<thead>
<tr>
<th>Fire Load</th>
<th>Energy Density (kW/m²)</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Hazard Category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>400</td>
<td>250</td>
<td>625</td>
<td>1250</td>
<td>2500</td>
<td>3750</td>
<td>5000</td>
<td>10000</td>
</tr>
<tr>
<td>2</td>
<td>800</td>
<td>125</td>
<td>313</td>
<td>625</td>
<td>1250</td>
<td>1875</td>
<td>2500</td>
<td>5000</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>83</td>
<td>208</td>
<td>417</td>
<td>833</td>
<td>1250</td>
<td>1667</td>
<td>3333</td>
</tr>
<tr>
<td>4</td>
<td>1600</td>
<td>63</td>
<td>156</td>
<td>313</td>
<td>625</td>
<td>938</td>
<td>1250</td>
<td>2500</td>
</tr>
<tr>
<td>5</td>
<td>2000</td>
<td>50</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>750</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>6</td>
<td>3000</td>
<td>33</td>
<td>83</td>
<td>167</td>
<td>333</td>
<td>500</td>
<td>667</td>
<td>1333</td>
</tr>
<tr>
<td>7</td>
<td>5000</td>
<td>20</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
<td>800</td>
</tr>
</tbody>
</table>

Barnett proposed a number of methods to determine the heat release rate of the fire.

He introduces the concept of mean or time averaged mass-loss rate and defines the value \( R_{80/30} \) to mean the mass-loss rate between 80 and 30% of the fuel being consumed. The most common formula suggested is based on Kawagoes work.

Equation 8.10

\[
R_{80/30} = 0.917A_r(H_r)^{1/2}
\]

To arrive at the amount of energy released in the compartment, Barnett assumes 50% of the energy in a compartment fire is either vented to outside or remains at the end of the fire as un-burnt fuel.

8.3.4 Särdqvist Method

Stefan Särdqvist of the Lund Institute of Technology has been researching the application of engineering to fire fighting for a number of years. In his 1996 report he discusses the merits of pre-incident planning and the need to decide on the fire-fighting tactics in advance.

He proposes that part of developing a pre-incident plan for a building is to determine the expected heat release rate and compare this with the extinction capacity of the fire brigade. The comparison of these two aspects will reveal if an offensive or defensive
operation is feasible. If the extinction capability of the fire brigade exceeds the heat release rate of the fire, the fire can be aggressively attacked by applying water to the fire. Alternatively if the resources are deficient, the brigade will only be capable (hopefully) of protecting adjoining buildings from radiation and flying brands and will allow the fire to consume the readily available fuel and self extinguish.

Tactics are decided on in terms of protecting the following in accordance to the hierarchy given:

1) People
2) Property
3) Environment

The first two are clearly distinguishable, however the latter is not. Fire fighters are compelled to attempt to extinguish a fire by whatever means possible. The idea of letting a fire burn without putting water on it because it will result in less damage to the environment, is counter intuitive to most fire fighters. Särdqvist (1996, 1998) has attempted to seek a relationship between water requirements and a buildings floor area. He also compared his data with other researchers (refer Table 8.8 and Figure 8.2 & 8.3)

Table 8.8: Correlation of fire data

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Location</th>
<th>No. of Fires</th>
<th>Area Size of Fire M²</th>
<th>Water Flow correlation l/min</th>
<th>Regression coefficient R²</th>
<th>Water Volume V (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas</td>
<td>1950</td>
<td>UK</td>
<td>48</td>
<td>&gt;200</td>
<td>Q=560A^{0.41}</td>
<td>0.59</td>
<td>V=3500A^{0.24}</td>
</tr>
<tr>
<td>Baldwin</td>
<td>1970</td>
<td>USA</td>
<td>134</td>
<td>&gt;20</td>
<td>Q=74A0.66</td>
<td>0.66</td>
<td>V=123A^{0.12}</td>
</tr>
<tr>
<td>Särdqvist</td>
<td>1970</td>
<td>UK</td>
<td>307</td>
<td>0.1 - 1000</td>
<td>Q=61A0.57</td>
<td>0.49</td>
<td>V=115A^{1.1}</td>
</tr>
</tbody>
</table>

Source: Särdqvist (1989)
Figure 8.2: Comparison of water flow Vs area (0 – 100 m$^2$)

Figure 8.3: Comparison of water flow Vs area (100 – 2000 m$^2$)
Särdqvist proposes that the heat release rate be identified either by using a $\alpha t^2$ fire or alternatively the Hazard 1 computer model. The method proposed for calculating the extinguishment capability of the fire brigade was to estimate the ability of the fire service to muster resources at a given building against a time line of the growing fire. The fire service resources have a water pumping capability and hence this will increase as more resources arrive on the fire ground. The water projected onto the fire must be given a heat absorption capability and he suggests the use of the calculation proposed by Barnett. This method calculates the theoretical cooling capability of water and modifies this figure by an efficiency coefficient.

Särdqvist uses the energy required to sensible heat water to $100^\circ C$, convert it to vapour and then heat it to $600^\circ C$. He also proposes an efficiency of 0.3 in comparison to the factor of 0.33 proposed by Barnett.

Rasbash (1986) noted in his experimental studies that it was necessary to remove 30 to 35 % of the released energy to successfully extinguish a diffusion flame. This then reduces the effectiveness of water in terms of its theoretical cooling capability to around 10%.

To account for the varying efficiencies of different methods of water projection, Särdqvist proposed the following efficiency factors (refer table 8.9).

Table 8.9: Efficiency factors of varying fire service waterway equipment;

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>Interior Fog Nozzle</th>
<th>Large droplet Nozzle</th>
<th>Long Range Monitor</th>
<th>Long Range Nozzle</th>
<th>Short Range Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

As already discussed the optimum water droplet size required for fuel surface cooling is larger (2.0 - 3.0 mm $\varnothing$) than that for flame cooling and thus it is important that the tactics applied reflect the extinguishment method adopted.

8.3.5 Iowa State University Method (ISU)

The Iowa State University Method defies the amount of water needed to extinguish a fire based on the water ability to absorb the energy of the fire and its ability to displace oxygen when it changes state.
Equation 8.11

\[
\text{Flow (GPM) rate} = \frac{V}{100}
\]
\[
V = \text{volume of space on fire (ft}^3\text{)}
\]

Or in metric units

\[
\text{Flow (l/s) rate} = \frac{V}{45}
\]
\[
V = \text{volume of space on fire (m}^3\text{)}
\]

The formula assumes that 80% of the applied water is converted to steam and that it is applied within 30 seconds. The formula is based on several Danish studies and some real fire tests conducted at ISU. The equation assumes the complete compartment is on fire.

8.3.6 Ontario Building Code Method

The Ontario Building Code requires an adequate fire fighting water supply that is immediately accessible and available. The water supply is required to have either sufficient water volume and/or flow to enable the fire service to control fire growth until the building is safely evacuated and search and rescue operations have been carried out. The water supply should also be adequate to prevent fire spread to adjacent buildings and provide a limited measure of both property protection and protection against fire growth in buildings with contents that could result in significant environmental damage. In this instance the Code recognises that control can only be achieved in the early stages of a fire.

The Ontario building code requires for new non-sprinklered buildings a supply of water available for fire fighting purposes not less than the quantity derived from the following formula:

Equation 8.12

\[
Q = KV S_{rot}
\]

Where

\[
Q = \text{minimum supply of water in litres (l)}
\]
\[
K = \text{water supply coefficient from Table 8.10}
\]
\[
V = \text{total building volume in cubic metres (m}^3\text{)}
\]

This standard requires a minimum water supply duration of 30 minutes in recognition that the fire service will only be able to save the building if it arrives soon after fire.
initiation. For sprinklered buildings the code does not require any additional fire-fighting water.

Table 8.10: Water Supply Coefficient – K

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Classification in Accordance with Ontario Building Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-2, B-1, B-2, B-3, C, D</td>
</tr>
<tr>
<td>Non-combustible</td>
<td>10</td>
</tr>
<tr>
<td>Heavy timber</td>
<td>16</td>
</tr>
<tr>
<td>Combustible with Fire resistance</td>
<td>18</td>
</tr>
<tr>
<td>Combustible</td>
<td>23</td>
</tr>
</tbody>
</table>


$S_{Tot} =$ total of spatial coefficient values from property line exposures on all sides, as obtained from the formula:

Equation 8.13

$$S_{tot} = 1.0 + \left[ (S_{side1}) + (S_{side2}) + (S_{side3}) + \text{etc} \right]$$

where $S_{Side}$ values are obtained from a graph

and $S_{Tot}$ need not exceed 2.0

Table 8.11: Minimum Water Supply Flow Rates, Ontario Building Code

<table>
<thead>
<tr>
<th>Q : Minimum Water Supply</th>
<th>Water Supply Rate l/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Storey Building:</td>
<td></td>
</tr>
<tr>
<td>$A_r &lt; 600 \text{ m}^2$</td>
<td>30</td>
</tr>
<tr>
<td>$Q &lt; 108,000$</td>
<td>45</td>
</tr>
<tr>
<td>$108,000 &lt; Q &lt; 135,000$</td>
<td>60</td>
</tr>
<tr>
<td>$135,000 &lt; Q &lt; 162,000$</td>
<td>75</td>
</tr>
<tr>
<td>$162,000 &lt; Q &lt; 190,000$</td>
<td>90</td>
</tr>
<tr>
<td>$190,000 &lt; Q &lt; 270,000$</td>
<td>105</td>
</tr>
<tr>
<td>$270,000 &lt; Q$</td>
<td>150</td>
</tr>
</tbody>
</table>

These water requirements are shown in figure 8.4

Figure 8.4: Water supply flow rates

8.3.7 National Research Council of Canada (NRCC) Method

A computer model for estimating fire-fighting water requirements is in the process of being developed by the Fire Risk Management Program of the National Research Council of Canada (NRCC). The methodology employed by the program is outlined in the article by Torvi et al (1999). The article indicates that the following aspects are considered in the model.

- Geometry of building
- Variable fire scenario
- Fire detection
- Fire suppression
- Adjacent properties
- Effectiveness of the fire service

From this information the model calculates, at the time of fire service intervention, the required flow rates for suppression of the fire and protection of exposures. The model allows the input of a heat release rate from either fire test data or from information taken from other models.
A fire sub-routine is provided to calculate the heat release rate based on the building geometry, fuels present and a selected fire scenario.

These scenarios are:

- Liquid pool fire
- Storage rack fire
- \( i^2 \) fire

Otherwise the user can input a heat release rate for the expected fire scenario. This is typical of most models and is one of the inherent weaknesses, in that it relies on the choices made by the user.

The model can also determine detection and sprinkler activation times or alternatively a time can be manually entered. The time to fire service intervention can be calculated from running a sub-routine that accounts for the various activities associated with notification, dispatch, preparation, travel and setting up.

The effectiveness of the fire service in applying water is estimated by the use of two values. These are:

\( \eta_a \): effectiveness of suppression (Sårđqvist indicates values between 0.1 and 0.4)

\( \eta_b \): effectiveness of exposure protection

An allowance for protection of exposures is also provided. The determination of fire service intervention time is user entered. In this regard the information from the AFAC FBIM could be utilised. This will provide a time to compare with the fires heat release curve.

The calculation of water flow required is based on the Barnett method already described.

Equation 8.14

\[
M_w = \frac{Q_{fm}}{\eta_a} Q_W
\]

Where:

\( M_w \) is the required flow rate of water to absorb the energy of the fire (l/s)
Q_{in} \text{ is the heat release rate of the fire at intervention}
Q_{w} \text{ is the theoretical energy absorption of water (2.6 MW/l/s)}

The required flow rate for exposure protection is added to this figure. The total water required is the sum of these values.

**8.3.8 National Fire Protection Association (NFPA) 1142 Method**

This Standard (formerly NFPA 1231) defines water requirements for suburban and rural fire fighting for areas without a reticulated supply. The methodology employed is similar to the ISO and Ontario Building Code method.

**8.4 Empirical Methods**

**8.4.1 Introduction**

The analysis of the NZFS FIRS data conducted by Beever & Davey (1999) indicates that the numbers of large fires are few in number and spread equally among building types (refer figure 8.5)
Figure 8.5: Types of property involved in fire

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>41%</td>
</tr>
<tr>
<td>Others</td>
<td>33%</td>
</tr>
<tr>
<td>Storage</td>
<td>4%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3%</td>
</tr>
<tr>
<td>Primary Industry</td>
<td>7%</td>
</tr>
<tr>
<td>Commercial</td>
<td>4%</td>
</tr>
<tr>
<td>Education</td>
<td>2%</td>
</tr>
<tr>
<td>Health Care</td>
<td>1%</td>
</tr>
<tr>
<td>Public</td>
<td>5%</td>
</tr>
</tbody>
</table>

Source: NZFS incident statistics 1993 - 1997

This would seem to indicate that the type of occupancy and the likelihood of ignition are irrelevant. Many studies have related horizontal fire area with the required water flow rate.
### 8.4.2 NZFS Fire Incident Reports

An analysis of the data collected by the NZFS Fire Incident Reporting System (FIRS) shows that on average 35% of the incidents handled by the fire service are fires (refer Figure 8.6).

Figure 8.6: Incidents handled by fire service

![Pie chart showing incident types](image)

Source: NZFS incident statistics 1993 - 1997

Of these fires, only 33% are structure fires. Chimney fires are dealt with separately and represent 7% of calls (refer Figure 8.7).
Of these fire incidents 41% are residential house fires (refer Figure 8.5). An analysis of these fire incidents reveals that 65% of these fires are extinguished by the fire service utilising a few high-pressure deliveries or one low-pressure delivery. Building occupants or passer-by are responsible for extinguishing 20% of the fires (refer figure 8.8 and 8.9)
An analysis of all fires and specifically structure fires reveals that on average, over a three-year period, a total of 96% of fires were either extinguished with non-reticulated water supplies or with less than 10 L/S of reticulated water supply. The remaining 4% of fires required more water. This represents a total of 290 fires (refer fig. 8.9).
The number of structures lost (100% damage) was 480. The study by Beever & Davy (1999) of water quantities used during a fire indicates that 90% of structural fires are controlled in less than one hour and a further 9.5% are controlled within 3 hours. (refer table 4.8)

Not all fires are attended by the fire service and overseas data indicates that only between 10 to 40% of fires are reported to the fire service (Fontana et al., 1997). In this regard the fires that go unreported are usually small and cause little damage. These factors emphasis the importance of first aid fire fighting equipment. Refer Table 8.12.
Building fires where structural damage occurs are identified separately. When the % of damage is analysed the data reveals that 30 % suffer more than 50 % structural damage and that 22% of buildings suffer sufficient structural damage (over 80%) to become insurance write-offs (refer figure 8.10).

Figure 8.10: % Structural damage due to fires

Source: NZFS incident statistics 1993 - 1997

8.4.3 London Fire Statistics

The study by Särdqvist (1998) into fires in non-residential fires in London between the years 1994 and 1997 reveals that most fires were extinguished with 10 L/S or less. An
interesting conclusion that Särđqvist came to is that both water flow rate and water quantity used where proportional to the square root of the fire area.

Särđqvist states that 75% of fires did not increase in size after the fire service arrived. This emphasises the importance of early detection. His studies also reveal that very few fires exceed 100 m² in area.

8.5 Mathematical methods

The various theoretical models available to predict fire suppression are complex and require data for their application that is not yet available. Rasbash (1986) recognised this when he proposed the “firepoint” equation:

Equation 8.15

\[ M''_w = \frac{S_c}{\lambda_w} \]

Where;

- \( M''_w \) is the critical extinguishing agent flow rate
- \( S_c \) is the critical value of net sensible heat flux : Wm⁻²
- \( \lambda_w \) is the abstraction (heat removal capacity) rate of the extinguishing agent: JKg⁻¹

A number of studies have been undertaken over the years to identify the required theoretical water quantity to suppress a fire (refer table 8.13).

Table 8.13: Experimental suppression tests

<table>
<thead>
<tr>
<th>Experiments by</th>
<th>Date</th>
<th>Type Of Fire</th>
<th>Compartiment Size M³</th>
<th>Flow Rate L/s</th>
<th>Spray Density L/m²</th>
<th>Applied Water L</th>
<th>Total FLED Mj/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas &amp; Smart</td>
<td>1950</td>
<td>.13</td>
<td>.17</td>
<td>2.5</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rasbash</td>
<td>1955</td>
<td></td>
<td>2.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JFRO</td>
<td>1960</td>
<td>Class A</td>
<td>49 (4.3<em>4.3</em> 2.65)</td>
<td>1.9</td>
<td></td>
<td>32</td>
<td>590</td>
</tr>
<tr>
<td>Rasbash</td>
<td>1962</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 l/m²</td>
<td></td>
</tr>
<tr>
<td>Salzberg &amp; Vodvarka</td>
<td>1970</td>
<td>Wood Crib</td>
<td>32</td>
<td>25mm</td>
<td></td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Scheffey &amp; Williams</td>
<td>1991</td>
<td>Wood Crib</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NBFU</td>
<td>1955</td>
<td>Wood Crib</td>
<td>1.2 (.9<em>9</em>1.2)</td>
<td></td>
<td></td>
<td>4 l/m²/min</td>
<td></td>
</tr>
</tbody>
</table>

Source: Drysdale (1997)

Recognising that the main mechanism of extinguishment of class A fires is by fuel cooling, most researchers have utilised water application rates in terms of fuel surface...
area. It would appear logical to use this data in a method to calculate fire fighting water requirements.

A variety of experiments have been carried out to determine the efficiency or otherwise of the method of manual water application i.e. spray or jet. It has been concluded that the method of application is very relevant to the overall extinguishment efficiency (Heskestad, 1980).

It has suggested by Takahashi (1985) that the rate of water application is important in that the entire fuel surface must be swept before reignition occurs. The importance or relevance of this to manual fire fighting is the need to extinguish the fire and then maintain the fuel surface below its characteristic ignition temperature (Fuchs) or firepoint (Rabash). In large fires where the water is applied progressively, the fuel already extinguished must be shielded from the radiation being emitted from the still burning portion.

Investigations into attenuation of radiation by water show that the best attenuation is achieved when the radius of the droplet equals the wavelength of the radiation. However all real fires emit radiation over a broad-spectrum dependant on the type of fuel burning. In real fires this will be a broad mix of fuel types. On the other hand, fire-fighting nozzles (branches) deliver a polydisperse range of droplet sizes. To arrive at an optimum situation, the range of droplet diameters must correspond to the wavelengths where the most intense radiation occurs. Another important factor in attenuating radiation is the mass of droplets in the path of the radiation and the path length of the radiation through the spray pattern (Grant et al, 1996).

In this regard small particles are more effective because of their lighter mass and hence increased buoyancy. However this effect is countered by the shorter residence time due to lighter droplets being either evaporated or carried away in the plume.

diMarzo (Grant et al, 1997) concluded that overall response of solid materials to spray cooling could be estimated by knowledge of the thermal diffusivity of the material \(\alpha=k/\rho c\) and the time constant (Drysdale, 1985). This may provide a simple but realistic methodology for calculating fire fighting water requirements.
In this regard the method would need to account for the following parameters:

- Surface temperature of fuel
- Specific heat of fuel and compartment surfaces
- Conductivity of fuel

In a post flashover compartment, most models assume a uniform temperature $T_g$. The typical class A fuel has a low conductivity and thus a thermally thin approach could be adopted (Drysdale, 1985). This would assume that a small thickness of fuel was influenced by the fire. The specific heat of the fuel is more variable and this is further complicated by water moisture content.

The Rasbash firepoint equation was developed further by Fuchs (1984). He correlated a number of experiments with his model and determined that 38% of the water was required to take up the heat of combustion and the remaining 62% was required to cool the fuel surface.

A computer based model called the fire demand model has been developed, using heat and mass balance to simulate the manual suppression of post-flashover compartment fires. Tuomisaari (1991) conducted a number of experiments using manually applied fog nozzles to ratify this model. He concluded that he did not have an accurate mechanism to account for the various losses of the water fog to the outside or evaporated in the plume. Grant (1997) reported that Pietrzak had conducted a comparison of the available experimental data and that he had concluded that the data compared well. The Grant report concludes by saying that more work is required in validating this model.
CHAPTER 9 . DISCUSSION

9.1 Introduction
The research conducted for this report has emphasised to the author the need for a fresh approach to sizing fire fighting water requirements. A robust model is required that links the research carried out in this field with the actuality of fire fighting. This model must be based on performance-based criteria that match resources with outcomes.

9.2 Extinguishment model
A comparison of the various numerical fire fighting water models based on a building parameter indicates a wide variance in flow rate with respect to area. A direct comparison is not possible due to the variation of definitions of either area or volume.

The ISO method utilises the floor area of the largest fire cell plus 50% of the floor area of an adjacent fire cell where as the IITRI method uses fire area, which could be assumed to be either a single room or the complete fire cell. The ISU method utilises the volume of space involved in fire. The attached figure (figure 9.1) plots area versus flow rate taking the minimum and maximum cases for each method. To normalise the comparison the water required for the protection of exposures has been ignored.

The ISO method calls for water flows from 32 to 757 l/s and storage times from 2 to 10 hours. In comparison the Ontario method requires flows from 30 to 150 l/s and a storage amount to last 30 minutes.

When compared with the actual equipment used for the majority of fires the Ontario code seems more reasonable, however the fundamental principal of this Code is that only a measure of property protection is included. An upper cap must be set on water quantity and thus fire size when it is recognised that to successfully extinguish the fire will cause more environmental damage and not change the outcome.
Figure 9.1: Comparison of Empirical Methods
The research conducted into the extinguishment of class A fires clearly indicates that the main mechanism of extinguishment is by the cooling of the fuel surface. Most researchers for this reason have given their results of water usage in terms of fuel surface area.

The various methodologies used for calculating fire fighting water reviewed in this report have ignored this basic fact. Most methods proposed have attempted to predict water usage based on correlations with a buildings parameter, either floor area or volume. Later approaches have been to relate water usage with the heat release rate of the fire. Whilst recognising heat release is intimately related to the radiation emitted back to the fuel, this approach would also need to consider the type of fuel burning, the size of the compartment etc.

The Fire Demand Model discussed in section 8, once validated could be used to determine fire fighting water requirements.

9.3 Fire Service Operations

With the changes that have occurred in legislation and the advances in technology it is clear from the foregoing that a review of the existing NZFS Code of Practice for fire fighting water supplies is required.

This needs to be done in conjunction with a review of fire service tactics. This will involve analysing the resources responded to fires. The requirements for responding a heavy pump, capable of pumping in excess of 60 l/s, appears never to have been analysed thoroughly. These pumps typically exceed a weight of 15,000 kg and cost in excess of $750,000 to purchase and equip. The running costs in terms of fuel, maintenance and repairs are also high.

Given that most fires are in residential properties and require less than 10 l/s of water to extinguish, the need for such a large machine is neither cost affective nor efficient. A smaller machine would be more agile, quicker to respond, cost effective and capable of getting into more confined areas and use weight-limited driveways without getting stuck. The training in emergency vehicle driving skills would also be less onerous. This is pertinent when a fire service relies on volunteers who do not get regular exposure to driving heavy vehicles under emergency conditions.
Turnouts are driven by the manpower requirements rather than equipment and this also seems to indicate a mismatch of equipment and manning resources.

9.4 Proposal

The methods discussed above provide a variety of methodologies to relate building type to quantity of fire fighting water required. The author has considered a number of methods for determining the expected water requirements.

Given that heat release rate and the heat content of the fuel are related, this appears to be the best interim measure for deriving a water quantity. The various prescriptive fire fighting water models described in previous sections require a considerable amount of judgement to apply successfully. The derivation of many of the variables is not described sufficiently to make good choices. Torvi (1999) in his paper compared five of the models and discovered variances in the predicted water flows of up to one order of magnitude. In the light of the deficiencies in existing methods it is proposed to utilise the same formulae used in the COMPF2 program to provide a heat output from a ventilation controlled fire. Fuel controlled fires will require an estimation of the mass burning rate.

These figures can be related to the cooling power of water by the method proposed by Barnett. His method proposed that 1 l/s of water has a cooling capacity of .84 MW.

However other aspects of the firecell/building need consideration such as:

- Occupancy
- Fire safety systems

As discussed it is considered essential to provide incentives where fire safety measures are installed and thus to this end it is proposed to recognise both first aid fire fighting and the use of automatic sprinkler systems.

To account for these factors it is proposed to factor the average heat release rate as follows:

Equation 9.1

\[ Q_{req} = K_1 \times K_2 \times Q \]
Where $Q$ is the heat release rate (kW)

And the coefficients are given below:

$K_1$ coefficient to account for human intervention and first aid fire fighting

Table 9.1: $K_1$ Human Intervention

<table>
<thead>
<tr>
<th>No facilities or building unoccupied</th>
<th>Building occupied and fire hose reel or extinguisher available</th>
<th>Building occupant trained in fire fighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>1</td>
<td>.9</td>
</tr>
</tbody>
</table>

$K_2$ coefficient to account for fire safety features

Table 9.2: $K_2$ Fire Safety features

<table>
<thead>
<tr>
<th>No detection or suppression system</th>
<th>Heat or smoke detection system</th>
<th>Fire suppression system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_2$</td>
<td>1</td>
<td>.5</td>
</tr>
</tbody>
</table>

The required heat release rate $Q_{req}$ is then compared with the suitable water flow rate taken from table 6.3.

It can be deducted that a given fire size and water quantity leads to a maximum firecell size. Refer Table 6.4.

Other aspect that must be considered is the ease in which this water can be utilised, the reliability of supply and the need for protection of exposures.

The calculation for the protection of exposures is necessary where adjoining buildings can be affected by radiation from the burning building. The New Zealand Building Code requires the protection of neighbouring property but does not require protection of buildings on the same legal title. In this respect adjacent property can still be affected by radiation from the fire. To overcome this, the fire service must project water onto these exposures.
Thus the water required for protection of exposures is:

Equation 9.2

\[ Q_{\text{water}} = \text{Exposed area} \times \Phi \]

Where

\( Q_{\text{water}} = \) The quantity of water required per square meter of exposed area

Drysdale recommends (1998) \( \Phi = 0.1 \, \text{l/s/M}^2 \)

The current NZFS Code of Practise for Firefighting Water categorises the fire risk into five water supply classifications. As already discussed these five risks are ill defined and based on geographical area rather than specific building fire risks.

To maintain some commonality with the existing code it is suggested that four of the five classes are retained. The existing A Class (Large fire Risk) needs to be replaced with a more onerous requirement for flow and storage. This recognises the large peak flows required for high challenge fires. A new zone should be introduced at the lower end for use in residential areas (refer table 9.5).

Table 9.3: Water Classification Table

<table>
<thead>
<tr>
<th>Old Class</th>
<th>New Zone</th>
<th>Water Flow</th>
<th>No of Hydrants</th>
<th>Storage Water Quantity</th>
<th>Distance x m closest Hydrant: Distance to Risk</th>
<th>Flow By Hydrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>1</td>
<td>400</td>
<td>12</td>
<td>8,640,000</td>
<td>6 45 m</td>
<td>33.3</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>200</td>
<td>8</td>
<td>2,880,000</td>
<td>4 45 m</td>
<td>25</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>100</td>
<td>6</td>
<td>10,80,000</td>
<td>3 45 m</td>
<td>16.7</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>50</td>
<td>4</td>
<td>360,000</td>
<td>2 70 m</td>
<td>12.5</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>25</td>
<td>2</td>
<td>90,000</td>
<td>1 70 m</td>
<td>12.5</td>
</tr>
<tr>
<td>New</td>
<td>6</td>
<td>10</td>
<td>1</td>
<td>36,000</td>
<td>1 70 m</td>
<td>10</td>
</tr>
</tbody>
</table>

Requirement

- 1 Hydrant within x M of Risk.
- Remaining Hydrants to be within 270 M distance, as measured along public roads and rights of way.
9.5 Future Developments

9.5.1 Introduction

An analysis of the many events that occur in the time between the initiation of a fire and its extinguishment reveals many opportunities to reduce this time interval. Any reduction in this time interval will mean the fire service can attack the fire earlier and reduce the quantity of fire fighting water required. The initiatives discussed below will also reduce the incidence of fire and its cost to the community.

Hand in hand with the introduction of new technology or techniques is the requirement for training. The effective utilisation of the increasing number of fire fighting tools provided requires not only the proficient use of the tool but also knowledge as to the applicability and effectiveness to the situation presented.

The drive to reduce the dangers faced by fire fighters also provides an additional incentive to introduce new technology into the fire ground. Although fire fighters in New Zealand enjoy a better working safety record than say the construction industry, the drive to reduce this risk further is always present. The risks inherent in adopting aggressive interior attacks are many and varied. Apart from the obvious dangers of the fire and structural collapse, numerous risks present themselves when working in a hot, low visibility environment. A common problem in modern buildings is the failure of particleboard floors when subject to a little heat and moisture. The glue holding the particleboard together losses its strength and fails when it gets warm and/or wet. Many firefighters have stood on these floors only to have them give way. The failure of the floor also exposes nails. For these reasons, compressed air foam is attractive as it provides an effective mechanism for external fire attack.

9.5.2 Fire Safety Education

An ongoing influence on fire service operations is society’s drive to reduce the incidence and consequence of fire. This drive is aimed at both the human and financial cost of fire. To this end it is necessary to consider the macroscopic effects of fire in terms of ongoing medical costs, rehabilitation, loss of amenity of public buildings and economic disruption due to the loss of commercial and industrial premises.
The fire safety campaigns underway to educate the general public such as the need for
smoke alarms in residential homes will lead to earlier discovery of fires and hence
earlier notification. The more widespread adoption of automatic sprinkler systems will
also reduce the number of fire losses.

9.5.3 Realistic Interior Fire Training (RIFT)

To assist fire fighters in recognising and understanding the dynamics associated with
fire; a realistic internal fire-training program is being introduced into the NZFS (refer
Rattel article).

The application of water to the fire by a fire fighter will vary according to the
individual’s experience and training.

The introduction of realistic interior fire training buildings together with refresher
training for both paid and volunteer staff will produce a safer, more efficient and
successful fire-fighting approach.

9.5.4 Thermal Imaging Cameras (TIC)

Thermal imaging cameras allow fire fighters to navigate around inside smoke logged
buildings faster. They operate by using the infrared part of the electromagnetic
spectrum to detect differences in heat. These devices can distinguish human bodies
against a cooler background or “see” the seat of a fire though visible obscured. This
enables fire fighters to conduct search and rescue operations and locate the seats of
fire faster. These cameras can also be used to locate hot spots that are invisible to the
human eye.

9.5.5 Compressed Air Foam (CAF)

The NZFS is introducing compressed air foam systems (CAF) with all new first
response vehicles. At present the CAF system will be in addition to the existing high-
pressure delivery (HPD) hoses. The CAF system hoses are 41 mm hose with screwed
couplings and will be permanently connected and stored on easily accessible reels.
The branch is a 25 mm straight nozzle with an on/off control. The nozzle can be
quickly interchanged with a standard combination nozzle. The introduction of CAF
must be considered one of the most significant recent advances in fire fighting.
The use of CAF has the following benefits:

- Reduction in water consumption
- Foam adheres to fuel
- Reduction in pressure drop through hose
- Maintain visibility due to reduction in steam
- Reduce flare ups
- Ability to apply from outside building
- Lower % concentration than other additives

The work done by Dunn (1998) on unshielded fires and by Gravestock (1998) on shielded fire indicates a 35 % reduction in water usage when using CAF. These studies also indicated that reignition is less likely with CAF and this further reduces the quantity of water used.

The figures quoted exclude the additional water used for damping down and the protection of exposures from radiation. The fire service project water between the fire and adjacent buildings, or onto the adjacent building, so as to minimise any damage from thermal radiation to the non-involved building. This water will have no effect on the reduction of the fire size but must be taken into account for calculating water requirements.

The traditional fire-fighting procedure for a residential household fire is to advance into the building and extinguish the fire with a high-pressure delivery.

The fire fighter forces the fire to vent through the windows, in that the fire fighter positions himself between the fire and the unburnt portion of the building. This procedure requires fire fighters to be skilled in the use of self-contained breathing apparatus (SCBA).

The use of CAF allows fire fighters to attack the fire through external openings and thus the need to enter the burning building is removed. This has the advantages, already discussed from the safety point of view. An added advantage for volunteer crews, who do not get a lot of experience in the use of SCBA, is the reduced need for the use of breathing apparatus. As CAF can be applied from outside the building, this
obviates the necessity to work in zero visibility in SCBA. The mounting of a CAF nozzle on a tele-boom (hydraulic arm) would allow a greater reach and thus fires in multi-storey buildings can be suppressed.

The foam is produced by the injection of foam concentrate into the water stream. This occurs in the piping between the pump outlet and the manifold discharge. Compressed air is then also introduced into the plumbing. The foam reduces the surface tension of the water in the hose and hence lowers the pressure resistance of the hose to the passage of the water/foam. This means the mixture may be pumped further. The selection of the fixed bore tip will dictate the type of foam generated and the throw of the foam. A smaller tip produces wetter foam but a longer throw than a larger tip.

CAF is termed a class A foam and is used at lower concentrations than other foams. These concentrations vary between 0.1 and 1.0 %. Because the concentrate is lower, CAF consists of a higher % of water. CAF breaks down the surface tension of water, which thus allows the foam to penetrate vegetation and stick to vertical surfaces. Because it adheres to the fuel surface it wets the fuel for a longer time and because of its bulk, brings more water into intimate contact with the fuel. The foam blanket shields the fuel from impinging radiation, which thus stops the production of more pyrozlates. The CAF blanket also excludes the oxygen from the fuel.

As the name implies the foam is aspirated with compressed foam at the truck rather than the traditional mechanical aspiration that occurs at the branch. This is because the pressure of the compressed air pushes along the foam and means the hoses are much lighter (approx. 65% lighter) and thus easier to manoeuvre. The reduction in pressure drop due to the low surface tension of the foam means longer lays of hose can be made. This is especially important when extinguishing vegetation fires, which are typically distant from where pumps can be located.

The main disadvantage of CAF is the inability to produce a dispersed wide pattern spray so as to protect fire fighters against the effects of radiation from the fire. To overcome this problem research is being conducted into prototype tips that are capable of producing a water shield as well as foam.

Preliminary tests into the effect CAF has on forensic evidence reveal that fingerprints etc remain unaffected. (Noble, 1999)
The NZFS CAF pumps are fitted with a helical screw water flow measuring. These are subject to mechanical damage and thus must be protected by upstream strainers. The electronic signal from the flow-measuring device is fed to an electronic gauge. This gauge has in-built logic to proportion the quantity of foam injected into the water stream based on the measured water flow. These measuring devices could be replaced with magnetic devices. However these devices are more expensive but having no moving parts, cannot be damaged. The magnetic devices have the drawback of attracting ferrous material and thus must be regularly cleaned.

This water flow data could be recorded by a data logger and would thus provide valuable information on the water used during a fire. This information coupled with other parameters will provide invaluable data on the operation and use of peak water flows, total water used and the time it takes to physically intervene in a fires growth.

**9.5.6 Positive Pressure Ventilation (PPV)**

Positive Pressure Ventilation is a procedure where fire fighters utilise mechanical fans to pressurise a structure so as to clear smoke and flames away from an advancing fire fighting team. This allows fire fighters to advance into residential properties faster. It also provides for the effective and safer use of high-pressure branches. PPV fans introduce an induced air stream into the building with the aim of clearing smoke and heat away from the intended entry point and pushing the products of combustion out through an external vent. This allows fire fighters to advance in a cool stream of air, unhindered by heat and visibility problems, onto the fire. Care must be taken with this procedure so as to not force the fire into a non-involved area.

**9.5.7 Robots**

The use of remote controlled vehicles is commonplace in many hazardous industries such as nuclear power plants, petroleum exploration undersea operations and bomb disarmament.

The main advantage of these vehicles is the ability to survive in very hazardous environments. The main disadvantages are their costs and the inability to get around obstacles. Robots are ideal in the time between marginal tenability conditions and structural collapse. They are suitable for deployment in large single story industrial buildings and vehicle tunnels. Both the Japanese and British (Fire International, 1999)
have experimented with robots and are experimenting a number of variants. The main task of these units so far has been in reconnaissance but some are fitted with hoses such that they can apply water to the seat of the fire. With the increase in hazardous substances the need for this type of resource will increase.

9.5.8 Water Additives

A number of water additives have been experimented with and marketed over the years with the aim of improving the effectiveness of fire fighting water. The most recent appliance being introduced into the NZFS have the provision for the injection of water additives. The benefits of adding additives are described below:

*Wet ability agents*

The introduction of surfactant chemicals into the water stream reduces the high surface tension of water. This makes it easier to pump the water as it reduces the friction loss and improves the water's penetration. Most class A fires occur with fuel that are three-dimensional objects. These objects have many vertical surfaces and thus anything that causes the water to penetrate the fuel bed sooner will improve the residence time and hence improve the water's extinguishing characteristics.

*Thickening agents*

Thickening agents are introduced to improve the water stream's adhesion to vertical surfaces, again with the aim of enhancing the residence time of the water and hence improving its extinguishing capability. This additive has long been used in rural fire fighting to pre-wet fuel in front of a fire front.

*Chemical inhibitors*

These agents interfere with the chemical chain reaction that occurs as part of combustion. The concentrations of these additives tend to be quite high and thus prohibitive.
Marking

Experiments have been conducted (Chen et al, 1998) with the use of marking agents, mainly as an indicator of the concentration of other additives but also as a means of indicating where water is falling during operations at night.
CHAPTER 10 CONCLUSION

The extinguishment of a class A fire requires the removal of heat from the fuel surface. Only 7 to 10% of the energy from combustion supports further production of pyrolyzates. Thus the water requirement is more related to the specific heat content of the fuel and the thermal conductivity of the fuel surface than the energy released from the combustion process. For this reason, effective fire fighting is best achieved by the application of a solid stream of water that is swept over the fuel surface. This requires emphasis in training and development of tactics, especially for large fires.

The fact that a very large proportion of fires are extinguished with less than 10 l/s of water emphasises the need to analyses the resources and tactics applied by the fire service.

A number of authors have attempted to adequately classify fire fighting water requirements but insufficient data is available at present to produce a definitive requirement. Existing methods of data gathering must be improved. The new models of appliances available now have the capability to measure water flow. A data recorder should enhance this.

This paper has sought to offer an alternative methodology based on our imperfect knowledge and recognises this subject requires more research.

A number of areas of further investigation have been identified in this report, they are:

Legislation

The current legislation is unclear and does not define in sufficient detail the responsible parties.

Fire Service Tactics

Tactics employed by the fire service need to be matched to the equipment utilised and the type of fire. One of the outcomes must be to recognise that certain fires are already too big when the fire service arrives and hence only a defensive strategy should be
considered. This is in recognition that an upper cap must be placed on water supply and available resources. This impacts on the required water storage.

First aid fire fighting

A significant proportion of fires are both detected and extinguished by the general public. This reinforces the need for training in first aid fire fighting so that individuals know when to either attack a fire or evacuate. The Fire Safety and Evacuation of Building Regulations and the Building Act require the installation of first aid fire fighting equipment but do not emphasise the need for training in its use. The analysis of the FIRS statistics also reveals that fire personnel use this equipment as well.

Incentives

The move to a market driven economy and performance based legislation requires the provision of incentives to obtain a win-win situation. Recognising the success of automatic fire sprinklers should allow trade-offs with other fire safety requirements such as building hydrant systems or higher fire fighting water requirements. It is imperative to provide incentives or trade-offs that recognise the reduction in fire risk the adoption of these initiatives will create. Likewise the adoption of a building based risk assessment process will allow a more transparent cost benefit analysis that all interested parties can be involved in i.e. the building owner, his insurer, the Fire Service and the TLA. The New Zealand Code of practice for Urban Subdivision NZS 4404 recommends to developers subdividing new industrial areas to have additional capacity in the water mains to improve the marketability of the sites.

The Fire Service must be honest in its appraisal of its service. If the investment in a resource does not improve the fire outcome, it was not worth doing it.
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<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Author</th>
</tr>
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<tbody>
<tr>
<td>95/1</td>
<td>Full Residential Scale Backdraft</td>
<td>I B Bolliger</td>
</tr>
<tr>
<td>95/2</td>
<td>A Study of Full Scale Room Fire Experiments</td>
<td>P A Enright</td>
</tr>
<tr>
<td>95/3</td>
<td>Design of Load-bearing Light Steel Frame Walls for Fire Resistance</td>
<td>J T Gerlich</td>
</tr>
<tr>
<td>95/4</td>
<td>Full Scale Limited Ventilation Fire Experiments</td>
<td>D J Millar</td>
</tr>
<tr>
<td>95/5</td>
<td>An Analysis of Domestic Sprinkler Systems for Use in New Zealand</td>
<td>F Rahmanian</td>
</tr>
<tr>
<td>96/1</td>
<td>The Influence of Non-Uniform Electric Fields on Combustion Processes</td>
<td>M A Belsham</td>
</tr>
<tr>
<td>96/2</td>
<td>Mixing in Fire Induced Doorway Flows</td>
<td>J M Clements</td>
</tr>
<tr>
<td>96/3</td>
<td>Fire Design of Single Storey Industrial Buildings</td>
<td>B W Cosgrove</td>
</tr>
<tr>
<td>96/4</td>
<td>Modelling Smoke Flow Using Computational Fluid Dynamics</td>
<td>T N Kardos</td>
</tr>
<tr>
<td>96/5</td>
<td>Under-Ventilated Compartment Fires - A Precursor to Smoke Explosions</td>
<td>A R Parkes</td>
</tr>
<tr>
<td>96/6</td>
<td>An Investigation of the Effects of Sprinklers on Compartment Fires</td>
<td>M W Radford</td>
</tr>
<tr>
<td>97/1</td>
<td>Sprinkler Trade Off Clauses in the Approved Documents</td>
<td>G J Barnes</td>
</tr>
<tr>
<td>97/2</td>
<td>Risk Ranking of Buildings for Life Safety</td>
<td>J W Boyes</td>
</tr>
<tr>
<td>97/3</td>
<td>Improving the Waking Effectiveness of Fire Alarms in Residential Areas</td>
<td>T Grace</td>
</tr>
<tr>
<td>97/4</td>
<td>Study of Evacuation Movement through Different Building Components</td>
<td>P Holmberg</td>
</tr>
<tr>
<td>97/5</td>
<td>Domestic Fire Hazard in New Zealand</td>
<td>KDJ Irwin</td>
</tr>
<tr>
<td>97/6</td>
<td>An Appraisal of Existing Room-Corner Fire Models</td>
<td>D C Robertson</td>
</tr>
<tr>
<td>97/7</td>
<td>Fire Resistance of Light Timber Framed Walls and Floors</td>
<td>G C Thomas</td>
</tr>
<tr>
<td>97/8</td>
<td>Uncertainty Analysis of Zone Fire Models</td>
<td>A M Walker</td>
</tr>
<tr>
<td>97/9</td>
<td>New Zealand Building Regulations Five Years Later</td>
<td>T M Pastore</td>
</tr>
<tr>
<td>98/1</td>
<td>The Impact of Post-Earthquake Fire on the Built Urban Environment</td>
<td>R Botting</td>
</tr>
<tr>
<td>98/2</td>
<td>Full Scale Testing of Fire Suppression Agents on Unshielded Fires</td>
<td>M J Dunn</td>
</tr>
<tr>
<td>98/3</td>
<td>Full Scale Testing of Fire Suppression Agents on Shielded Fires</td>
<td>N Gravestock</td>
</tr>
<tr>
<td>98/4</td>
<td>Predicting Ignition Time Under Transient Heat Flux Using Results from Constant Flux Experiments</td>
<td>A Henderson</td>
</tr>
<tr>
<td>98/5</td>
<td>Comparison Studies of Zone and CFD Fire Simulations</td>
<td>A Lovatt</td>
</tr>
<tr>
<td>98/6</td>
<td>Bench Scale Testing of Light Timber Frame Walls</td>
<td>P Olsson</td>
</tr>
<tr>
<td>98/7</td>
<td>Exploratory Salt Water Experiments of Balcony Spill Plume Using Laser Induced Fluorescence Technique</td>
<td>E Y Yii</td>
</tr>
<tr>
<td>99/1</td>
<td>Fire Safety and Security in Schools</td>
<td>R A Carter</td>
</tr>
<tr>
<td>99/2</td>
<td>A Review of the Building Separation Requirements of the New Zealand Building Code Acceptable Solutions</td>
<td>J M Clarke</td>
</tr>
<tr>
<td>99/3</td>
<td>Effect of Safety Factors in Timed Human Egress Simulations</td>
<td>K M Crawford</td>
</tr>
<tr>
<td>99/4</td>
<td>Fire Response of HVAC Systems in Multistorey Buildings: An Examination of the NZBC Acceptable Solutions</td>
<td>M Dixon</td>
</tr>
<tr>
<td>99/5</td>
<td>The Effectiveness of the Domestic Smoke Alarm Signal</td>
<td>C Duncan</td>
</tr>
</tbody>
</table>
Post-flashover Design Fires
An Analysis of Furniture Heat Release Rates by the Nordtest Design for Escape from Fire
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Fire Spread on Exterior Walls
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Heat Transfer Program for the Design of Structures Exposed to Fire
An Analysis of Pre-Flashover Fire Experiments with Field Modelling Comparisons
Fire Engineering Design Problems at Building Consent Stage
A Comparison of Data Reduction Techniques for Zone Model Validation
Effect of Surface Area and Thickness on Fire Loads
Home Fire Safety Strategies
Accounting for Sprinkler Effectiveness in Performance Based Design of Steel Buildings in Fire
A Guideline for the Fire Design of Shopping Centres

School of Engineering
University of Canterbury
Private Bag 4800, Christchurch, New Zealand

Phone 643 364-2250
Fax 643 364-2758