EVALUATING METHODS FOR FIRE PROTECTION AND RELATED FIRE RISK CATEGORIES IN RURAL TOWNS OF THE WESTERN CAPE, SOUTH AFRICA

By

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ABSTRACT

Water flows required for fire protection (fire flows) from water distribution systems (WDS) in rural towns in the Western Cape Province, South Africa, were evaluated as part of this research project. The fire flow requirements specified in different South African guidelines, as well as a number of international standards, were compared. Various guidelines and codes used in South Africa, including the South African National Standards, specify fire flow requirements according to the risk category of the area concerned. Alternative methods of firefighting and new firefighting technologies that can reduce the reliance on potable water resources for firefighting were evaluated. The traditional method of designing a WDS to provide potable water for firefighting, commonly employed in South African municipal areas formed the focus of the study. The potential fire risk costs (potential costs of damages if a fire was to occur) should also be considered, in addition to the network construction costs, when designing a WDS, in order to determine the most economically feasible option. Data obtained from the fire departments of three municipalities in rural towns of the Western Cape, was analysed to determine the actual flow rates that were required to extinguish fires in these towns. The records considered covered approximately one year in each case and included a total of 564 fire incident reports suitable for this study. According to the data, a small fraction (11%) of the fires was extinguished using water from the WDS by connecting firefighting equipment directly to a fire hydrant. The majority of the fires were extinguished by means of water ejected from a firefighting vehicle. This method implies the use of water drawn from the potable network at a certain location; the water is shuttled by firefighting vehicles, from either the fire station or from a central abstraction point in the WDS. The location of the said abstraction point was found to have a notable impact on the WDS and this received attention in this study. The data showed that 99.8% of the flows required in rural towns were lower than the flows recommended for moderate risk areas in typical South African guidelines. Hydraulic modelling of a hypothetical WDS model was conducted to illustrate that the provision of fire flows according to commonly used South African fire flow standards leads to higher costs. The latter hypothetical case study illustrates that designing a network to provide fire flows according to the referred standards resulted in 15% higher costs, compared to designing a network that would have provided for the actual recorded fire flows according to the data set obtained from the selected rural towns compiled for this study. The hypothetical case

study also showed that the cost for a WDS, where sufficient pressure is required at all hydrants during peak fire flows, is 2.4% higher than the cost for a distribution system where water is supplied via predetermined hydrants for refilling firefighting vehicles. A WDS with central, predetermined abstraction points for refilling firefighting vehicles offers a solution to providing fire flows in areas where the distribution systems may be inadequate. The revision of the current fire flow standards of South Africa would, therefore, be a logical next step along with the reassessment of methods used for supplying fire flows.

OPSOMMING

Water vloei vir brandbestryding (brandvloei) uit waterverspreidingstelsels (WVS) in plattelandse dorpe in die Wes-Kaap, Suid Afrika, is as deel van hierdie navorsingsprojek geëvalueer. Die brandvloei soos gespesifiseer in verskillende Suid-Afrikaanse riglyne, asook ŉ aantal internasionale standaarde is vergelyk. Verskeie riglyne en kodes wat in Suid-Afrika gebruik word, insluitende die Suid-Afrikaanse Nasionale Standaarde, spesifiseer brandvloei-vereistes op grond van die risiko-kategorie van ŉ spesifieke gebied. ŉ Verskeidenheid alternatiewe metodes vir brandbestryding en nuwe brandbestrydings-tegnologieë is ondersoek, om sodoende die afhanklikheid van ons beperkte drinkbare waterbronne vir brandbestryding te verminder. Die tradisionele metode om water aan munisipale areas te voorsien, die gebruik van ŉ WVS, is ook geassesseer. Hierdie metodes dui daarop dat die potensiële brandgevaar-kostes (potensiële koste van skade indien ŉ brand sou plaas vind) ook in ag geneem moet word, tesame met die konstruksie kostes van ŉ WVS, om sodoende die mees ekonomies haalbare netwerk te bepaal. Data wat verkry is vanaf die brandweer departement van drie plattelandse munisipaliteite in die Wes-Kaap is ontleed om die werklike vloei-tempos vas te stel wat nodig was om brande te blus in hierdie dorpe. Die data is verkry vir ŉ tydperk van een jaar en 564 brandverslae was bruikbaar vir die doeleindes van hierdie studie. Volgens die data was ŉ lae aantal (11%) van die brande geblus vanuit die WVS deur die koppeling van brandbestrydingstoerusting direk aan ŉ brandkraan. Die meeste van die brande is geblus met behulp van water wat voorsien is deur ŉ brandbestrydingsvoertuig. Met hierdie metode word water deur die brandbestrydings-voertuie aangery vanaf die brandweerstasie of onttrek vanuit ŉ sentrale ontrekkingspunt in die WVS. Daar is gevind dat die ligging van laasgenoemde ontrekkingspunt ŉ beduidende impak op die WVS het – hierdie aspek is daarom verder ondersoek. Die data het getoon dat 99.8% van die vloei-tempo’s wat nodig is om brande te blus in plattelandse dorpe, laer is as die brandvloei riglyne vir matige risiko-areas volgens tipes Suid-Afrikaanse standaarde. Hidrouliese modellering van ŉ hipotetiese WVS is uitgevoer om te illustreer dat die verskaffing van brandvloei volgens die standaarde wat algemeen gebruik word, hoër kostes tot gevolg het. Die laasgenoemde hipotetiese gevallestudie illustreer dat ŉ netwerk ontwerp om brandvloei te verskaf volgens die huidige standaarde 15% duurder is as vir netwerke wat ontwerp is om die werklike aangetekende brandvloei te voorsien soos getoon deur die veld-data wat vir hierdie

studie verkry is. Die hipotetiese gevallestudie het ook getoon dat die koste vir ŉ WVS, waar voldoende drukke gehandhaaf moet word by alle brandkrane terwyl piek brand vloeie voorsien word, 2.4% duurder is as vir ŉ WVS waar die brandvloei verskaf word by voorafbepaalde brandkrane vir die hervulling van brandbestrydingsvoertuie. ŉ WVS met sentrale onttrekkingspunte vir die hervulling van brandbestrydingsvoertuie, bied ŉ metode om brandvloei te voorsien in gebiede waar die WVS onvoldoende is, bv. informele nedersettings. Die hersiening van die huidige brandvloei standaarde van Suid Afrika sou dus ŉ logiese volgende stap wees, tesame met die herevaluering van die metodes wat gebruik word vir die verskaffing van brandvloei.

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List of abbreviations

AADD	-	Annual Average Daily Demand
AFFF	-	Aqueous Film Forming Foams
AR-AFFF	-	Alcohol Resistant Aqueous Film Forming Foam
AWSS	-	Auxiliary Water Supply System
AWWA	-	American Water Works Association
BOCA	-	Building Officials Code Administrators
CAFS	-	Compressed Air Foam Systems
CCBFC	-	Canadian Commission on Building and Fire Codes
CRADA	-	Cooperative Research and Development Agreement
DoD	-	Department of Defence
FPASA	-	Fire Protection Association South Africa
FSRS	-	Fire Suppression Rating Schedule
FUS	-	Fire Underwriters Survey
GDP	-	Gross Domestic Product
gpm	-	Gallons per Minute
HD	-	Highest Daily Consumption
ICBO	-	The International Conference of Building Officials
ICC	-	International Code Council
IFC	-	International Fire Code
IITRI	-	Illinois Institute of Technology Research Institute
ISO	-	Insurance Service Office
ISU	-	Iowa State University
NBC	-	National Building Code
NBR	-	National Building Regulations
NFA	-	National Fire Academy

NFC - National Fire Code of Canada

NFPA - National Fire Protection Agency

NIMSS - National Injury Mortality Surveillance System

NIST - National Institute of Science and Technology

NRCC - National Research Council Canada

RFF - Required Fire Flows

SABS - South African Bureau of Standards

SANS - South African National Standards

SBCCI - The Southern Building Code Congress International

UnFC - Unified Facilities Criteria

WDS - Water Distribution System

List of symbols

A - Effective Area

C - Factor Related to Construction Type

d - Discharge Supplied at Hydrant

F - Construction Type Coefficient

n - Number of Exposed Sides of Building

O - Factor Related to Occupancy Type

p - Pressure Supplied at Hydrant

P - Factor Related to Communication Between Buildings

T - Duration in minutes

X - Factor Related to Exposure of Building

1 Introduction

1.1 Study background

In South Africa, rapid changes have taken place over the last few years, leaving the infrastructure of the country in dire need of upgrades to meet the current problems and challenges in the provision of water, sanitation and basic services.

Unfortunately, South Africa is a land of inconsistency in certain aspects, as can clearly be seen in the provision of basic services to the people of the country. In South Africa with all its know-how and experience in e.g. inter-catchment water transfer schemes, there are still over 12 million people who do not have access to a sufficient supply of potable water and more than 20 million people who do not have access to basic sanitation services. This situation is unacceptable and the authorities are responsible for changing this.

According to the Department of Water Affairs, one of the primary goals of the South African Government is to ensure that all South Africans are provided with basic water and sanitation services. The Reconstruction and Development Programme that was adopted by the government consisted of a list of services that must be improved to ensure the growth of this country. Part of the objective to increase and improve the basic services is to re-evaluate the way in which South Africa's already limited water resources are used (DWAF, 1994). This can only be done by finding and implementing ways to conserve water, e.g. using non-potable water for activities such as irrigation and firefighting. To further aid in pursuing this goal of protecting our already limited resources, an analysis of firefighting aids and alternative methods of extinguishing fires e.g. dual systems and foams was initiated to assist in decreasing our reliance on and usage of our potable water resources.

Even though supplying water for potable needs is the main priority of water distribution systems (WDS), large volumes of water are required to fight fires. To realise the significance of providing water for this purpose, it is only necessary to look at the damaging effects of a fire. According to a report published by The Fire Protection Service of South Africa the value of insurance claims for fire losses increased from R400 million in 1990 to R1.4 billion in 1998, an increase of more than 400% (Davey, 2011). It is thus apparent that the provision of fire protection is of high importance, especially if it is taken into account that the previously mentioned claims are only for the direct losses. The indirect losses, such as loss of income, personal suffering and the loss of hundreds of lives every year, are not even considered.

An effective fire protection system does not consist only of an efficient WDS but also require an operational fire service and firefighting equipment. Fire protection consists of two fundamentals, the prevention of fires (including sprinklers, fire education and building regulations) and fire suppression (including fire services, provision of water by the distribution network and other firefighting techniques).

Numerous methods could be used to extinguish fires; however, presently, using water for firefighting is generally the most cost effective and efficient method. It is therefore of great importance to ensure that the required fire flows (RFF) and pressures required are always available for extinguishing fires, generally via the municipal WDS. The main goal of a municipal WDS is to provide adequate supplies of potable water to the consumers. It is also common practice for water distribution networks to be designed to provide sufficient quantities of water for use in case of a fire, in addition to providing water for domestic and industrial uses.

The addition of fire flow requirements to the WDS can have an adverse impact on the quality of the water. Storing high volumes of water for fires that rarely, if ever, occur results in an increase in the time the water resides in the pipes which, in turn, leads to the possibility of residual loss of disinfectant, increasing the formation of by-products and bacterial growth. The installation of larger pipes will lead to a reduction of the flow velocities in the pipes, resulting in the deposit of sediments.

Due to the previously mentioned urgent need for sufficient fire flow water, along with the problems caused by the provision of these flows, it is extremely important to ensure that the level of fire flow required for all areas is regularly assessed. Assessment is required especially in high-density, commercial and industrial areas, where the original fire flow requirements might no longer be adequate. This is because of faster densification of the area than was originally estimated, higher demands by consumers, construction of high buildings, higher losses through pipe bursts and old networks requiring increased maintenance.

A number of different methods are used to determine the RFF for an area, e.g. the Insurance Service Office (ISO) method, the Iowa State University (ISU) method, the National Fire Association method that are used in the United States of America as well as the Fire Underwriters Survey (FUS) in Canada. All these methods are reviewed in Chapter 2. South African law does not require water service providers to provide fire flow, and the provision of water for firefighting is left with the local authorities. The provision of fire flow and residual water pressures in South Africa is guided by three different documents, namely the South

African National Standards (SANS) 10090:2003, the SANS 10252-1:2004 and the Guidelines for human settlement (CSIR, 2003), commonly referred to as the “Red Book”, which is based on the original revision of the South African Bureau of Standards(SABS) 090:1972.

The RFFs differs significantly for each country. A possible explanation for this is the diverse types of building structures and materials used or the different fire requirements prescribed in these building codes. The fire flow requirements of several countries, including South Africa, are old and dated. Revision should be considered to determine whether the high flows required could be reduced as a result of changes in building regulations, different materials being used, faster response times by fire departments, and other recent improvements made in the infrastructure. The possibility of reduction in these flows would consequently result in the decrease of the required pipe sizes, design and operating costs as well as an increase in the water quality.

1.2 Thesis objective

The main objective of this thesis was to compare the actual fire flows used to fight fires in rural towns in the Western Cape to the requirements specified in the South African National Standards as well as overseas standards and information from literature. This was done in order to determine whether the required fire flows are realistic and in line with actual flows recorded to extinguish fires, and to expose the inadequacies, if any, of the current design codes of South Africa.

The thesis also evaluated different methods used to provide fire flow. The two methods were the provision of fire flow from the WDS at the scene of the fire while maintaining a minimum pressure and the provision of fire flow at predetermined abstraction points for the refilling of firefighting vehicles used to transport water to the fire.

1.3 Scope and limitations of investigation

Only three out of the eight fire departments in the Western Cape that were approached provided data; the data consisted of fire reports over a period of one year as well as additional statistical information for two of these fire departments. The limited database could result in fire flows that are inaccurate over longer periods. The study was also limited by the fact that the fire departments only provided averaged fire flow rates (averaged over the duration of a firefighting operation). The latter limitation prevented the obtaining of peak flows within the firefighting operation.

Fire incidents from the data obtained were categorized into the following categories: structural fires, informal settlement fires, vegetation (grass, veld and refuse) fires, automobile accidents (with fires) and special services. The data was sorted and organised, removing all irrelevant data, e.g. reports where either the flows or the time durations were not provided. The data was used to determine the actual flows required for extinguishing fires in rural towns in the Western Cape. These flows were compared to the fire flow guidelines of the South African standards.

An evaluation of different methods of providing fire flow in rural towns was done in a hypothetical case study to compare the economic impacts on the design of the network. Decision matrices were used to evaluate different techniques of supplying fire flow and new technologies used to increase the efficiency of water as fire extinguishing agent. This evaluation was discussed and the most practical and economically feasible option for rural towns in the Western Cape was selected.

1.4 **Organization of report**

The structure of this thesis is as follows:

1. Introduction and aim of study
2. Literature survey
    - 2.1 Chemistry of fire
    - 2.2 Firefighting methods
    - 2.3 International fire flow regulations
    - 2.4 Firefighting in South Africa
    - 2.5 The design and operation of a WDS
    - 2.6 Summary of literature study
3. Evaluation of firefighting in rural towns in the Western Cape
    - 3.1 Statistics of Western Cape rural fire flows
    - 3.2 Impact of Western Cape rural fire flows on a WDS
    - 3.3 Evaluation of firefighting techniques and technologies testing to rural Western Cape
4. Conclusions
    - 4.1 Literature survey
    - 4.2 Evaluation of firefighting in rural towns in the Western Cape
5. Recommendations and further studies

2 Firefighting

In this chapter different methods for extinguishing fires are explained, including the most generally used, i.e. water from the distribution network, dual water systems, firefighting foams, etc. Different fire flow guidelines in South Africa and other international countries are also compared in this chapter along with the impact of fire flow on a WDS. However, before these are presented it is considered important to first address the basic principles of fire.

2.1 The chemistry of fire

Fire is a process where oxidation takes place resulting in rapidly producing heat and light. Four basic elements are needed to ignite and sustain a fire; reducing agent, heat, self-sustaining chemical chain reaction and an oxidising agent (oxygen). These four components are called a fire tetrahedron.

During the combustion process the fuel is being oxidised (burned). The energy component of the fire tetrahedron is heat and when heat comes into contact with fuel, it provides enough energy to ignite the fuel. This causes a continuous reaction where the ignition of vapours and gases, resulting from the burning of the fuel keeps the reaction going (Hartin, 2011).

The evolution of fire depends primarily on:

- The stages of fire development (incipient, flashover or smouldering phases)
- The type of material providing fuel, particularly in the early (incipient) stages of fire development
- The supply of oxygen available to the fire.

The transitional nature of fire within a building can be divided into 5 different phases; ignition, smouldering, flame growth, fully developed and decay.

If these phases are compared, as shown in Figure 1, it is evident that the least productive time to start the fire extinguishing process would be in the fully developed phase. The growth of the fire depends on the availability of the elements of the fire tetrahedron.

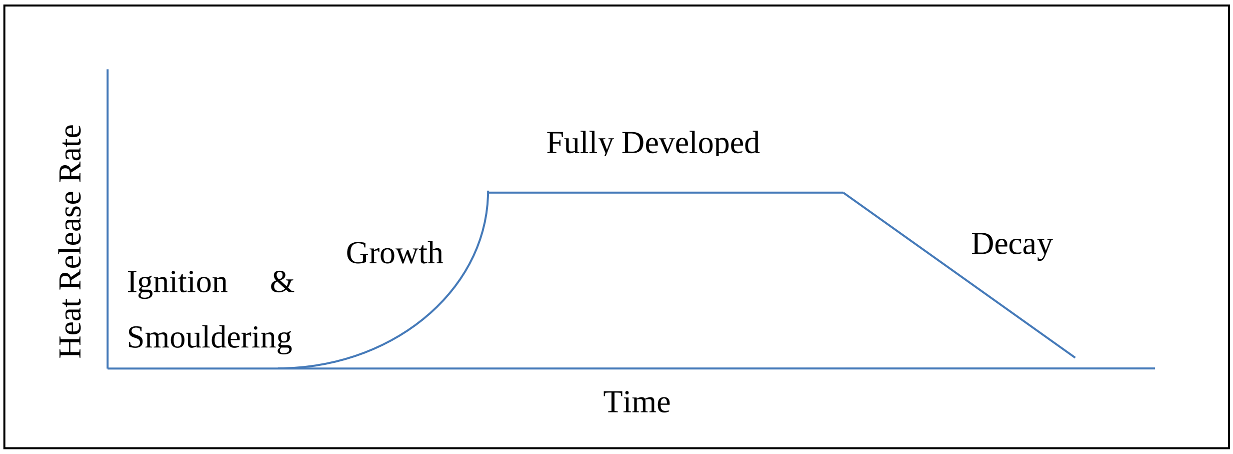

Figure 1: Typical fire progression (Davis, 2000)

2.2 Firefighting methods

A fire can be extinguished by eliminating any one of the four basic components needed for a fire. This could be done by removing the fuel, removing the oxidizer, inhibiting the chain reaction or reducing the temperature. Extinguishing fires depends merely on the provision of firefighting agents, but also on numerous other factors, e.g. the efficiency of the firefighter/ department and the method used to extinguish the fire.

2.2.1 Fire department response strategies

Two types of firefighting strategies are used by fire departments, namely, offensive or defensive. The type of strategy used depends on the available water flow and consumption rates, as well as the potential risk to the occupants (Klaene, n.d.).

- The offensive/interior attack

  This strategy consists of firefighters taking an aggressive approach towards extinguishing the fire, e.g. entering the building with hose lines and stopping the fire from spreading, as well as extinguishing it. This type of attack is usually more effective in saving lives and properties.

- Defensive/exterior attack

  This form of attack is generally used in scenarios where fighting a fire from within a building is not practical, e.g. structural integrity of the building is threatened, the fire is too large or the occupancy of the building could be a threat to the firefighters.

> If a defensive attack strategy is necessary, determining a RFF is no longer necessary. The main concerns of the firefighters would be the following: protecting fire response personnel, protecting nearby buildings and suppressing the fire. At this stage, maximum available fire flows, at reasonable pressures, are provided.

In buildings with built-in sprinkler systems, the first action that is taken by the fire department is to support and supply water to the sprinkler system. This is done by providing additional water to the system, as well as boosting the pressure by linking pumpers (pumping systems of firefighting vehicles) to the sprinkler network.

2.2.2 Using water to extinguish fires

Water has long been the most commonly used fire-extinguishing agent. The great majority of fires are extinguished using only water, whether it is from a hose, a sprinkler system or manually, using buckets. Water has specific physical qualities that make it ideal for extinguishing most types of fire.

One of the characteristics of water that makes it fit for extinguishing fires is its cooling ability. This is made possible through the ability of water to absorb heat and evaporate as result thereof. Without the heat, one of the vital components of the tetrahedron of fire is inhibited.

Another quality of water that makes it attractive as a fire-extinguishing agent is its ability to produce steam with a volume of 1700 times the volume of the liquid, when it is exposed to a fire or the heat of it. This large volume of steam then displaces equal amounts of air surrounding the fire and thus reduces the volume of air (oxygen) available to sustain the combustion of the fire. Applying water in the form of ice would evidently utilize water’s most effective cooling action, though practical equipment for such applications is not yet available.

2.2.2.1 *Considerations for using water to extinguish fires*

Even though water is generally readily available for firefighting, the following factors must be considered when water is supplied via a WDS: the cost, the reliability of water distribution networks, the quality of the water used and the flow and pressures required.

2.2.2.1.1 The cost

Even though water is one of the least expensive and most available agents for fire extinguishing, the costs of processing, treatment and distribution of the water are still noteworthy. The National Research Council Canada (NRCC) (Davis, 2000) did a study in 1999 to evaluate the costs of designing a water distribution system to provide fire flow in addition to the annual average daily demand (AADD). The study concluded that it was more cost effective to provide a tanker supply for firefighting than to increase the size of the reticulation system to be able to provide fire flow. According to the Auckland Regional Council Lifelines Project (Auckland Regional Council, 1999) the total cost of the national water infrastructure of New Zealand was R 19.15 billion (New Zealand $3 billion), of which R 5.74 billion (New Zealand $0.9 billion) could be attributed to the provision of fire flow. The annual insurance claims due to fire losses in New Zealand were only R 766 million (New Zealand $120 million).

2.2.2.1.2 The reliability

A WDS provides water via a number of pipes, pumps, valves and hydrants. All of these elements are vulnerable and could be damaged, causing temporary disruptions in the supply of water from the WDS, which would consequently result in the need to find alternative resources to provide water for firefighting. Possible resources are swimming pools, rivers, ponds or the transportation of water from supplementary hydrants in the distribution network.

2.2.2.1.3 The quality of the water

The quality of water required for firefighting is much lower than the quality required for water used for human consumption. The only obvious prerequisite for water used for firefighting is the need to limit the concentration of suspended materials to a size that would not damage, corrode or block the firefighting equipment.

2.2.2.1.4 Required fire flows and pressures

The volume of water required for firefighting, as well as specified residual pressures that must be available in the network, differs from country to country. The main rationale behind the requirements is not to ensure that sufficient pressures are available for firefighting, since fire brigades are equipped with high-pressure pumps, but to prevent negative pressures developing in other parts of the network.

2.2.3 Fire suppression systems using water

A number of different types of fire suppression systems are available. Most of these systems use pipes to convey the fire-suppressing agents to the area where the fire hazards are. The nature of the fire protection system depends on the type of building, the area, the building contents, applicable codes and requirements, as well as the physical environment and aesthetics.

2.2.3.1 *Sprinkler systems*

Sprinkler systems are frequently used to protect buildings against fires. The type of building and its occupancy determine the type of sprinkler system that is installed. The following sprinkler types are generally used (Hickey, 2008).

- Automatic sprinkler system

  An automatic sprinkler system is a network of pipes to which automatic or open sprinklers are attached. The piping network is distributed throughout the protected area. The system is connected to the distribution system and begins spraying water if a fire or smoke is detected. Sprinkler systems are designed with special control valves that include wet-pipe and dry-pipe systems.

  The wet-pipe system is more popular for residential and industrial usage. In the wet-pipe system, the pipe distribution network with sprinkler heads is filled with water and under pressure. If a fire occurs, all the sprinklers subjected to the heat of it will spray water to suppress and extinguish the fire.

  Unlike the wet-pipe system, the dry-pipe system is filled with air or inert gas under pressure. When any of the sprinkler heads are subjected to heat, the air or gas is discharged until the air pressure is depleted, at which point water then flows into the pipe network. Dry-pipe systems are used only in situations in which it would not be possible to store the water in the system, e.g. when temperatures below freezing point are common, in which case frozen water could damage the network.

- Deluge sprinkler system

  A deluge sprinkler system is similar to the automatic sprinklers discussed previously; the only difference is that when any of the fire detection devices placed on the network is exposed to the heat/smoke of a fire, all of the sprinklers discharge. Deluge sprinklers are used mostly in buildings with highly combustible occupancies.

- Foam based sprinkler system

  Any of the formerly discussed sprinkler systems could be enhanced by adding one of several different types of foaming agents to the water, especially for the protection of highly challenging types of fire hazards. Firefighting foams will be discussed in more detail in section 2.2.5.

2.2.3.2 *Wet and dry standpipe systems*

A standpipe system consists of a network of rigid water piping that supplies water for manual fire suppression, usually in multi-storey buildings. Standpipe systems are used to provide water for automatic sprinkler fire systems, as well as the manual application of water for firefighting.

- Dry standpipes

  Dry standpipes are pipes that are permanently fixed into buildings with an intake located near a driveway to ensure accessibility for fire trucks to provide water to the system. Dry standpipes are not filled with water until it is needed to extinguish fires, at which point this is done by connecting fire hoses to vertically positioned pipes inside the building.

- Wet standpipes

  Wet standpipes are always pressurized and filled with water. These pipes do not necessarily have to be used for firefighting, but can also be used for domestic purposes inside the building. These standpipes usually come with hoses to enable occupants to extinguish fires immediately.

The main advantage of a standpipe system is the amount of time that would be saved by using pipes that are already installed for the purpose of extinguishing fires. The time it takes to lay hoses up the stairs and into buildings, is saved by having fixed hoses outlets already in place. This also results in stairwells being kept empty and safe, allowing safe passage for occupants out of the buildings and firefighters into the building.

2.2.4 More effective firefighting

2.2.4.1 *Firefighting foam*

Firefighting foam used to extinguishing fires, by cooling the fires as well as coating the fuel, preventing contact with oxygen and thus "smothering" the fire. Firefighting foam has been used since 1904 when Aleksandr G. Loran, a Russian engineer and chemist, invented it. In his patent application for registering a method to extinguish fires he wrote "*…the burning surface is covered with an aqueous solution of any of the well-known extinguishing agents not in liquid form, but as semi-porous material obtained by foaming of the solution at the time of extinguishing the fire*." (P-lab.org, 2007).

Surface-active agents (surfactants) are added to the water to produce foam. Foam used for firefighting also contains the following components: organic solvents, foam stabilisers and corrosion inhibitors. Most of the firefighting systems using foams also use compressed air foam systems (CAFS). A CAFS is defined as a standard water pumping system that has an entry point where compressed air can be added to a foam solution to generate foam. The air compressor also provides energy, which, litre for litre, propels compressed air foam farther than aspirated or standard water nozzles (Rochna, 1991)

As has already been established, water has a number of characteristics that makes it an efficient extinguishing agent. Unfortunately, water's extinguishing abilities are restricted by high surface tension caused by water molecules being attracted only to one another. This results in only 5 – 10 % of the water that is sprayed onto a fire actually being used for extinguishing the fire. The surface tension of water also prevents it from penetrating certain fibres, making it difficult to reduce temperature and extinguish flames in these fabrics. Another limitation of water is the fact that it cannot form a protective coating on most substances nor can it suppress vapour production unless there is enough water to ensure that the vapours can be inundated. These limitations can be overcome by using a Class A foam, see section 2.2.4.1.

Depending on the type of foam, it can have different expansion abilities. Low-expansion foams have an expansion rate of less than 20 times the original volume with high-expansion foams expanding more than 200 times, and medium-expansion foams anything in between. The advantage of low-expansion foams is in their mobility and ability to spread and cover large areas quickly. The high-expansion foams are used in small areas where rapid filling is needed.

Alcohol resistant foams contain a polymer that forms a protective layer between a burning surface and the foam. This prevents the foam from being broken down by the alcohols of the burning fuel. These foams are used for types of fuel that contain oxygenates or liquids containing polar solvents.

2.2.4.1.1 Class A foams and compressed air foam systems

Class A foams are synthetic detergent hydrocarbon surfactants, which reduce surface tension, causing the volume of the water drop to expand, ensuring that a large volume of each water drop is exposed to the fire which, in turn, results in greater heat absorption (Colletti, 1992). These surfactants also emulsify most of the potential barriers that would prevent water penetration, e.g. oil, grease and paints (Fornell, 1991). The bubble characteristics of the foam also increase the extinguishing capabilities of the water-foam mixture. Class A foams are generally used in conjunction with CAFS.

According to tests done by the Osaka fire department in Japan (Liebson, 1990), it was determined that the smaller the size of the water drops, the more effective they are in extinguishing fires. When the foam is directed into the fire, the air in the bubbles heats up, bursting the bubbles and rupturing the water solution into very small particles with greater extinguishing abilities. During the breaking of the bubbles, the water moves towards the source of the heat. As the solution drains out of the bubble mass, it penetrates the fuel, extinguishing the fire.

2.2.4.1.2 Advantages of using Class A foams and CAFS

In a report that was published by the U.S Fire Administration as part of the Major Fires Investigation Project (Stern & Routley, 1996) numerous fire departments claimed an increased performance in firefighting due to CAFS and Class A foams.

The report stated the following advantages of Class A foams in addition to the unique ability of CAFS to produce different types of foam:

- Class A foam allows faster fire suppression and extinguishing than plain water
- Class A foam helps with the conservation of the water supply
- Foam clings to most surfaces and protects them from exposures longer than water
- Foam can be used on flammable liquids
- Class A foam may reduce water damage to property.

The two main advantages of using foams are the decrease in the use of potable water, in addition to, more efficient fire extinguishing. Table 1 shows the estimated reductions in water usage as well as the time duration for extinguishing a fire when using foam (Liebson, 1991). Graphs to illustrate the reduction of time and water usage when foam and CAFS are used are shown in Figure 2 and Figure 3.

Table 1: Comparison between water, Class A foams and CAFS

Extinguishing agent	Time to extinguish fire (min)	Volume of water used (m^3)	Amount of foam agent used
Plain water	X	Y	N/A
Class A foam without CAFS	0.7X	0.5Y	Z
Class A foam with CAFS	0.25X	0.3Y	0.35Z

Other estimates made regarding the comparison between plain water and foam systems state that using Class A foams and CAFS makes firefighting up to 10 times more effective (Davis, 1997; Stern & Routley, 1996; & Liebson, 1991). Certain estimates even claimed it would be up to 20 times more effective (Darley, 1995). However, there are currently no test methods or requirements specified by the NFPA in the *Standard for Foam Chemicals for Wildland Fire Control*, or elsewhere, to evaluate the effectiveness of Class A foams and CAFS.

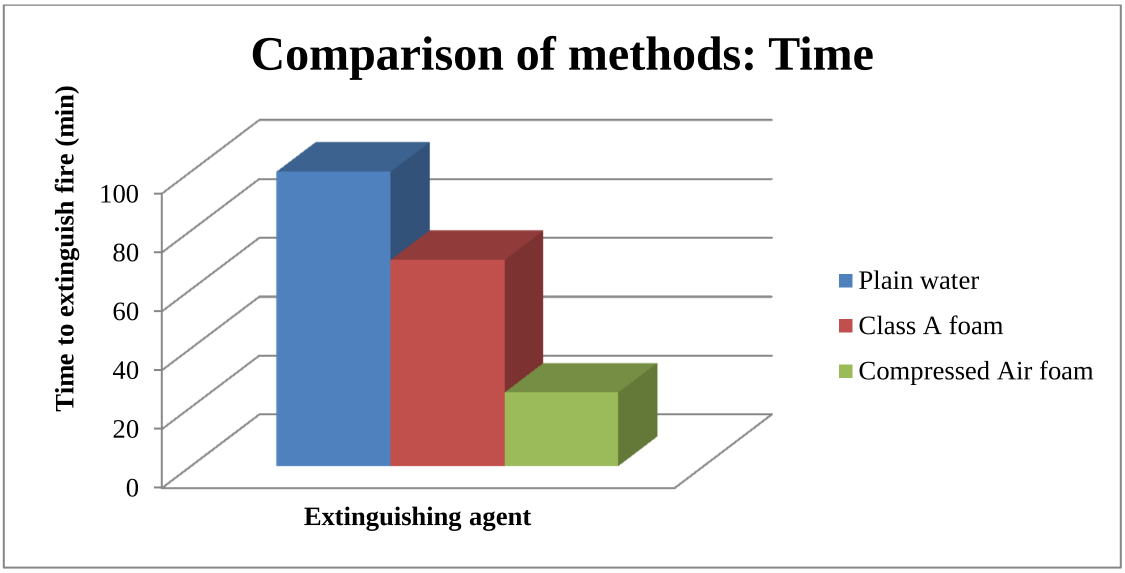

Figure 2: Comparison of time duration

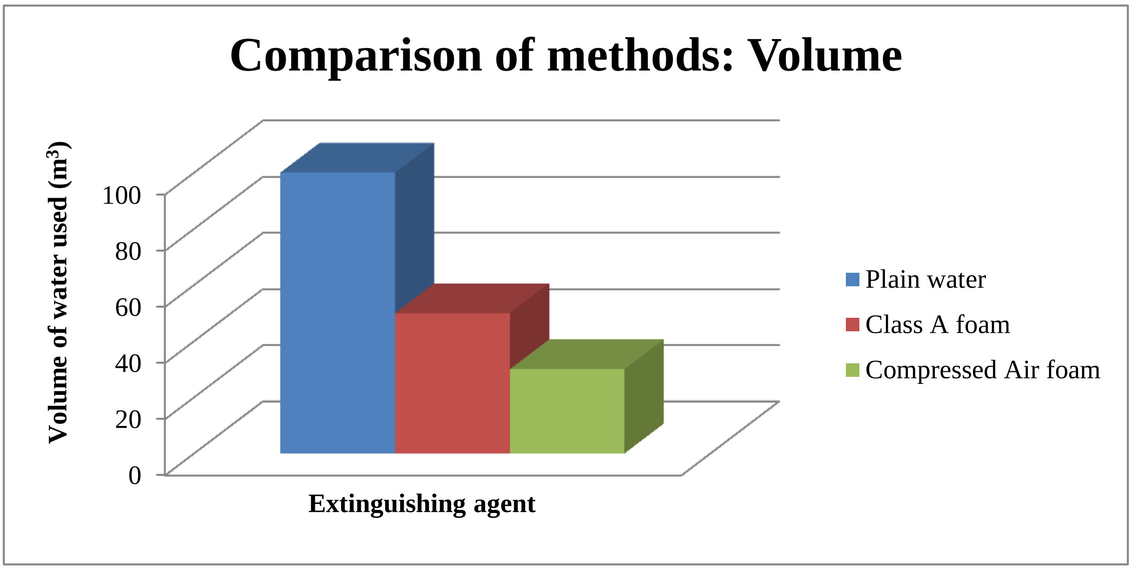

Figure 3: Comparison of water usage

Samuel Duncan evaluated CAFS for the U.S Army Tank-Automotive Command in 1994. His assessment of using foam and CAFS was: "*Based on the results and conclusions of this evaluation, it is the unanimous recommendation of the project members of the CRADA [Cooperative Research and Development Agreement] that CAFS technology would significantly improve the performance of most fire trucks…The technology is…effective enough in extinguishing fires to be of great value"* (Taylor, 1997).

2.2.4.1.3 Limitations and disadvantages of CAFS

As with most technologies, there are various problems and concerns about the use of Class A foams and CAFS. The following are the most prominent:

- Class A foam concentrate is classified as a hazardous material
- Class A foams are relatively corrosive (similar to strong cleaning agents)
- Class A foams could cause irritations to the skin, eyes and respiratory system as well as contact dermatitis and sensitization dermatitis (Brackin et al., 1992)
- Malfunctions that prevent the foam from flowing cause slug flow; the compressed air and water separate inside the hose, causing violent hose movements and an ineffective stream. This could also lead to accelerated hose wear ((Colletti, 1996), (Liebson, 1991))
- Even though Class A foams have been approved as biodegradable, it is still uncertain what the long term impacts would be on water resources
- The initial costs of installing CAFS systems are relatively high.

2.2.4.1.4 Class B foams

Class B foams are used to extinguish fires on flammable liquids. If Class A foams were to be applied on this type of fire, the result could be undesirable, since the Class A foams are not designed to contain the explosive vapours that are produced by flammable liquids. There are two types of Class B foams:

- Synthetic foams

  Synthetic foams are based on synthetic surfactants and provide good flow and quick suppression of fires. Aqueous film forming foams (AFFF) are water based and usually contain hydrocarbon-based surfactants, which enable foam to spread over the surface of hydrocarbon-based liquids. Alcohol resistant aqueous film forming foam (AR-AFFF) is resistant to the effect of alcohol on foam and is therefore able to form a protective film on the liquid.

- Protein foams

  The foaming agents in this type of foam are natural proteins. These foams are biodegradable, unlike the other foams. Despite the fact that they are slower to spread and cover the fire, the foam cover is more heat resistant and durable than that of the synthetic foams.

2.2.4.2 *Water additives*

Numerous water additives could be used to improve the effectiveness of water in firefighting, such as:

- Wettability agents

  Surfactants increase the penetration abilities of the water. These additives are especially effective in fires with many vertical surfaces, since the water would be then able to penetrate the fire and the fuels more effectively.

- Thickening agents

  Thickening agents are injected into the water stream to improve the adhesiveness of the water, increasing the time the water "sticks" to the burning surface and thereby the extinguishing capabilities of the water.

- Chemical inhibitors

  These chemicals break the chemical chain reaction that keeps a fire burning by ensuring combustion of the fuels. The concentrations of these inhibitors must be high to be effective, making the use of inhibitors expensive.

2.2.5 Alternative fire suppression methods

The need to find alternative methods for extinguishing fires is not only to provide fire suppression in situations where standard water application would not be suited, e.g. electrical fires, but also to mitigate the use of the expensively treated limited supply of potable water for firefighting.

2.2.5.1 *Gaseous fire suppression systems*

Gaseous fire suppression systems are provided in areas where water is not suitable as an extinguishing agent, such as water-sensitive areas or electrical rooms. Recently, the most commonly used gas is carbon dioxide. Carbon dioxide is one of the most effective firefighting agents available. The carbon dioxide reduces the volume of oxygen to a level where a fire cannot be sustained. There are two types of applications utilizing carbon dioxide, total flooding and local application.

For total flooding, the gas is stored in pressurized cylinders or tanks and activated by an electrical signal from a separate detection system. To be effective, the extinguishing agent must be maintained in the protected area for 10 minutes or more.

The main disadvantage of using carbon dioxide for total flooding is that at the designed concentration that is needed to suppress fires, human survival is not possible. Carbon dioxide would be a safety hazard and can only be used in spaces where there are no humans or after sufficient alarm and evacuation processes. Using carbon dioxide for local application would not be hazardous, due to the small amount of carbon dioxide in a fire extinguisher. Unfortunately, the use of a fire extinguisher is therefore limited to relatively small fires.

2.2.5.2 *Dry and wet chemicals*

Dry chemical extinguishing agents are generally used in restaurants and other places associated with cooking appliances in the form of portable fire extinguishers, since these chemicals can be used on flammable liquids as well as solid fuel combustions.

The main disadvantages of the dry chemicals are the corrosive residue it leaves behind and the possibility of causing breathing problems (Fire Extinguishers Kent Sussex Surrey, 2010). Wet chemicals extinguish fires by forming a foam blanket over the burning substance and cooling the substance below temperatures necessary for combustion. The main disadvantage of wet chemicals is the high costs.

2.2.6 Alternative method utilizing the WDS: Dual systems

As is implied by the name, a dual system is a water distribution system consisting of two different water supply sources, as well as two separate water distribution systems. The two distribution systems work independently of one another within the same area of the network. Most dual systems today are installed by adding reclaimed water lines parallel to potable water lines. These systems are designed to provide potable water via the one network and non-potable water via the other network. The purpose of these systems is to enhance the volume of water available in the network by providing untreated (or poorly treated), non-potable water that can be used for purposes such as irrigation or firefighting. It is also possible to use seawater as the non-potable water source as was done in Rouse Hill, Australia (Sydney Water, n.d.).

2.2.6.1 *Description*

Dual systems are designed as two separate pipe networks: a potable system and a non-potable system. If the non-potable resource were seawater, pumps would be required to extract seawater and to lift the water to higher levels in the network. If reclaimed water were to be used it would also be necessary to use pumps to lift water from wastewater sumps or other wastewater storage points.

The pumping systems consist of a pumping station containing the water intake, a pumping well, as well as an elevated storage tank for emergencies. These pumps require foot valves or one-way valves to ensure that the water is retained. The water is then pumped through a manifold into the alternative (secondary) water distribution system.

2.2.6.2 *Advantages and Disadvantages*

Using a dual system provides a method to mitigate the decrease in available water resources by providing an alternative resource for water used for non-potable applications. Dual systems also provide a cheaper source of non-potable water for the purpose of e.g. irrigation and firefighting.

The following are disadvantages of using a dual system:

- This system requires the installation of two distribution systems, resulting in double the cost.
- Since there is potable and non-potable water in the system, the possibility of cross-contamination cannot be ignored. Even though this would not be a big

concern with a seawater system, contamination with non-potable wastewater could have serious consequences.

- Regular testing of the systems is required, whether they are used regularly for irrigation or irregularly for firefighting. Foot valves must be cleaned regularly to remove fungal and other growths, which could hinder the opening and closing of the valves.

- Seawater can be extremely corrosive to metal pipes, fittings and other metal components of the network, this would add to the already high costs.

- If the water from the seawater system were to return to the wastewater plant it could have a negative impact on the treatment processes, since the high salt content would affect the activated sludge reactors as well as the bio filters.

This system could be improved by implementing the following:

- Systems can be developed to use non-corrosive materials, like fibreglass, in a seawater system.

- Using materials like PVC for the foot valves would prevent fungal and other growths that might damage the valves.

- Public awareness will reduce the risk of cross contaminating the potable water distribution system.

2.2.6.3 *Implementing dual systems*

In cities where the potable water distribution network was designed to provide fire flow, there are three possible options to incorporate dual systems.

The most generally used method is to install a second distribution network for the reclaimed water. The purpose of this system would be to reduce the demand on the potable water system by providing non-potable water for non-potable uses.

The second option is to convert the current potable network, which already provides for fire flow, to be used for reclaimed water. This would allow a new potable water distribution system to be designed with smaller pipes and storage facilities. Since the pipes required are smaller, more corrosion-resistant materials could be used at relatively low costs. Smaller pipes would also result in fewer joints and consequently fewer leaks, water quality would increase and the hydraulic capacity of the network would be reduced.

The third option would be to design a completely new dual system for a city. This was done in the City of St. Petersburg, Florida. This would be the most effective, but also the most expensive option.

2.2.6.4 *Case studies of cities using dual systems*

Case studies done by Snyder et al. (2002) discussed the following cities with dual systems, where reclaimed water is used for firefighting, or could potentially be used for firefighting.

- St. Petersburg, Florida

  St. Petersburg has been using dual systems since 1976. The reclaimed water network was fitted out for potential firefighting, among other applications. The city's four water-reclamation treatment plants handled more than 150 million litres of wastewater daily in 2002. The wastewater plants were upgraded by adding sand filtration and chlorine treatments to increase the quality of the water.

  The water was initially used for irrigational purposes. Later on, it was also used for cooling towers of power plants, industries, plant nurseries as well as firefighting. The system provides up to 10 000 homes, 51 schools, 86 parks, 6 golf courses and 11 commercial cooling towers with reclaimed water (McKenzie, 2005).

- San Francisco, California

  After the 1906 earthquake in San Francisco, where over 80% of the city's properties were destroyed by fires that followed the earthquake, the National Fire Protection Agency estimated the losses to be $7.5 billion, in 2006 value. The city installed a separate auxiliary water supply system (AWSS) for the sole purpose of fighting fires. The AWSS is an independent high-pressure water distribution network used for firefighting. The system consists of an immense network of underground networks and strategically placed reservoirs, pump stations and water tanks.

The original AWSS provided fire flows only to the central area of the city; the system was later updated to provide reclaimed water to the rest of the city for non-potable uses, the main use being firefighting, but also including irrigation, cooling and even toilet flushing. The upgraded AWSS consists of 2 pump stations, 2 water storage tanks, 1 reservoir, 172 cisterns and approximately 217 km of pipes. There are suction pipes along the northern and eastern waterfront from which the fire engines can pump water from the ocean and two boats that supply salt water to the AWSS by pumping the water into the system.

The primary aim of the system was to provide additional water for firefighting during earthquakes; however, the system also aided in reducing the use of potable water.

- Rouse Hill, Australia

The community of Rouse Hill was the first residential development that installed a dual system where the reclaimed water was used for all non-potable purposes. The scheme started in 2001 and more than 20 000 homes are now consuming more than 1.7 billion litres of reclaimed water each year for non-potable uses. The aim for this scheme is to eventually supply up to 36 000 homes with more than 70 billion litres by 2015. The dual system has reduced the need for potable water by up to 40% (Sydney Water, n.d.).

The domestic effluent is treated at a nearby treatment plant and the water is then returned via the non-potable water distribution network. The dual system installed “Lilac” taps (these adaptors have a left-handed threat) and pipes (with “Lilac” stripes) for the non-potable network to distinguish the network from the potable network (Urban Ecology Australia, 2006).

This system not only provides all the irrigation water, water for toilet flushing and cooling, but also the water needed for firefighting. One of the reasons for installing a completely different network for the non-potable water was to ensure that the pipes in the potable network would be as small as possible. This would help guarantee that the drinking water would be of high quality.

2.2.6.5 *Discussion of dual systems*

The use of dual systems in a distribution network is becoming more popular in certain countries, like the United States and Australia. The implementation of such a system provides a method to relieve the pressure on potable resources to provide water for growing communities. Non-potable water provided by dual systems can be used for a number of different applications, including firefighting.

If a dual system is used, the potable water network would not be required to provide fire flow and smaller pipes of higher quality could be used. If a dual system were to be installed in a city, it would be more viable to use the current network for non-potable uses and design the new network for potable use. New developments would save a lot of money if the water distribution network were designed with a dual system from the beginning, like the system in Rouse Hill, Australia.

2.2.7 Alternative water delivery systems

The water used for manual as well as automatic firefighting is generally provided via the WDS. The rate at which the fire flow can be provided depends on the available flows and pressures in the network. Alternative water resources are of highest value in areas that are otherwise not able to provide the RFF specified for that area.

The two most important objectives of alternative resources are:

- These resources could be used to supply water to augment the available water supplies in the case of a fire.

- Alternative resources could be used for emergency water supplies in the case of disturbances to some parts of the WDS, as well as to ensure that sufficient supplies of water are available for firefighting.

Alternative sources of water used for firefighting are not influenced by the domestic water consumption, but the following factors must be considered:

2.2.7.1 *Non-system supplied*

In areas lacking a distribution system, or if the system is inadequate, water for firefighting must be provided using firefighting vehicles. Most firefighting vehicles can transport and provide up to 5kℓ. To be able to use these mobile firefighting vehicles for scenarios where water needs to be applied over longer periods, the devices are used in a shuttle application, with fire ground attack pumpers, hose lines and main streams that draw their water from connected tankers (nurse tankers) or portable water storage tankers. Other firefighting vehicles shuttle water from a fresh water resource or central, predetermined abstraction points then refill these tankers.

2.2.7.2 *Non-potable water supplies*

The most preferable source for firefighting water is non-potable water resources. This could be anything from streams, lakes, ponds, canals or even the sea. However, if this type of water is not treated at some point before being used it could result in problems due to contaminants in the water. Seawater, for example, has been used in a few cities but the high corrosion factor of raw seawater makes it impractical. In dual systems, the use of treated wastewater could be a possible solution; dual systems were discussed earlier in section 2.2.6. Fire departments can use reclaimed water or seawater for firefighting with great success, provided that care is taken to regularly clean the systems to ensure that solids would not block or damage the system.

If natural resources are to be used for firefighting, the following should be considered:

- Low rainfalls and droughts could result in depleted resources
- Access to the resources must be guaranteed at all times.

2.2.8 Summary of methods

Currently the most economical and practical method to extinguish fires in rural towns are the use of potable water from the WDS. In some cases, the WDS are not sufficient and should be upgraded. Care should be taken to prevent the cost of providing fire protection exceeding the losses due to fires, as was the case in New Zealand, see section 2.2.2.1.1.

Sprinklers are the most commonly used suppression system in buildings. Dual systems, discussed in section 2.2.6, provide a method to reduce the reliance on potable water resources for non-potable uses; however, installing such a system is expensive.

Using additives to increase the efficiency of water for extinguishing fires is a more practical solution to reduce the volumes of water required for firefighting. Numerous additives are available to increase the efficiency of water for extinguishing fires, of which the most effective is the use of firefighting foam with CAFS.

The most preferable source for firefighting water is non-potable water resources, provided that this type of water is treated to avoid damage to the firefighting equipment. In areas lacking a distribution system, or if the system is inadequate, water for firefighting must be provided using firefighting vehicles shuttling water from fresh water resources or central, predetermined abstraction points.

2.3 International fire flow regulations

2.3.1 International firefighting codes

Private and publicly owned water companies in North America and Europe function within a controlled setting and are expected to provide services to consumers that are satisfactory at a minimum cost. Satisfactory services entail providing water that meets all water regulation requirements, is aesthetically pleasing and is supplied at acceptable minimum flows and pressures. These services also require that the WDS must be able to provide adequate amounts of water for fire flows at all times.

Water required for extinguishing fires is usually added to the AADD already allocated to a certain area. The amount of water needed for extinguishing fires differs throughout communities, since the fire flow requirements are generally determined according to the type of construction, building size and occupation of buildings in a certain area.

According to an analysis done by the ISO as part of the fire and property insurance rating system for over 130 insurance companies in the United States, the fire suppression capabilities of a community were categorized according to the protection features in the community (Hickey, 2008). The three protection features were analysed and a percentage according to the importance of each feature for extinguishing fires was assigned as follows:

- Fire department - 50%
- Water supply - 40%
- Handling fire alarms - 10%

Total 100%

The weight determined for the water supply shows the dire need for an adequate WDS that is able to meet the domestic demands as well as the RFF under maximum daily conditions. For firefighters to be effective in extinguishing fires, sufficient flows and adequate residual pressures are required. Different methods can be used to determine the fire flow and each method uses different parameters.

In countries such as the Unites States of America, Germany and South Africa, communities and local authorities are responsible for determining their fire flow needs. The different methods used to determine fire flows vary between countries and will be discussed in this section.

2.3.2 Fire flow requirements in the United States of America

2.3.2.1 *Fire flow codes*

In the United States of America, several model fire codes were used before 2000. The three main codes were:

- Building Officials Code Administrators (BOCA)

  The code developed by the BOCA was used mainly throughout the northeast of the United States.

- The International Conference of Building Officials (ICBO)

  The ICBO developed the Uniform Code that was used in the western United States.

- The Southern Building Code Congress International (SBCCI)

  The Standard Prevention code was developed by the SBCCI and was used in the southern United States.

Each of the abovementioned codes and the following calculation methods were developed with the idea that local authorities could implement and modify them according to their specific local requirements. These requirements tend to vary for each region, due to different types of buildings, different vegetation and the volume and type of water available for firefighting.

The BOCA, ICBO and the SBCCI were combined to develop an International Fire Code (IFC), which was published in 2000. The National Fire Protection Agency (NFPA) also developed a separate set of national fire codes that are referenced by the IFC.

As has already been stated previously, the provision of fire flow is left up to the local authorities to determine for their specific regions. Presently certain organizations such as the ISO and the FUS aim to help determine the fire flow needed by providing guidelines to determine the minimum pumping and storage requirements, hydrant distribution requirements, available pressures as well as the flows required to extinguish fires.

The RFF is the flow rate needed to extinguish a fire, determined by certain estimation methods. These fire flow estimations are calculated by taking the construction type, building area, combustibility of the building occupancy, inter-building fire exposure, communication and the presence of fire protection measures into account (Fillion & Jung, 2010).

2.3.2.2 *The Insurance Service Office Method*

The ISO is the main source, used internationally, that provides information, products and services related to property and liability risks related to fires. The ISO is used to evaluate the fire suppression delivery systems in buildings. Insurance companies determine suitable insurance premiums for buildings by using these evaluations. The more comprehensive the fire protection is in the buildings, the lower the insurance premiums will be.

The ISO uses a Fire Suppression Rating Schedule (FSRS) to define the criteria used in the evaluation of a building's fire defences. The FSRS also provides a method to determine the RFF for a specific building (ISO, 2008). These calculated fire flows are then used to determine the required water volume, the adequacy of the WDS, as well as the apparatus that will be needed to extinguish a fire, e.g. pumps and hoses.

The ISO determined fire flows by evaluating the data of a number of fires that caused exceptionally large amounts of damage. The average RFF, as well as the construction type, occupancy type, location of buildings and exposures were all taken into account

(ISO, 2008).The RFF is calculated as a function of the construction type, area, occupancy, building exposure and communication factors.

The formula used is as follows:

$$Fire\ Flow = (C)(O)[1.0 + (X + P)]$$

Where: RFF - Required fire flow (gpm)

C - Factor related to the construction type

O - Factor related to the occupancy type

X - Factor related to the exposure of the building

P - Factor related to the communication between buildings

The RFF can be determined by combining the fire flows determined in the equation with the recommended fire flow durations provided in the National Fire Protection Association Handbook.

2.3.2.2.1 Type of construction and effective area

The formula used to determine the fire flow attributed to the construction and the area is as follows:

$$C = 18F(A)^{0.5}$$

Where: C - Factor related to the construction type

F - Coefficient related to construction type, Table 2

A - Effective area (ft^2)

A range of *C*-coefficients is provided for different areas and construction types in Appendix A, Table A.1. The values calculated for *C* must be rounded off to the nearest 950 ℓ/min (250 gpm).

Table 2: Values for coefficient related to construction

Construction class	Description	Value for F
1	Wood frame construction	1.5
2	Joisted masonry construction	1
3	Non-combustible construction	0.8
4	Masonry non-combustible construction	0.8
5	Modified fire-resistive construction	0.6
6	Fire-resistive construction	0.5

2.3.2.2.2 Definitions for the classifications of different types of construction

These following definitions are used by the ISO to determine the different types of construction (ISO, 2008):

a) **Combustible materials:** Wood and other materials that will ignite and burn when subjected to fire. This also includes combinations of combustible materials with other materials, such as:

  i) Metal walls or floors sheathed on either interior or exterior surface with wood or other combustibles
  ii) Metal floors or roofs with combustible insulation or other combustible ceiling material attached to the underside of the floor or interior surface of the roof deck
  iii) Combustible wall materials with an surface of brick, stone or other masonry materials
  iv) Non-combustible wall or roof construction on a skeleton wood frame
  v) Combustible wall or roof construction on a non-combustible or slow burning frame
  vi) Composite assemblies of non-combustible materials with combustible materials, such as a combustible core between two non-combustible panels with a combustible insulation material
  vii) Composite assemblies of non-combustible or slow burning materials combined with foamed plastic materials, unless the plastic materials are classified as slow burning.

b) **Fire-resistive**: Non-combustible materials or assemblies with a fire resistance rating of more than one hour.

c) **Masonry:** Adobe, brick, cement, concrete, gypsum blocks, hollow concrete blocks, stone, tile and similar materials.

d) **Non-combustible:** Materials that will not ignite and burn when subjected to fire, such as aluminium, asbestos, glass, gypsum, plaster, slate, steel and similar materials. This also includes fire resistive and protected metal assemblies, as well as materials with low flame spreading abilities.

e) **Protected metals:** Metals that are protected by materials that results in an assembly with a fire-resistance rating of more than one hour.

f) **Slow burning:** Materials with low fire-spreading abilities as well as materials with thermal barriers.

g) **Unprotected metal**: Metal with no fire-resistive protection, or with a fire-resistive rating of less than an hour.

2.3.2.2.3 Classification of basic construction types

Six different construction types are identified by the ISO, as has already been mentioned in Table 2 (ISO, 2008); a description of these types of construction is shown in Table 3.

Construction Type 1 - wood frame construction
Construction Type 2 - joisted masonry construction
Construction Type 3 - non-combustible construction
Construction Type 4 - masonry non-combustible construction
Construction Type 5 - modified fire resistance construction
Construction Type 6 - fire-resistive construction.

Table 3: Construction type for ISO method

Construction Type	Description: Type of building
1	Exterior walls, floors and roof of combustible materials or buildings with exterior walls of combustible or slow burning materials
2	Exterior walls of fire-resistive construction (more than an hour) or masonry and combustible floors and roof
3	Exterior walls, floors and roof of non-combustible or slow burning materials with non-combustible or slow burning support
4	Exterior walls of fire-resistive construction or of masonry with non-combustible or slow burning floors and roof
5	Exterior walls, floors and roof constructed of masonry or fire-resistive materials
6	Buildings constructed of any of the following combinations: ○ Solid masonry ○ Hollow masonry of more than 12 inches ○ Hollow masonry less than 12 inches with fire resistance rating of more than 2h ○ Assemblies with fire-resistance ratings of more than two hours

2.3.2.2.4 Classification of mixed constructions

Buildings do not always consist of merely one type of construction. Buildings constructed of more than one type use certain guidelines provided by the ISO to determine the appropriate construction class. These guidelines will not be discussed in detail; for more information, see the *Guide for determination of needed fire flow* by the ISO (ISO, 2008).

2.3.2.2.5 Determining the effective area

The effective area must be calculated to determine the portion of fire flow needed according to the type of construction. The following areas are not taken into account due to sufficient protection, fire-resistive materials or a low tendency to start burning.

a) Exempted areas:

i) Areas where the entire floor is protected by an acceptable automatic fire protection system if there are no Type C-5 occupancies that are rapid/flash burning, see 2.3.2.2.6.
ii) Empty basement and sub-basement areas, with occupancies of Type C-1 or Type C-2, see 2.3.2.2.6.
iii) All perforated operating desks which contains no storage
iv) Courts with no roofs
v) Roof structures, sheds and similar buildings and additions
vi) Areas of mezzanines of less than 25% times the square foot area of the floor below.

b) Effective area calculations:

The effective area is calculated as the total square foot area (these calculations and equations use Empirical units) of the largest floor in the building plus the following percentage of the total area of the other floors:

- Buildings of Construction Type 1- 4

  Fifty percent of all the floors in the building must be added.

- Buildings of Construction Type 5-6

  If all the vertical openings in the building are protected: 25% of all floors not exceeding the largest floor. If one or more vertical openings in the building are unprotected, 50% of the other floors with unprotected openings not exceeding eight floors.

2.3.2.2.6 The Occupancy Factor

The occupancy combustibility classifications are a reflection of the combustibility of the contents within a building structure. According to the ISO, the following definitions are used to determine the combustibility classification and the examples are provided by Hickey (2008).

a) **Non-combustible (C-1)** - Any product or materials, including furniture, which does not constitute an active fuel for the spreading of fire, e.g. steel or concrete products storages.

b) **Limited-combustible (C-2)** - Any product or materials, including furniture of low flammability, with limited availability of flammable materials. These products are usually found in:

- Apartments
- Hotels
- Offices
- Metal industries
- Parking garages
- Hospitals
- Concrete industries
- Schools.

c) **Combustible (C-3)** - Any product or materials, including furniture of moderate combustibility.

- Recreational areas
- Department stores
- Dairy processing
- Hardware
- Leather processing
- Unoccupied buildings.

d) **Free-burning(C-4)**-Any product or materials, including furniture which burn freely, providing an active fuel.

- Aircraft hangers
- Freight deposits
- Furniture stores
- Warehouses
- Wood products (sale / storage)
- Building materials.

e) **Rapid burning or flash burning (C-5)** - Any product or materials, including furniture which either burn with great intensity, spontaneously ignite and are difficult to extinguish, give off combustible or explosive vapours at regular temperatures or produce large quantities of fine debris, e.g. dust, subject to flash fires.

  - Chemical sales and storage
  - Petrochemical refinery and storage
  - Cleaning/drying materials
  - Paint sales/storage
  - Distilleries
  - Cereals/flour mills
  - Upholstering factories
  - Waste and reclaimed materials

There are different factors listed in Table 4 that reflect the influence of the combustibility of the occupancy of the building.

Table 4: Occupancy factors that influence the RFF

Occupancy Combustibility Class	Description	Occupancy factor
C - 1	Non-combustible	0.75
C - 2	Limited-combustible	0.85
C - 3	Combustible	1.00
C - 4	Free-burning	1.15
C - 5	Rapid/flash burning	1.25

For more examples and detailed descriptions of the different occupancy types, see *The guide for the determination of fire flow, Edition 5* by the ISO (2008).

2.3.2.2.7 Communication and exposure factor

The factors determined to take communication (P_i) and exposure (X_i) into account portrays the effect of adjacent and connected buildings on the RFF. A building within less than 30m (100ft) from the fire is seen as an exposed building and buildings with adjoining passageways are seen as communicating buildings. The formula used to calculate the influence of the exposure and communication for each side of the building is:

$$(X + P)i = 1.0 + \sum_{i=1}^{n} (Xi + Pi)\,, with\ a\ maximum\ value\ of\ 1.75$$

Where: n – number of sides of building on fire

- The Communication factor (P)

  The factor P depends on the protection of the wall openings of the communicating buildings and the length and type of construction of communication between the fire divisions. If more than one type of communication exists for a sidewall, apply the largest P. If there are no communications, P = 0. Factors are given in Table A.2 in Appendix A.

- The Exposure factor (X)

  The factor X depends on the type of construction and the length-height ratio (the length of the wall in feet times the height of the building) of the exposed buildings as well as the distance between the facing walls of the subject building and the exposed building. The factors are given in Table A.3 in Appendix A, for more detailed information on applying these factors; see *The guide for the determination of fire flow, Edition 5* by ISO.

2.3.2.2.8 Automatic sprinkler systems

The ISO uses the Specific Commercial Property Evaluation Schedule (SCOPES) to evaluate sprinkler protection of a property. For a property to be registered as a sprinkled property, it must score at least 10/100 in the ISO's automatic sprinkler grading. The grading consists of a 100-point system that represents a two-source water supply (wet- and dry-pipe) installation. The system must also pass all the requirements specified by the NFPA. This includes *Standard 13(Standard for installation of sprinkler systems, NFPA 25 - standard for inspection, testing and maintenance of water-based fire protection systems).*

If a property is categorized as a sprinklered property according to the ISO, it must meet the following requirements:

- The building must have appropriate maintenance
- Flushing and hydrostatic tests must be conducted on the system
- Every 4 years a full flow main drain test must be conducted
- Dry-pipe trip tests must be conducted for dry-pipe systems every 4 years
- Fire pump tests must be conducted for fire pump installations every 4 years
- The usable unsprinklered area is not allowed to exceed a certain percentage depending on the type of occupancy combustibility, see Table 5.

Table 5: Percentage allowable unsprinklered area for ISO method

Occupancy Combustibility Type	Allowable unsprinklered area (%)
C - 1	25% of total area
C - 2	20% of total area
C - 3	20% of total area
C -4	10 000 ft^2(930 m^2)or 10% of total area
C -5	5000 ft^2(465 m^2)or 10% of total area

In areas where one and two family apartments are grouped closely together and the apartments are protected with residential sprinkler systems that meet the NFPA 13D *(Standard for sprinkler systems in one- and two-family dwellings and mobile homes)* the fire flow may be reduced to 1 900ℓ/min at 138 kPa (20 psi).

For residential occupancies with four or less storeys that are protected by an automatic sprinkler system, installed according to the NFPA 13 *(Standard for the installation of sprinkler systems in residential occupancies up to and including four stories in height*), a reduction in fire flow might be appropriate. The RFF for such installations may be reduced to 3 800ℓ/min(1000 gpm)at 138 kPa (20 psi) except for scenarios where the calculated RFF is already less than 3 800 ℓ/min(1000 gpm).

2.3.2.2.9 Additional considerations for determining fire flows

A number of additional factors and possible scenarios should be considered when determining the RFF for a building.

- The maximum allowable fire flow is 45 200 ℓ/min (12 000 gpm) and the minimum is 1 900ℓ/min (500 gpm).

- When the building that is on fire or exposed buildings nearby have a wood-shingle roof covering, the roof can aid in the spreading of the fire, an additional 1 900ℓ/min (500 gpm) should thus be added to the RFF.

- The ISO method rounds the calculated fire flow value to the nearest 950ℓ/min (250 gpm) if the flow is less than 9 500ℓ/min (2 500 gpm) and to the nearest 1 900ℓ/min (500 gpm) for fire flow values higher than 9 500ℓ/min (2 500 gpm).

- If the one and two family apartments do not exceed two storeys in height, the following fire flow values are suggested by the ISO, Table 6.

- For any other buildings used for living purposes, the maximum fire flow should not exceed 13 200 ℓ/min (3 500 gpm).

Table 6: Required fire flows for one and two family apartments according to the ISO

Distance between buildings (m)	Required fire flow
More than 100	1 900ℓ/min(500 gpm)
31 – 100	2 900ℓ/min(750 gpm)
11 – 30	3 800ℓ/min(1000 gpm)
Less than 10	5 700ℓ/min(1500 gpm)

2.3.2.2.10 The provision of fire flow

Even though the ISO states that a RFF of up to 45 200ℓ/min (12 000 gpm) could be determined for extremely high-risk buildings, the water suppliers in the United States are only required to provide 13 200ℓ/min (3 500 gpm) (Insurance Services Office, Inc, 1980).

The required duration of fire flow depends on the type of building, building area, number of storeys, construction materials and occupancy. Studies were done based upon full-scale fire tests conducted by the National Institute of Science and Technology (NIST), the duration of fire flow required for one-storey residential buildings was determined to be 1 hour or less (Snyder et al., 2002).

2.3.2.3 *The Illinois Institute of Technology Research Institute Method*

This method is based on data that was collected from actual fires that occurred. The data from 134 fires in different types of buildings and with different occupancies was analysed to determine the fire flow that was necessary to control the fire at each of these scenarios. The Illinois Institute of Technology Research Institute (IITRI) method used a curve fitting analysis to determine the following equations that could be used to determine the RFF. The equations are based upon the area of the affected building and the occupancy of the building:

Residential occupancies: $Flow(gpm) = (9\times 10^{-5}\times A^2) + (50\times 10^{\cdot 2}\times A)$

Non-residential occupancies: $Flow(gpm) = (-1.3\times 10^{-5}\times A^2) + (42\times 10^{\cdot 2}\times A)$

Where: A - Effective area of fire (ft^2)

This method is very simple and easy to use and would be well suited for quick calculations. However, this method is not very accurate and is therefore not recommended for scenarios where information that is more detailed would be required.

2.3.2.4 *The ISU Method*

The ISU method, published in 1967, is one of the oldest methods used to determine fire flow. This method calculates the RFF by addressing the volume of water needed to extinguish a fire as well as the effects of different application procedures and tempos. The ISU method is based on the amount of water needed to evaporate in order to extinguish a fire. The formula used for this method requires both the quantity of water needed to extinguish a fire and the effects of various application rates and techniques (American Water Works Association, 2008).

If the supply of oxygen is eliminated or reduced by high volumes of steam, the fire would also be reduced. The vaporisation of the water into steam decreases the heat of the flames and aids in the extinguishing of the fire. This equation is based on the combustion of fuel being dependent on the available oxygen supply in the closed compartment and the vaporization of applied water into steam.

The equation for the method is as follows:

$$Flow(gpm) = \ (Area[ft^2] \times Height\ of\ building[ft]/100)$$

This method is somewhat limited due to the assumption that the whole building is on fire and that therefore the total volume must be taken into account, including lower ground floor, roof space and any other void spaces. According to Burns and Phelps (1994), this method should not be used to determine the RFF in scenarios in which there are lives at stake, since it often results in flows that are too low.

2.3.2.5 *The National Fire Academy method*

The National Fire Academy (NFA) method is similar to certain other methods, and was developed to determine the required flow at the scene of the fire with relatively simple equations. The method is a modification of the ISU method and is used to determine the flow based on the fire floor in buildings with four or fewer floors. In cases with more than one floor, the sum of the areas of all the floors is used. This method also takes into account the potential exposure of all buildings within 9m (30ft) of the fire building. For each of the potential exposures, 25% of the initial fire flow is added to the total fire flow. The following formula is used to determine the flow:

$$Flow(gpm) = \left[(Area\,[ft^2]) \div 3 \times Storeys\right] + \left[Exposures\; x\; (Area[ft^2] \div 3) \times 0.25\right]$$

2.3.2.6 *The NFPA Method*

The *NFPA 1141: Standard for fire protection in planned building groups* suggests that it is left to the local authorities to determine the RFF for their specific regions. For areas with water distribution networks maintained by the municipality, the fire flow calculations must be used to determine the required flow. For areas without such a distribution network, the *NFPA 1142: Standard on water supplies for suburban and rural firefighting* is applicable. The NFPA requires that a minimum of 950 ℓ/min (250 gpm) must be available under all circumstances.

Even though the RFFs are specified for certain areas, this does not necessarily mean that sufficient and reliable water supplies are available. The NFPA recommends that the fire departments of each jurisdiction should do on-site surveys for all areas. The fire departments must take into account the occupancy hazard, type of construction, structure dimensions and exposures.

The NFPA provides calculations to determine the minimum RFF for buildings based on their exposure hazard, total area of structure, occupancy hazard classification and construction classification number.

2.3.2.7 *The Uniform Fire Code*

The Uniform Fire Code (UFC) was one of the standards applied by the NFPA. The UFC provides fire and life safety regulations for new and existing buildings. In the fifth edition of the UFC the minimum fire flow requirements for one- or two storey family dwelling with an area less than 560 m^2 (5 000 ft^2) was provided. There are numerous scenarios that would result in the reduction of the fire flow, e.g. if an approved sprinkler system were available (50% reduction) and if the building was more than 10m away from other buildings (25% reduction). The minimum fire flow recommended is 1 800 ℓ/min (500 gpm) for a duration of at least one hour.

2.3.2.8 *The International Code Council*

The International Code Council (ICC) develops fire and life safety standards. The ICC published the International Fire Code (IFC), which is used to regulate the provision of fire flow in buildings. According to the IFC, all buildings must be provided with sufficient supplies of water for domestic uses as well as the RFF. The method of supplying fire flow could be determined by the individual authorities in the area (Blanksvard, 2009).

According to the IFC method the minimum fire flow for one and two family residential buildings smaller than 345m^2 (3 600 ft^2) is 3 800 ℓ/min (1 000 gpm). Buildings in excess of 345m^2(3 600 ft^2) should provide fire flows as specified in Appendix B, Table B.1.

The type of construction for non-residential buildings is characterized in the *International Building Code* (Unified Facilities Criteria, 2002). According to the IFC method, the RFF could be reduced by up to 75% if the buildings were equipped with approved sprinkler systems. The reduced fire flows are not allowed to be less than 5 200 ℓ/min (1 500 gpm) and have to be supplied for a minimum duration of two hours.

2.3.2.9 *Unified Facilities Criteria*

The Unified Facilities Criteria (UnFC) system provides planning, design, construction, restoration and modernization criteria and applies to the Military Departments, Defence Agencies, Department of Defence (DoD) field activities as well as public and private ventures (Unified Facilities Criteria, 2002) .

The purpose of the UnFC is to provide the minimum fire flow requirements for all DoD buildings. The method is based on the National Insurance Underwriters method and may exceed the national standards, since these requirements reflect the importance of the protection of lives, properties and missions (Unified Facilities Criteria, 2002)

2.3.2.9.1 Buildings with approved sprinkler systems

In buildings with approved sprinkler systems, the fire flows required for the sprinkler systems depends on the type of occupancy of the building, the discharge density, design area, type of construction and the type of sprinkler system.

The occupancy hazard classification used to determine the automatic sprinkler densities and demands is shown in Table 7. Note that the basic hazard occupancy does not necessarily define the hazard occupancy for the whole area; fire flow should be provided according to the most hazardous occupancy.

Table 7: Classification of occupancy hazards

Type of occupancy	Description	Examples
Light Hazard	Quantity and combustibility of contents are low and fires with low heat release rates are expected	Churches, gymnasiums, clinics (dental/outpatients) and offices
Low Hazard (Group1)	Occupancy with low combustibility and quantity is moderate	Bowling alleys, clubs, kitchens, bakeries, and parking garages
Moderate Hazard (Group2)	Occupancy where quantity and combustibility is moderate	Airports, libraries and woodworking shops
High Hazard (Group1)	Occupancy where quantity and combustibility is high	Department stores, paper mills and furniture warehouses
Severe Hazard (Group2)	Occupancy where quantity and combustibility is extremely severe	Saw mills, explosives and wood manufacturers.

The calculations of the RFF utilize the following factors; the results of the calculations are shown in Table 8.

- *Water demand for sprinklers*: The water demand required for sprinklered buildings depends on the occupancy, construction type and type of sprinkler system used.

- *Design densities:* The densities provided are the minimum distances/areas between sprinklers discharging specific required flow rates.

- *Design areas:* Design areas are the areas for which the system of sprinklers must be able to provide fire flow.

- *Water demand for hose streams*: Hose streams are required to provide the flow required at each of the sprinklers.

Table 8: Sprinkler system requirements (Unified Facilities Criteria, 2002)

Occupancy Classification	Sprinkler system		Hose stream allowance (ℓ/min)	Duration of supply (min)
	Design density (ℓ/min/m^2)	Design area (m^2)		
Light Hazard	4.1	280	950	60
Ordinary Hazard (Group 1)	6.1	280	1 900	60
Ordinary Hazard (Group 2)	8.2	280	1 900	90
Extra Hazards (Group 1)	12.2	280	2 840	120
Extra Hazards (Group 2)	16.3	280	2 840	120

Table 9: Weighted factors for fire flow (Unified Facilities Criteria, 2002)

Weighted factors for unsprinklered buildings		
Type	Category	Value
Response time by fire department[1]	On-site fire department (within 1.6km)	1
	On-site fire department (within 1.6km - 4.8km)	2
	On-site fire department (more than 4.8km away)	3
	Off-site fire department (within 3.2km)	2
	Off-site fire department (more than 3.2km away)	3
Type of construction[2]	Type I	1
	Type II	2
	Type III	3
	Type IV	2
	Type V	4
Number of storeys	Single storey	1
	Double storey	2
Separation distance[3]	> 18.3m	1
	6.4m - 18.3m	2
	< 6.1m	4
Building floor area	< 697 m^2	1
	697 - 1394 m^2	2
	1394 - 2323 m^2	3
	2323 - 3716 m^2	4
	> 3716	5
Firefighting access[4]	< 55m	1
	55 - 70m	2
	>70m	4

1. On-site fire departments are familiar with the hazards and layout of the building (usual private fire department for the specific type of building).
2. Categorization of construction types is done according to the IBC classifications.
3. The distance between the fire building and nearby structures.
4. Height of the building.

2.3.2.9.2 Buildings without sprinkler systems

The fire flow requirements for buildings without sprinkler systems are based on the fire department hose stream requirements. The hose stream demands and duration requirements for these buildings are determined by the following factors:

- Type of construction
- Occupancy classification
- Separation distance
- Building floor area
- Firefighting access.

The total fire flow is determined by assigning a weight to each of the factors above. These six weighted values are then used according to Table 9, to assign fire flow and durations according to the weighted values. After determining the weighted values from Table 9, in addition to the type of occupancy, the RFF and duration could be attained from Table 10.

Table 10: Weighted factors for fire

Total weighted value						
Occupancy hazard classification	Fire flows (ℓ/min) at 137 kPa			Duration (min)		
	6 - 10	11 -15	>16	6 - 10	11 -15	>16
Light Hazard	2 810	4 260	5680	60	90	120
Ordinary Group 1	3 785	5 680	7 570	90	120	150
Ordinary Group 2	5 680	8 520	11 360	90	120	150
Extra Hazard (Groups 1 & 2)	9 465	14 195	18 930	150	195	240

2.3.3 Canada

In Canada, each metropolis is responsible for its own individual building regulations and standards. A few codes make recommendations about providing fire flow.

2.3.3.1 *Model codes for fire flow*

The National Building Code (NBC) does not provide a fire flow but recommends that sufficient water supplies should be available in the case of a fire. The Canadian Commission on Building and Fire Codes (CCBFC) maintain the National Fire Code of Canada (NFC), which is a recommended model code available for implementation by metropolises in different areas. The NFC provides the minimum RFFs for buildings and any other structures that may need fire protection. (Canadian Commission on Building and Fire Codes, 1999).

Some authorities prefer to use methods that are more detailed for determining fire flow, in order to achieve more realistic and applicable fire flows. The most popular method in Canada is the FUS Method.

2.3.3.2 *The FUS method*

This method is rather similar to the ISO method used in the United States of America. The FUS method is based on extensive research as well as the experience of fire protection engineers (Fire Underwriters Survey, 2009).

The method uses an empirical equation to determine the RFF as a function of the building characteristics, e.g. the construction type, floor area, number of storeys, occupancy and the exposure risk.

The FUS also provides for a number of alterations that can be made to the equations, depending on the construction type, combustibility of the building and the presence of fire protections, i.e. sprinklers.

These alterations can increase or decrease the RFF. The FUS also provides recommendations for fire flow durations as well as hydrant distributions depending on the RFF (Fire Underwriters Survey, 2009).

2.3.3.2.1 The FUS Equation

An estimate of the fire flow required could be determined by using the following equation:

$$F = 220C\sqrt{A}$$

Where: F - required fire flow in l/min

C^* - coefficient related to building construction type

- 1.5 for wood frame construction (large percentage of material is combustible)

- 1.0 for ordinary construction (brick or masonry walls, combustible floors and interior)

- 0.8 for non-combustible construction (unprotected metal structures, masonry or metal walls)
- 0.6 for fire-resistant construction (fully protected frame, floors and roofs)

A** - total floor area in m^2 (all levels, except basements)

* For buildings where the type of construction does not fall into one of the above the coefficient categories, a value between 0.6 and 1.5 could be determined by interpolating between different construction types, depending on the fire resistance of the construction type concerned.

** For buildings that are relatively fire resistant, the two largest adjacent floors and 50% of the floors above them must be considered if the vertical openings of the buildings are not adequately protected.

2.3.3.2.2 Modifications to the FUS method

The following modifications can be made:

a) Occupancy of building

The values calculated for F using the formula above, can be increased or reduced by up to 25% depending on whether the occupancy of the building is a low or a high fire hazard, see Table 11.

Table 11: Increase/decrease to fire flow due to occupancy hazard

Occupancy type	Fire hazard	Decrease/increase for fire flow
Non-combustible	Very low	-25%
Limited combustibility	Low	-15%
Combustible	Moderate	No change
Free burning	High	15%
Rapid burning	Very high	25%

b) Sprinkler systems

The value determined using the formula with the modifications of **(a.)** could be reduced with up to 50% if the building is provided with an adequate and complete automatic sprinkler system. If the system conforms to the NFPA standards, the flow can be reduced with up to 30%. The percentage reduction of the needed fire flow depends on the ability of the sprinkler system to extinguish fires and prevent fires from spreading.

c) Exposure

The flow value determined according to the occupancy in **(a.)** should also be increased by a percentage, depending on the exposed structures within 45m of the building. The percentage depends on the height, area and construction of the nearby buildings, as well as the separation between the buildings, the length and intensity of the exposure, sprinkler systems, occupancy of the buildings and the possibility of potential vegetation fires.

The additional increase to the flow that depends on the separation between the buildings is shown in Table 12. If more than one side of the building is exposed, the total increase of the fire flow required is the sum of all the increases. However, the total percentage added on account of nearby buildings should not exceed 75%.

Table 12: Increase in fire flow due to exposures

Separation	Increase in fire flow
0 – 3m	25%
3.1 – 10m	20%
10.1 – 20m	15%
20.1 – 30m	10%
30.1 – 45m	5%

2.3.3.3 *Calculating the fire flow*

According to the FUS method the fire flow should not exceed 45 400 ℓ/min nor be less than 2000 ℓ/min. The FUS method also provides a relatively easy method that could be used to determine the RFF for one and two family dwellings that do not exceed two storeys in height.

This method is usually used for quick onsite calculations and only considers the exposure distance between the houses and the construction materials used, see Table 12. The RFF must be rounded off to the nearest 1 000 ℓ/min. The values for the short method are shown in Table 13.

Table 13: Short FUS method according to construction types

Exposure distances	Suggested required fire flow	
	Wood frame	Masonry or Brick
Less than 3m	*	6 000 ℓ/min
3 – 10m	4 000 ℓ/min	4 000 ℓ/min
10.1 – 30m	3 000 ℓ/min	3 000 ℓ/min
Over 30m	2 000 ℓ/min	2 000 ℓ/min

*.Wood frame structures separated by less than 3m should be considered as one fire area.

2.3.4 Fire flow requirements in other countries

No general guidelines are provided to determine the required fire flow in European countries, each of the countries is responsible for developing its own fire flow requirements.

2.3.4.1 *Germany*

Germany re-evaluated its water requirements in the 1970s. After the modifications, the authorities were responsible for supplying only a basic level of fire flow, called the “base flow”, whereas the owner of the property is responsible for ensuring that sufficient water supplies would be available for firefighting. If the “base flow” was not sufficient, the owners had to provide the rest of the water at their own expense. This method ensures that for scenarios where there is a high risk building in a low risk area it would not be necessary for the authorities to provide high risk fire flow for the whole area, since it would be the responsibility of each property owner to ensure the provision of sufficient fire flow for his building.

The German standards for fire flows are based on comprehensive fire risk categories that allocate the level of risk according to the type of building, the number of storeys and the risk of the fire spreading. The RFF ranges from 760 ℓ/min (200 gpm) for low risk areas to 3 200 ℓ/min (850 gpm) for high-risk areas. According to the German fire flow requirements, the fire flow must be sustained for a duration of two hours at a minimum pressure of 140 kPa (20 psi) for all building categories (Hickey, 2008).

2.3.4.2 *The United Kingdom*

In the United Kingdom, the national guidance document provides guidelines for fire flow provision. Similar to the German standards, the flows are based on the classification of different building categories (Water UK, 2011). The description for each of the categories and the recommended fire flow for each category are shown in *The National guidance document on the provision of water for firefighting.* The fire flow determined in the UK range from 450 ℓ/min (120 gpm) for low risk areas to 4 500 ℓ/min (1 200 gpm) for high risk areas

2.3.4.3 *Greece*

The Technical Chamber of Greece recommends a fire flow between 760 ℓ/min (200 gpm) for low risk areas and 7 200 ℓ/min (1 900 gpm) for high risk areas. The fire flow must be sustained for at least 30 minutes at a residual pressure of 414 kPa (60 psi). Note that the required residual pressure is relatively high. The high pressure would not only prevent negative pressures in the system but also provide pressure to the fire hoses of the fire department (Snyder et al., 2002).

2.3.4.4 *France*

Similar to most European countries, France determines the RFF based on the type of property threatened by the fire. According to the standards currently used in France, determined in 1967, fire flows of 1000 ℓ/min (260 gpm) must be supplied for a duration of 2 hours. The local authorities and fire departments are required to do assessments of properties to determine whether the fire requirements are realistic. In the City of Paris, for example, the fire flow requirements were modified to 2 000 ℓ/min (530 gpm) for residential buildings with two floors or less and 10 000ℓ/min (2 640 gpm) for more high-risk industrial areas (Hickey, 2008).

2.3.4.5 *Spain*

The fire flow standards in Spain are similar to the French fire flow standards. The fire flows are based on the potential fire risk of the area, a fire flow of 1 000 ℓ/min is required over a period of two hours at a residual pressure of 90 kPa (Real Decreto, 1993).

2.3.4.6 *Russia*

The fire flow requirements in Russia are determined according to the fire risk category of the building, taking into account the occupancy of the building, the size of the building and the degree of fire protection in the building. The Russian standards also differentiate between water supplied via trunk mains (large diameter pipes direct from source) and distribution mains. The minimum RFF is 300 ℓ/min for small residential buildings, see Table C.1, and the maximum fire flows is 6 000 ℓ/min for large apartment buildings in densely populated areas, see

Table C.2 in Appendix C. If the fire flows determined for an area varies according to the tables, the larger of the two fire flows is to be used. All the flows must be provided for at least 3 hours at pressures of at least 90 kPa and less than 550 kPa according to SNIP 01409 (Hickey, 2008)

2.3.4.7 *Netherlands*

The KIWA Mededeling 50 provided the original fire flow requirements in the Netherlands. These flows were exceptionally high, among the highest in Europe. The fire flow was determined according to different fire risk areas and then added to the daily water demands.

The following two risk areas, with fire flows at a residual pressure of 207 kPa (30 psi), were defined:

High risk:	6 000 ℓ/min (1 600gpm) over a period of 6 hours
Low risk:	1 500 ℓ/min (400 gpm) over a period of 2 hours

These fire flow requirements were revised in 1999 by KIWA and new flows were determined taking into account the cost of the WDS and water quality as well as the fire risk areas. According to the new approach, a fire flow of 500 ℓ/min (130 gpm) would be adequate for most types of building. The decrease in the required flow is a result of up to 90% of the buildings built after the 1950s meeting the regulations of the fire protection code for buildings. However, high-risk buildings and areas would still require higher fire flows; 1 000 ℓ/min was recommended. In the Netherlands, the fire departments use the WDS for the first 15 -30 minutes, after which they start using non-potable water from the canals or other available sources KIWA (Snyder et al., 2002).

The methods and fire flow requirements discussed in this chapter are presented in Appendix E.

2.3.5 International fire statistics

The International Association for the Study of Insurance Economics (The Geneva Association) is a one of a kind organisation formed by the Chief Executive Officers (CEOs) of 80 high profile insurance companies throughout the world, including Europe, America, Asia, Africa and Australia. Their primary objective is researching insurance claims and the effect of these claims on the economy. In 2005, the organisation presented its annual report to the United Nations Committee on Human Settlements at its meeting in Geneva. The following fire statistic comparison was reported (International Association for the Study of Insurance Economics, 2005), Table 14 shows the percentage of the Gross Domestic Product (GDP) that is lost due to damages caused by fires, as well as money spent on protecting buildings against fires. Note that these are only direct costs; indirect losses, loss of living quality, medical costs and loss of lives are not taken into account.

Table 14: International fire statistics

International fire statistics			
Country	Total fire losses (Direct and Indirect)	Cost of fire protection to buildings	Deaths / 100 000 persons
	Percentage of GDP (2000 - 2002)	Percentage of GDP (2000 - 2002)[2]	
Singapore	0.075	0.40	0.12
Japan	0.116	0.16	1.73
Slovenia	0.143	0.16	0.93
Hungary	0.149	0.42	2.06
U.K.	0.151	0.20	1.06
Canada	0.192	0.25	1.25
France	0.184	0.16	0.95
New Zealand	0.175	0.15	0.95
Germany	0.201		
Italy	0.194	0.33	0.68
Netherlands	0.207	0.30	
Sweden	0.012	0.29	1.50
United States	0.242[1.]	0.36	1.74[3.]
Switzerland	0.325	0.29	0.56
Austria	0.276		1.35
Norway	0.282	0.33	1.36

1. Including 9/11 losses

2. Values for fire protection differ according to building type

3. Including 2 791 lives lost in 9/11

2.3.6 Comparison of methods

In this section, a number of different methods for calculating required fire flow have been mentioned and the more popular methods were explained in detail. These methods generally use equations or tables to determine the RFF. In most of these methods, the size of the building played an important role in the determination of the fire flow; the IITRI method used the volume of the building, whereas the other methods used the total area of building, taking into account the number of floors (Blanksvard, 2009).

Most of these methods have some form of limitation; the ISO method is only applicable for one or two storey buildings, the UFC for areas less than 560 m^2 (5 000 ft^2), and the IFC for areas less than 390 m^2 (3 500 ft^2).

The various fire flow calculation methods use different parameters and input factors, resulting in different flows. Examples of calculations for three scenarios using the different methods are shown in Appendix D. The different methods were used to calculate the flows for a one storey residential building, an apartment building and a commercial building. The results of these calculations as well as the comparison of the methods for each scenario can be seen in Appendix D, Table D.1, Table D.5 and Table D.9 respectively. The comparison of the values calculated using the different methods can be seen in Appendix D, Figure D.1, Figure D.2 and Figure D.3.

It is highly likely that some of the methods have overestimated the RFF, whereas some methods have most likely underestimated it. The overestimation would lead to unnecessarily high costs, and water quality problems due to longer retention times. The underestimation would result in insufficient flows during fires, possibly resulting in relatively high loss of properties, belongings and even lives.

Note that in cases where different firefighting techniques, e.g. foam or fog sprays, are used, the calculated RFF would not be relevant, since the previously described methods are applicable only for water streams with no additives.

The IITRI method has the advantage of examining fire flow requirements individually for each building. However, in cases where further construction of buildings has taken place it could result in an overestimation of the RFF. This method is limited by the fact that the RFF depends only on the building size.

The IITRI method for residential buildings frequently gives the highest determined values for fire flow, and it is followed by the NFA method. The NFA method was developed for quick calculations at the scene of the fire; the accuracy of this method is therefore questionable. This method is only suitable for buildings with four floors or less, and is applicable for smaller rural towns rather than cities (Blanksvard, 2009).

Unlike the ISO, FUS, IFC, FUC method, the ISU, IITRI and NFA methods do not reduce the RFF in buildings with sprinkler systems, leading to recommendation of higher RFFs than necessary in sprinklered buildings. Whereas the UnFC have different methods of determining the fire flow for sprinklered and unsprinklered buildings.

The utilisation of a large range of different parameters and factors to determine the fire flow in the ISO method is not necessarily a strength, this leads to an over complicated method for the type of results it produces (Blanksvard, 2009). Another problem with the ISO method is the rounding off of the total fire flow to the nearest 250 gpm (940 ℓ/min) if the flow is less than 2 500 gpm (9 400 ℓ/min) or to the nearest 500 gpm (1 900 ℓ/min) if the flow is greater than 2 500 gpm (9 400 ℓ/min). If rounded down, this could lead to a shortage in flow, if rounded up it could lead to additional costs.

Failure to meet the fire flows required could lead to increased insurance premiums, however, designing a system to provide the fire flow leads to complex calculations and possible overestimations. The use of the IFC method is therefore more efficient, since this method was derived from the ISO method, but is more accessible, since the values and information are in table format. The IFC method also provide the same fire flows or higher than the fire flows determined by the ISO method in buildings with sprinklers (Blanksvard, 2009). A comparison of the parameters required for each of these methods is shown in Table 15.

Table 15: Fire flow calculations method input parameters

Fire flow determination method input parameters								
	Fire Flow Method							
Inputs	ISO	IITRI	ISU	NFA	NFPA	UNFC	IFC	FUS
Building area	X	X		X	X	X	X	X
Building volume			X					
Construction type	X				X	X	X	X
Occupancy	X	*			X	**		X
Exposures	X			X	X	X		X
Sprinkler system	X					X	X	X
Communication	X							

* Method considers the residential structures and non-residential structures individually

** For buildings with sprinklers, flows are provided according to occupancy type

2.3.7 Conclusion

Each of the fire flows discussed is designed for the specific requirements of a country, taking into account the type of water networks available as well as the alternative types of resources that could be used for firefighting. Irrespective of what methods these countries use to determine their flows, one can but look at the world statistics of losses and damages caused by fires to acknowledge the importance of providing adequate fire flows.

2.4 Firefighting in South Africa

The main purpose of firefighting in South Africa is to protect lives and properties if a fire were to occur. It is imperative for fire services to be well organised to ensure the operations are effective. The two most important fundamentals for providing fire protection are the provision of efficient fire services and the provision of an adequate water supply.

2.4.1 Fire flow regulations

There are a number of different guidelines which are used in South Africa, the South African National Standards, the Department of Water Affairs regulations and the *"Guidelines provided by the department of Public Works",* that each provide different requirements concerning fire flows and residual pressures during fires. These codes and standards differ to some extent from the original standards that were provided in 1966 by the SABS 090 (Van Zyl & Haarhoff, 1997). The original codes were compiled with the assistance of organisations from the UK, Canada, New Zealand and Germany. It is probable that many systems, especially the older systems, do not fully comply with these standards (Van Zyl & Haarhoff, 1993a).

In South Africa, the task of providing fire flow is left to the local municipalities, who are not legally required to provide fire flow (Department of Co-operation and Development, 1984). According to the National Building Regulations (NBR) in South Africa, it is up to the property owner to ensure the availability additional water for firefighting if the water distribution network is not able to supply sufficient flows. An analysis that was done by the Fire Protection Association of South Africa showed that only a few of the municipalities are able to supply the RFF in the moderate and high risk areas (Van Zyl & Haarhoff, 1997); the percentages can be seen in Table 16.

Table 16: Municipalities able to provide required fire flow

Risk Category	Percentage municipalities able to provide required flows
High risk (12 000ℓ/min)	22%
Moderate risk (6 000ℓ/min)	24%
Low risk (900 ℓ/min)	90%

The discrepancies between the fire flows available and the flows required according to the standards should be addressed. It is possible that some of the fire flow requirements of the standards are too high, resulting in over-designed systems or developers excluding fire flow from the design on account of its unrealistically high costs.

2.4.1.1 *South African National Standards: 10090:2003*

The SANS provides advice and guidelines on the actions that should be taken to ensure effective firefighting. It also includes a schedule against which the performance potential of each aspect, as well as all the aspects of fire services, can be evaluated. A method of rating the potential fire risk of an area is based on this schedule and can be used to indicate the potential extent to which property and loss of life can be avoided.

The SANS codes are compiled from a number of international and national standards. The following were used (SANS 10090:2003, 2003):

- **NFPA 291**: Recommended Practice for Fire Flow Testing and Marking of Hydrants
- **NFP2 1201**: Standard for Developing Fire Protection Services for the Public
- **NFPA 1561**: Standard on Emergency Services Incident Management System
- **NFPA 1710**: Standard for the Organization and Deployment of Fire Suppression, Emergency Medical Operations and Special Operations to the Public Career Fire Departments
- **NFP4 1901**: Standard for Automotive Fire Apparatus
- **SANS 10400 (SABS 0400)**: The Application of the National Building Regulations

The Fire Protection Agency of Southern Africa (FPA) is a non-profit technical advisory and educational body on all matters of fire safety. One of the responsibilities of this organisation is to evaluate fire brigade services and water supplies in accordance with the SANS 10090:2003 (Van Zyl & Haarhoff, 1993b)

2.4.1.1.1 Providing Fire Protection

To determine the fire flow rates required for an area, a survey must be conducted to determine the fire hazards in the area, according to the SANS 10090:2003.

The survey of each building should include the following characteristics:

- Means of approaching the building
- Height of the building
- Type of construction
- Water supply available
- Any features that could influence the fire risk of an area
- Occupancy of building.

The surveys should be redone every three years to ensure that the information is still relevant.

2.4.1.1.2 Fire risk categories:

Areas are divided into sub-areas which fall into different fire-risk categories as defined by the SANS: 10090 (SANS: 10090, 2003), Table 17.

Table 17: SANS: 10090 risk categories

South African National Standards 10090		
Risk Category	Description	Risk
Category A	Central business districts, commercial and industrial areas, usually in cities or large towns	Extremely high property and life risk
Category B	Limited central business districts, smaller commercial and industrial areas, usually in smaller towns and decentralized areas of cities and larger towns	High property and life risk
Category C	Conventionally constructed residential areas	Moderate property and life risk
Category D	Rural and remote urban areas with limited buildings	Low property and life risk
Category E	Areas requiring special attendance, e.g. shopping centres, hospitals, prisons, high rise buildings	Special risk areas

2.4.1.1.3 Fire Brigades

As was mentioned earlier, one of the fundamentals of fighting fires, aside from the water requirements, is the fire services that must be provided. There are different classifications of fire brigades, Categories 1 – 5, depending on their ability to comply with the recommendations of the NFPA 1201. The better the compliance, the higher the category.

The classifications take into account the type as well as the quantity of their equipment and are done according to the following criteria using the evaluation forms in Annex A, B and C of the SANS:10090 (SANS: 10090, 2003).

- Risk profile of area
- Weight/ speed of response
- Call receiving/ processing
- Vehicle and equipment availability/maintenance
- Incident management procedures
- Pre-fire planning and risk visits
- Water supplies
- Fire safety functions.

2.4.1.1.4 The Response of the fire brigades

The effective control and extinguishing of a fire depends on the capabilities of the fire services and the fire appliances to provide sufficient flows, fire services arriving as soon as possible and the ability of the network to supply the RFF.

The equipment used in a response should be able to provide sufficient fire protection for the area protected by the brigade, see Table 18.

Table 18: Required responses to fires for different categories

Risk Category	Min. number of pumping units	Min. manning level per appliance	Min. pumping capacity of each unit (ℓ/min)
A	2	5	3 850
B	2	4	3 850
C	1	4	2 250
D	1	4	2 250
E	As determined by individual risk assessments		

In brigades with only one station, the number of appliances must be sufficient to meet the full demands of a first call to the most congested area and be able to provide at least one pump to a second call. In brigades with more than one station, the number of appliances should be determined according to the fire-risk category that is assigned to the specific station (SANS: 10090, 2003).

The assistance for additional services, e.g. vehicle fires, grass/bush fires, as well as the need for aerial appliances and water carriers is determined by local conditions.

2.4.1.1.5 Water supply

The water supply from reservoirs is regulated to ensure that the supply to any area is delivered from more than one direction, in case disruptions occur in the network. The volume of water that should be available at all times is based on the highest daily consumptions (average taken over the last three years) plus the RFF. These flows must be maintained for the minimum allowable duration at the required residual pressure.

The following should be taken into account when assessing the water supply potential of an area (SANS: 10090, 2003).

- Quantity of water available in network
- Sources that supply water to the network (including emergency resources)
- Minimum residual pressure in the network
- Reticulation components including pumps, filters and piping systems
- Type, size, distribution and availability of hydrants.

2.4.1.1.6 Fire Flow

The water flow rates required for firefighting, as well as the required duration for each of the risk areas, is given in Table 19. The fire flows are based on possible partition sizes for buildings as described in the SABS 0400. The fire flow calculations are based on the RFF of the Insurance Survey Office (ISO) suppression rating schedule.

It is important to ensure that sufficient fire flow is available when the firefighting teams arrive at the scene. It would be ideal if a liaison between the water suppliers and the fire departments could be sustained, ensuring that if a fire was to occur during a peak demand period, or any other problems might occur, the water supply could be augmented towards the area where the fire is.

Table 19: Minimum required fire flow (SANS: 10090, 2003)

Risk Category	Possible Fire Size	Flow in ℓ/min	Required duration
A	Non-residential buildings with divisions < 5 000 m^2	13 000	4h
B	Non-residential buildings with divisions < 2 500 m^2	9 000	4h
C	Non-residential buildings with premises < 1 250 m^2	6 000	2h
D1	Houses > 30m apart	1 900	2h
D2	Houses 10m - 30m apart	2 850	
D3	Houses 3m - 10m apart	3 800	
D4	Houses < 3m apart	5 700	
E	As determined by risk assessment		

As has already been mentioned, the minimum amount of water that must be available should be based on the highest daily consumption plus the RFF. This supply must be maintainable for a minimum duration at the required residual pressure of at least 200 kPa.

The fire flow volume that would be required at the scene can be calculated according to the following formula:

$$Supply\ requirement\ (m^3) = \frac{(RFF + HD) \times T}{1000}$$

Where:

RFF - Required fire flow according to the risk category (ℓ/min)
HD - Highest daily consumption (ℓ/min)
T - Duration in minutes according to risk category (2 – 4 h)

2.4.1.1.7 Hydrants

Section 11.5.1 of the SANS: 10090 provide minimum fire flows for each hydrant as well as the maximum spacing of hydrants for the different risk areas. The flows and distances are given in Table 20.The municipalities must ensure that these hydrants are serviced and the flows must be measured to ensure that the required fire flows, according to Table 19, could be provided.

Authorities in the region must ensure that hydrants are serviced as follows:

- Category A & E - Every year
- Category B - Every two years
- Categories C & D - Every three years

Table 20: Hydrants required flow and spacing

Risk Category	Minimum required hydrant flow (ℓ/min)	Maximum distance between hydrants (m)
A	2 000	85
B	2 000	120
C	2 000	200
D1 (Houses < 30m apart)	1 200	300
D2 (Houses 10.1 - 30m apart)	1 200	200
D3 (Houses 3 - 10m apart)	1 400	200
D4 (Houses < 3m apart)	2 000	200

2.4.1.2 *South African National Standards: 10252-1:2004*

2.4.1.2.1 Flow and pressure requirements

Unlike the other South African standards, the SANS 10252 does not provide fire flows according to specific risk categories, only pressure specifications. According to clause 7.2.2.1 of the SANS 10252, *"A water pressure of at least 70 kPa at the level of the highest protected point shall be maintained when one hose reel is in full operation in any combined installation* (SANS 10252, 2004). The fire installation must be constructed as follows according to clause 7.2.2.2 of the SANS 10252:

- A sufficient supply of water must be available for the effective operation of all the hose reels and hydrants that can be operated, or come into operation, simultaneously in any partition of the building.
- A flow pressure of at least 300 kPa must be provided at any hose reel or hydrant.
- Flow rates at any hose reel or hydrant must be at least 30 ℓ/min per hose reel and 1 200 ℓ/min per hydrant.
- The installation should incorporate devices that limit the gauge pressure at any hydrant valve to 700 kPa under full flow conditions.

2.4.1.2.2 Storage tanks for fire flow

A storage tank with a volume of at least 25m^3 as well as a pumping system must be available at all times from public or private reservoirs for buildings higher than 25m. For public buildings, such as schools, hospitals and old age homes the water storage tank capacities for non-firefighting purposes can be seen in Table 21.

If these storage tanks were to be incorporated for fire flow, the storage tanks must be divided into two compartments, in case one of the compartments needs to be emptied for maintenance, to ensure that fire flow is readily available at all times.

Table 21: Minimum water storage capacity required for premises

Category and premises	Minimum storage
Boarding schools, residential nurseries	4 - 8 h demand
Commercial premises, offices	4 - 8 h demand based on gross floor area
Educational institutions	4 - 8 h demand for the design population of the building
Hotels, motels, boarding homes	4 - 8 h demand per bed space
Hospitals, clinics, nursing homes	24 h demand for every bed in the building
Buildings requiring continuous water supplies	4 h per day
Multiple storeys, exceeding 25m	8 h demand per dwelling unit
Old age homes	8 h demand per capita

2.4.1.3 *Guidelines provided by the CSIR*

The CSIR (2003) made deviations and modifications to the SABS 090:1972, despite the fact that it was updated in 2003 in the form of the SANS 10090:2003. The fire flow requirements according to CSIR (2003) are as follows:

2.4.1.3.1 Fire risk categories

The areas that need protection from fires can be categorized into different risk categories:

- High risk area

  The risk of a fire and the spreading of fires are high in this area, e.g. congested industrial areas, central business districts and multi storey buildings (four storeys or more).

- Moderate risk area

  The risk of a fire and the spreading of fires are moderate in this area, e.g. general residential areas, buildings with less than three storeys and smaller industrial areas.

- Low risk areas

  The risk of a fire and the spreading of fires are low. There are four different groups in low risk areas:

- Group 1: Residential areas, gross floor area > 200 m^2
- Group 2: Residential areas, gross floor area 100m^2 – 200 m^2
- Group 3: Residential areas, gross floor area 55m^2 – 100 m^2 (This group includes low cost housing where gross floor area < 100 m^2. The dwelling units are attached but separated by a fire wall with a fire resistance rating of 1hour)
- Group 4: Residential areas, gross floor area < 55m^2 (This group includes low cost housing and attached dwelling units that are separated by a firewall with a fire resistance rating of 1hour).

2.4.1.3.2 Water supply

The minimum fire flows and hydrant requirements for each of the risk areas must be available at all times, see Table 22.

According to these guidelines, no specific fire flows are assigned to low risk areas (Group 4). Hydrants should still be installed on all the water mains if possible, especially near schools, hospitals and any commercial areas. The firefighting in this risk area is usually conducted by transporting water in trailer mounted water tanks to the area of the fire and then refilling these tanks at the nearest available hydrants.

In cases where the minimum RFF is not available for high, moderate and low (group 1-3) risk areas, arrangements must be made for onsite fire flow storage to augment the shortage in water supplies. The number of hose reels required in a building is determined according to the Architectural Division of the Department of Public Works in the SABS 0400 (Department of Public Works, 2004).

Table 22: Design fire flow according to the CSIR (2003)

Fire Risk Category	Minimum design fire flow (ℓ/min)	Maximum number of hydrants discharging simultaneously
High risk	12 000	All hydrants within 270m of the fire
Moderate risk	6 000	
Low risk (Group 1)	900	1
Low risk (Group 2)	500	1
Low risk (Group 3)	350	1
Low risk (Group 4)	N/A	N/A

The reservoirs used to store water for fires must store the volume of water needed for the average daily demands, as well as the water needed for fire flows in the area, for the durations required as set out in Table 23. Hydrants should be serviced on a regular basis and the flow rate and pressures checked to ensure that the requirements in Table 24 are met.

Table 23: Duration of design fire flow according to CSIR (2003)

Fire Risk Category	Duration of design fire flow (hours)
High risk	6
Moderate risk	4
Low risk (Group 1)	2
Low risk (Group 2)	1
Low risk (Group 3)	1
Low risk (Group 4)	N/A

According to the SABS: 0252, elevated domestic storages must retain at least 24 hours supply of the AADD in towns with reliable and well-maintained water reticulations. A 48 hours supply must be stored for rural areas with pumped or unreliable sources, (CSIR, 2003). The elevated fire storages must be at least 9kℓ for all public buildings, e.g. hospitals, educational institutions and government buildings. No elevated fire storages are required for residential buildings. The elevated fire storages must be placed at a certain height to ensure residual pressures of at least 70 kPa for a minimum of 2 hose reels (Department of Public Works, 2004).

Table 24: Fire flow designs for hydrants according to CSIR (2003)

Fire Risk Category	Minimum hydrant flow rate at each hydrant (ℓ/min)	Minimum residual head at each hydrant (m)
High risk	1500	15
Moderate risk	1500	15
Low risk (Group 1)	900	7
Low risk (Group 2)	500	6
Low risk (Group 3)	350	6
Low risk (Group 4)	N/A	N/A

2.4.1.3.3 Sprinkler systems

According to section 4.36.1 of the SANS 10400-T, "*a fixed automatic firefighting system that is designed, installed and maintained by competent persons in accordance with the SABS 306-4, SANS 10287 or SANS 14520-1 must be provided…*"for all public buildings that exceed 30m in height and all basement storeys with floor areas exceeding 500 m^2 (SANS: 10400, 2011)

2.4.1.4 *Design parameters*

According to the standards previously mentioned, between three and six different fire risk categories are specified. These categories depend on the possible risk of a fire starting and spreading. When a WDS is designed, the RFF is added to the public demand; however, the guidelines differ in the definition of the public demand in this instance, depending on the country. WDS in South Africa are generally designed under two separate loading conditions (Van Zyl & Haarhoff, 1997):

- The public demand used under design peak flow conditions is referred to as the *normal public peak demand.*

- A reasonable public peak demand assumed to occur at the same time as a large fire in the supply area (fire *public peak demand* plus the fire flow demand required for the fire at the most critical part of the network).

Generally, according to other countries, the *fire public peak demand* is lower than the *normal public peak demand*, assuming that the water consumption would decrease if there were a major fire in the area. For South Africa, this is not the case; the loading for both of these demands is the same and referred to as the *design instantaneous peak domestic demand.* This has resulted in the South African standards being higher than the standards of other countries such as the United States of America, Germany and Netherlands (Van Zyl and Haarhoff, 1997) provided the follow arguments to lower fire public peak demands:

- The *instantaneous public peak demand* only occurs during a very short time in the year, the chances of a major fire occurring at the exact same time are extremely unlikely.

- According to a study that was done using the data of fires reported in Johannesburg, it was revealed that the probability of a major fire occurring is highest during the winter, when the *normal public peak demand* is at its lowest.

- When a major fire occurs in an area, it could be assumed that the water usages will decrease, partly because of the lower residual pressures available in the network caused by firefighting, but also due to the lower water usages due to public interest.

- Very few fires can be classified as major fires, needing high amounts of fire flow. Especially in smaller rural towns, fires rarely occur that require the full fire flow specified for that specific fire risk area.

When all of the above arguments are considered in addition to the fact that the fire flow is added to the *instantaneous public peak demand*, it suggests a scenario where a major fire occurs at the exact same time that the maximum flow demands are required, without any decrease in the demand due to loss of pressure or public interest (Van Zyl & Haarhoff, 1997). The chances of this occurring are exceptionally small.

2.4.1.5 *Comparison of South African standards*

Since more than one standard is available for assigning fire flows in South Africa, the different methods should be evaluated to determine which of these methods, if any, is relevant to fire flow requirements in real life. The different standards were discussed earlier; a comparison between the standards provided by the SANS 10090 and the CSIR (2003) are shown in Table 25.

Table 25: Comparison of South African standards

SANS:10090					CSIR		
Description	Required flows (ℓ/min)	Required duration	Pressure at fire node	Description	Required flows (ℓ/min)	Required duration	Pressure at fire node
High	13 000	4h	20m	A	12 000	6 h	15m
Moderate	6 000 – 9 000	2 – 4h	20m	B & C	6 000	4 h	15m
Low risk (Group 1 - 4)	1 900 –5 700	2h	20m	D	350 - 900	1 – 2h	15m

The fire flows provided in the SANS: 10090 are higher than the fire flows provided by the CSIR (2003), especially in the lower risk areas. The SANS: 10090 is based on the outdated SABS 090. The fire flow requirements for the higher risk areas were increased for the new edition of the SANS: 10090 standards.

2.4.1.6 *Comparison of South African standards to international standards*

The standards for fire flow provided in South Africa range between 350 ℓ/min for the low risk groups to 12 000 ℓ/min for the high-risk groups according to the CSIR (2003). The standards according to the SANS: 10090 are 1 900 ℓ/min and 13 000 ℓ/min for the low risk and high risk areas respectively. The international standards discussed in section and the comparison of these standards shown in Appendix E, show that for the United States, Canada and some of the European countries the standards for minimum required flow varies between 450 ℓ/min for the UK to 1900 ℓ/min for the United States of America and Canada. The maximum required flows, for high risk areas, vary between 3 200 ℓ/min for Germany and 45 400 ℓ/min for Canada.

Figure 4 shows the differences between the minimum fire flows in different countries. Note that the fire flows according to the CSIR (2003) are the lowest of all the minimum fire flows, whereas the fire flows according to the SANS: 10090 are among the highest, together with those of the United States and Canada. This further accentuates the large discrepancies between the different fire guidelines of South Africa, especially in the low risk categories.

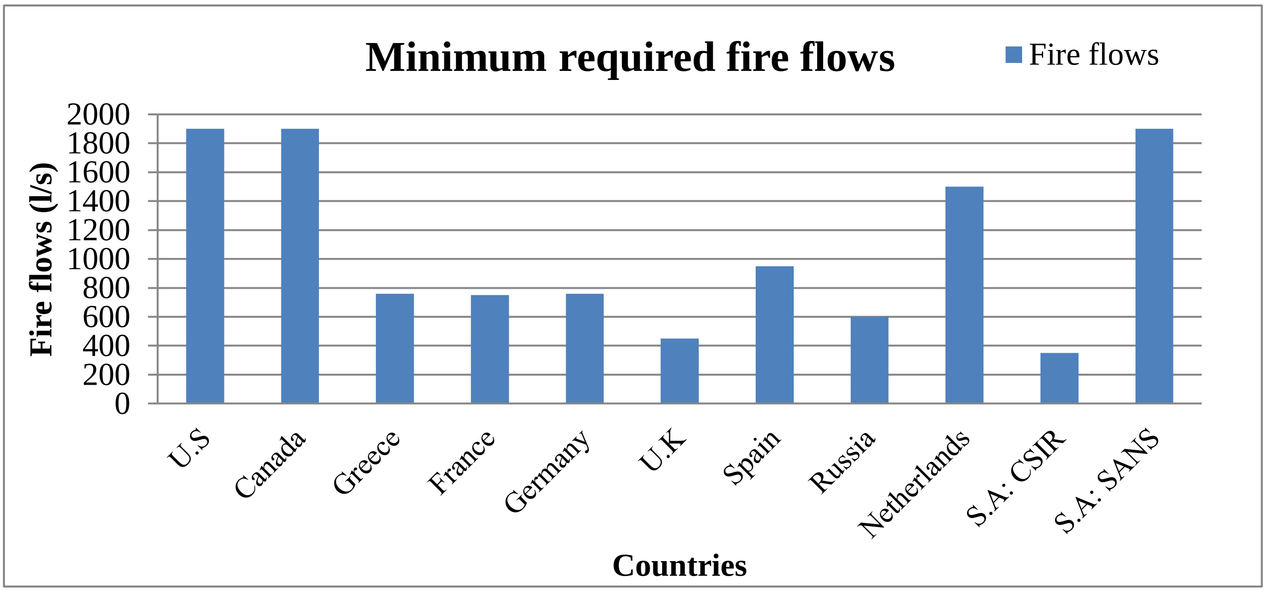

Figure 4: Comparison of minimum RFFs

Figure 5 compares the maximum fire flows required for the same countries. In this scenario, the fire flows required by both South African standards are quite similar. The fire flow standards are higher than all the European countries and lower only than Canada and the United States of America. Maximum flows are not provided for France and Spain. According to this comparison, the fire flow regulations for South Africa in the high risk areas appear to be more in line with one another than the fire flow regulations for low risk areas. The fire flows recommended for the United States of America and Canada are unusually high, since their maximum required fire flows are assigned for extremely high risk areas. These "special" risk areas are defined in Category E of the SANS: 10090 and the fire flow requirements are determined by an individual risk assessment.

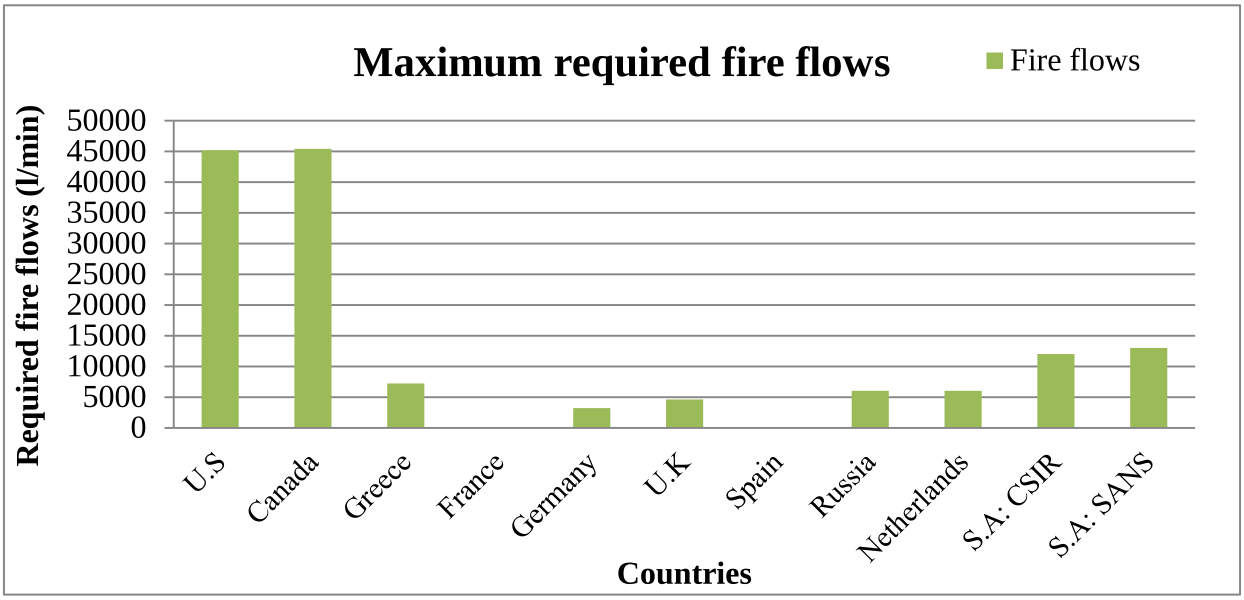

Figure 5: Comparison of maximum RFFs

2.4.2 Fire services in South Africa

The ability to use water effectively for extinguishing fires does not depend only on how soon the fire department can get to the fire, but also on the complexity of the incident and how it evolves during its phases (Govender, 2011).

2.4.2.1 *Firefighting equipment*

Firefighters learn during their training (recruit training as well as continuous in-service training) how to use a fire stream effectively (a fire stream is the stream of water after it leaves the fire hose and nozzle until it reaches the desired point). Water fire streams reduce the temperature and permit closer proximity firefighting, as well as helping with the dispersion of heated smoke gases from the fire area.

The water fire streams are categorized according to their size and rate of discharge. There are three different types of fire streams: solid streams (jet), fog (mist) and a broken stream. It is important to note the following concerning the characteristics of streams depending on their origin.

- Low volume streams have a discharge of less than 160 ℓ/min
- Hand-line streams have a discharge between 160 -1400 ℓ/min depending on the type of landline and pumps used
- Master streams have a discharge of more than 1 400 ℓ/min.

2.4.2.2 *Firefighting techniques*

Firefighters in South Africa use the following methods to extinguish fires:

- Open fires

  The extinguishment of open fires can only occur when the effect of the extinguishing agent is directed at the point at which the combustion is occurring. Consequently, the best method for extinguishing an open fire is to direct a stream of water directly to the seat of the fire. A strong spray not only ensures that water arrives at the seat before evaporation but also has a mechanical effect, by possibly dispersing the combustible product that is acting as a fuel.

- Closed-space fires

  For closed-space scenarios, spraying the seat of the fire could have destructive consequences. As the water is sprayed towards the seat, air is pushed in front of it, providing the fire with extra oxygen before the water can reach it. This instigation of the fire, in combination with the mixing of the vapours, which is produced by the water, can create a flashover.

In most cases, solid streams are used during defensive firefighting. It is important to provide a substantial amount of water-spray to ensure that the cooling of the water and atmosphere is sufficient to ensure the steam would not burn the firefighters. Once the seat is dispersed, broken streams and more frequently, fog streams are used. Not only do the fog streams minimize water damage, they also dissipates more heat due to the maximum water surface area, and assist in the ventilation of the heated gas, thus preventing the forming of rolling flames of burning gases on the ceiling. According to Mr. Govender, some fire departments use surfactants in their first response water tanks on the fire engines, which give the water added fire extinguishing properties.

Since water resources are becoming scarcer and water treatment costs are high, Fire & Rescue services are looking for new methods as an alternative to the use of potable water. One of these trends is to harness the new technology of CAFS as first line fire extinguishing application, as it requires less water application per volume of fire involved. However, as with most technologies, the CAFS systems are exceedingly expensive and beyond the reach of most of the fire departments.

Some fire departments in South Africa make use of firefighting vehicles with storage tanks for firefighting of different capacities, ranging from 0.5kℓ to 7.5kℓ. All of these units can be connected directly to a fire hydrant in the municipal distribution network and can pump water either directly from the network or via the firefighting vehicle’s tank. In terms of connections to a hydrant, incoming lines (65mm diameter hoses) are directed into the pump of an engine pumper (an engine driven pump) and then split into four lines which will have high pressures and increased flow rates in order to cover more exposures of a fire.

The tanker pumpers (vehicles with a storage tank and a pump) can draw as many lines as required from the hydrants and then be used either as storage reservoirs that relay pump to engine pumpers or for direct attacks from the tanker pumper itself. Both the engine and tanker pumpers can also be used to draw water (via a 150mm hard rubber hose through the pump) from open water sources such as dams, rivers and swimming pools (Govender, 2011).

2.4.3 Fire statistics of South Africa

2.4.3.1 *Cost to insurance companies*

South Africa has a relatively large cost associated with attending to fires, including the losses due to fires and the provision of firefighting services.

The South African insurance industry reflects a national trend, according to statistics during 1990-1998. These statistics show that there was a dramatic increase in the value of claims paid during this period. In 1990, a total amount of R 400 million was paid out, which increased to R 1.4 billion paid out in 1998. During 1993-1998, the total value of claims quadrupled (Davey, 2002). After investigating these claims and determining whether there was any correlation between the number of claims and the total insurance losses due to fires, it was found that the number of claims had in fact decreased since 1990. The increase in the amount of money paid out by insurance companies for fire losses, in spite of the decline in claims, proves that the average value of the claims had increased drastically (Davey, 2002).

The direct cost of fires in South Africa is still increasing; according to the Fire Protection Association South Africa (FPASA) the value of claims in 1999 was an estimated R 2.4 billion, which at the time was, 0.3% of the country’s gross national product. The Worcester fire department provided current information regarding losses due to fire damages. The total fire damages for the Worcester area was R 35.8million(R 98 035.07/day) in 2009 and in 2010 it was R40.8 million (R 111 873.15/day), with 58 lives lost due to fires in 2009 and 60 in 2010.

A study by the organization Children of Fire (2011), showed the cost of operating/maintaining fire brigades, providing an indication of additional expenses caused by fires, see Table 26. These fire losses do not include consequential losses and losses of uninsured properties. To determine the real costs of the threat of fire to society, the following should also be taken into account: the cost of public fire services, public fire education, fire research, the cost of fire protection equipment and even the cost of treating burn injuries. These costs are not known. The operating budgets of a number of South African centres (in Gauteng) in 1999 are presented in Table 26 – these give an indication of the significant cost involved in firefighting.

Table 26: Operating budgets for Gauteng fire departments and the cost per incident

Town	Cost (R million)	Cost/incident (R)
Alberton	4.4	11 587
Boksburg	15.6	25964
Brakpan	7.4	*
Germiston	8.6	5 207
Nigel	2.4	4 025
Benoni	6.8	1 058

*Cost/incident rate not known

2.4.3.2 *Cost to human life*

According to the annual report of the National Injury Mortality Surveillance System (NIMSS) in 1999, 14 824 fatal injuries (25% of the estimated 60 000 fatal injuries of the whole country) were registered at 10 mortuaries in five of the provinces. According to the reports determining the cause of the death, fires ranked first in the age group for children between one and four years, causing 41% of the 1 149 deaths in the category accidental deaths. Of all 14 824 cases that were registered, fires caused 823 (9%) of the deaths (Children of Fire, 2011).

The cost for medical treatment needed for fire related injuries could not be determined, however, any type of medical treatment is relatively expensive, especially if hospitalisation is required. This adds to the already significant amount of the country's money that is being lost due to fires.

The amount of money spent in extinguishing fires and avoiding property losses is high enough, but one cannot put a value on human life and quality of life. Methods to provide efficient firefighting at the lowest possible costs should thus be of high importance for this country.

2.4.4 Firefighting in South African cities

Van Zyl and Haarhoff (1994) compared the South African standards with the actual volumes of water used for firefighting in Johannesburg using data obtained from the Johannesburg Municipality. According to the study, 99.94% of the fires in the high risk category could be extinguished using 3 100 ℓ/min (74% lower than the South African standards) or less. The study also showed that 90% of the fires in the low risk areas required 144% higher flows than the fire flows recommended in the South African standards.

Van Zyl, Davy and Haihambo did a study in 2011 to analyse fire volumes, distributions and fire flow rates over a period of five years for the greater Cape Town area (Van Zyl et al., 2011). According to this study, of the nine categories into which residential fires fall (five from the CSIR (2003) and four from the SANS: 10090, only two, one from each document, can be considered valid. Two of the fire flow requirements are too low (the low risk areas) and five of the fire flow requirements are overly conservative (the moderate and high-risk areas) (Van Zyl et al., 2011).

2.4.5 Discussion

When taking into account the high losses due to fires, the differences in the fire flow standards, the unnecessarily high costs caused by an over-designed WDS, and the possible damages due to insufficient fire flows in low risk categories, the importance of realistic fire flow standards become apparent. It is recommended that the South African design codes are revisited, the guidelines provided by the CSIR (2003) must be updated according to the SANS 10090:2003 and the overall water requirements for different risk areas should be revised.

2.5 **The design and operation of a water distribution system**

The cost of a WDS is significantly influenced if fire flow has to be provided for in addition to the normal consumption demand. Providing fire flow for a WDS would likely result in the following problems, as well as increased costs due to possible over-designed networks:

- Water quality

  If the water distribution network were designed to be able to provide fire flow for the unlikely possibility that a fire does breakout, it would lead to the system being over-designed. This would result in longer residence time for the water, increasing the possibility of taste, colour and odour problems, the increased formation and biodegradation of disinfection by-products and bacterial growth.

- Flow velocities

  The larger pipes designed for the fire flow would result in a decrease in the flow velocities, which could lead to the deposition of sediments, further affecting the water quality.

A number of commercially available WDS modelling software could evaluate the impacts caused by designing a WDS to provide fire flow. The EPANET and Wadiso software are available at the

University of Stellenbosch for academic purposes and were used for the case study in Chapter 3. A short description of EPANET and Wadiso is presented below:

- EPANET – water distribution system modelling software package developed by the United States Environmental Protection Agency's Water Supply and Water Resources Division. (www.EPANET.de)

- Wadiso – a comprehensive computer programme used for the analysis and optimal design of water distribution networks, developed by GLS Consulting in Stellenbosch.(www.gls.co.za)

2.5.1 Hypothetical network evaluated using EPANET

An example of a water distribution network was defined by AWWA in order to demonstrate the influence of designing for fire flow on a system using EPANET (Snyder et al., 2002). Simulations were done to evaluate the impact of the following four scenarios on a distribution network (the analysis included a steady state analysis as well as a time varying simulation):

- The base pipe and storage facilities
- Modified (downsized) pipes and storage that still meet the full fire flow requirements in addition to the maximum daily demand
- Modified pipes and storage to meet reduced fire flow requirements associated with the sprinklers being installed, in addition to the maximum daily demand
- Modified pipe and storage with no fire flow requirements.

The detail of the analysis is presented in "*The impacts of fire flow on distribution system water, quality design and operation*" by AWWA (Snyder et al., 2002).

The evaluation showed that meeting fire flow requirements in a network has a significant impact on the design of the network. In the second scenario it was determined that the pipes and storage capacities could be downsized due to the initial over designing of the network to provide fire flow. Likewise, in the third and fourth scenarios substantial downsizing would be possible due to the decrease in RFF.

Although the pipe and storage capacities were significantly reduced, it was noted that this does not necessarily lead to significant reductions in costs; the costs were reduced by less than 20%. This could be explained by the relatively high percentage of the costs being fixed, independent of the size of pipes or tank sizes. On the other hand, the study showed significant reductions in the water age, consistent with the decrease in the pipe sizes, resulting in the overall improvement of the water quality (Snyder et al., 2002).

2.5.2 The “Anytown” model

The “Anytown” model (a model of a hypothetical WDS) has been used since 1987 for evaluation of WDS optimisation software. It was set up by Walski et al. in the *Battle of the network models: Epilogue”* (Walski et al., 1987). The model has a realistic benchmark on which to compare and test network optimisation software and has features and problems typical of those found in many real systems.

Figure 6 shows the hypothetical model, Anytown. The town receives water from a river, three identical pumps, in parallel, are used to supply water to the network. The town is formed around an old town centre, as indicated in Figure 6.

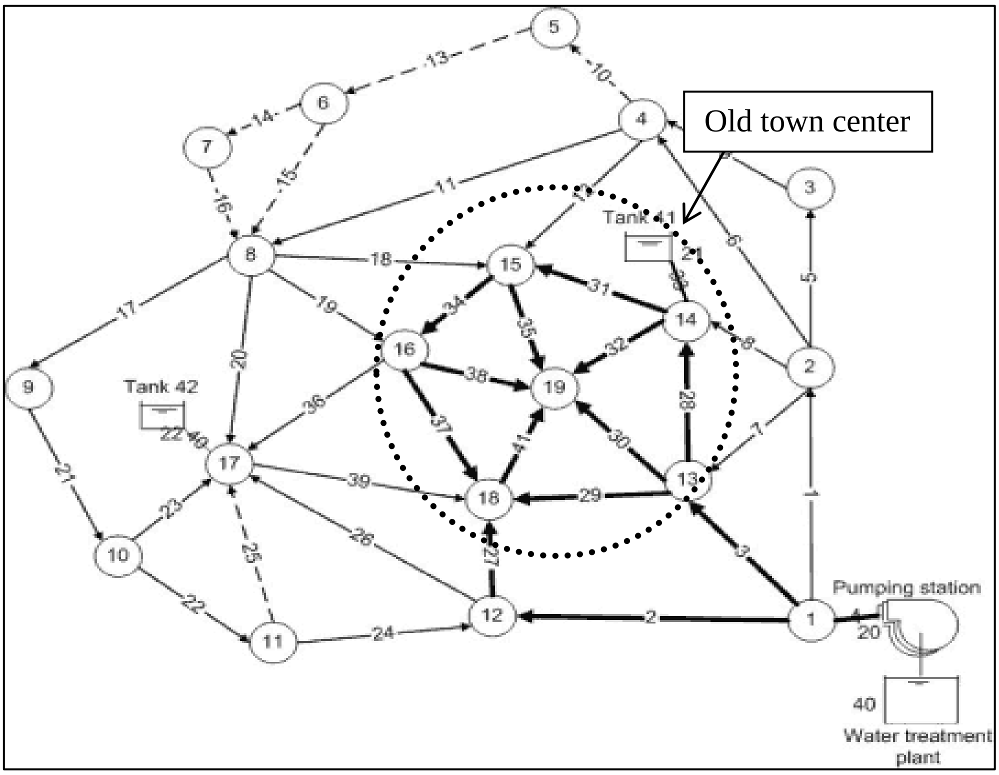

Figure 6: Anytown model (University of Exeter, 2007)

There is a surrounding residential area with a number of industries near node 17 and a new industrial area in the north. An input file with the average daily water use at each node, as well as the elevations of the nodes, is provided as part of the Anytown problem.

The objective of the Anytown network is to determine the most economically effective design to reinforce the existing system to meet the projected demand, taking into account pumping costs as well as capital expenditure. The model can be used for all water distribution network designs to determine the optimum design for different scenarios.

2.5.3 Adequacy and reliability of distribution systems

A water supply is considered fully adequate if it can deliver the RFFs to all points in the distribution system with the consumption at the maximum daily rate. A reliable WDS would be able to supply sufficient quantities of water, even if the system was disrupted for a certain period of time.

An evolutionary multi-objective optimisation method to determine the most suited design for a water distribution network was provided by Farmani et al. (2006) using the Anytown Network model. This method takes into account the total cost, water quality as well the reliability of the WDS. The reliability of the network is an indication of the ability of the network to provide consumers with sufficient quantities of high quality water.

2.5.4 Least cost design of water distribution networks including fire networks

According to Fillion and Jung (2010), *"the implicit goal of a water network design is to provide acceptable service during normal and peak demands and to limit the damages to property and people during fires."* They also comment that, despite the above-mentioned purposes of a water network, fire damages (damages to properties and loss of human lives caused by fires) are seldom explicitly included in the design of a WDS.

The paper by Fillion and Jung (2010) presented an optimisation programme that incorporated a new measure of the expected conditional fire damages, to size local water distribution mains for fire flow protection in residential areas.

2.5.4.1 *Fire flow in network models*

The purpose of a distribution network is to provide the required domestic water demands, pressure demands, fire flow demands and water quality requirements during peak and off-peak periods, while keeping the construction and operation costs as low as possible.

Despite the impact that the provision of fire flow has on the system, the current least-cost optimisation techniques that are available do not consider fire damages. These damages could be caused either directly by the fire or could be the result of low- or high pressure hydraulic failures that occurred during the firefighting process. Since generally used optimisation techniques do not take these damages into account, the potential risk of fire damages cannot be determined in a specific design solution. Given that damages that result from death or human injury are not traded in the market, they do not have a direct economic value, nonmarket evaluation techniques such as willingness-to-pay and contingent valuation developed in the field of economics could be used to estimate the value and cost of human life and human injury (Adams et al., 2007). Up until recently, the only effect of fires on a system was considered as part of the minimum-pressure constrictions, which occur when high volumes of water are rapidly pumped out of the system.

Different methods can be used to determine the fire flow needed at a specific point in the network. The required fire flows are then added as extra loads to the system, typically during worst-case scenarios. The loads should also be added to the points in the system with the highest demands and lowest available pressures, to ensure that the whole network would be able to handle the added fire flow, since a fire can occur at any point on the network. The system flows and pressures are then compared to the minimum allowable values according to the guidelines, depending on the recommended flows for the area. If the required flows can be provided and the pressures are high enough, the system is considered acceptable.

2.5.4.2 *Optimisation methods*

Fillion et al. (2007) proposed an in-depth mathematical optimisation and algorithms to account for the uncertainty innate in the determination of the required fire flow and to incorporate the potential fire damage risks into the network solution. The size and the design of the distribution network generally depends on the fire flow requirements and not on the domestic and industrial demands since the fire flows that are required are considerably larger than normal demands in most instances.

2.5.4.2.1 Method for determining fire damages

The method developed by Fillion and Jung (2010) calculates the optimal water distribution network by taking the potential fire damages as well as the uncertainties in providing the RFF into account. A full description of the analysis is presented in the referred paper.

The method developed by Jung and Fillion was used to optimise a WDS for fire flow protection in residential service areas. The method was applied to an 8-pipe network as well as a 34-pipe network to determine the correlation between pipe sizes, costs and fire damages. A sensitivity analysis indicated that the provision of fire flow had a greater influence on the pipe size, costs and fire damages than the standard deviations of the fire flow. According to this, it is assumed that the level of uncertainty of the fire flow has a relatively low impact on the pipe size and cost in the 8-pipe network. The study done by Jung and Fillion showed that the method they developed could be used effectively, by engineering companies and developers, to determine the cost effectiveness of adding more pipes and the reduction in the potential fire damages in the distribution networks. The authors of the referred paper demonstrate that an analysis can be done to determine whether the money spent is justified by the money that could be saved.

2.5.4.2.2 Method for determining damages due to low- and high pressure

There are three different types of failure in a WDS: structural, hydraulic and water quality failures. Structural failures occur when some of the components of the network are out of order. Water quality failure is if, as the name implies, for some reason the quality of the water does not meet the required standard.

Hydraulic failures occur when the residual pressure in the network falls below a minimum required value, e.g. due to firefighting. This could result in negative or low pressures causing pipes to collapse and, in the event of fires; it could result in loss of property and life. When the pressure in the network is too high, it could lead to pipe burst and equipment failure (Adams et al., 2007).

In a paper presented by Adams et al. (2007), they presented a stochastic design approach to quantify the expected annual damages sustained to residential, commercial and industrial consumers during low and high pressure hydraulic failures. The method integrates stochastic models of water demand, fire flows and system failures with a Monte Carlo simulation. An in depth analysis of the mathematical calculations for this method is presented in the referred paper.

2.5.4.3 *Summary*

Designing and analysing water distribution networks by using optimisation methods, which include the normal hydraulic requirements as well as potential damages, would provide a great advantage to the engineer designing the system. By incorporating new methods, such as those published by Fillion and Jung (2010) and Adams et al. (2007) water distribution networks could be designed more realistically. This could be done by considering the flow and pressures requirements as well as the potential damages to the system (due to low/high pressures or fires) for a specific design. A realistic optimisation would be possible in the design process of a WDS, especially from an economic perspective, since the losses due to fire damages and hydraulic pressures are taken into account along with the usual network components costs. This would also ensure that scenarios are not created where upgrading and installing water distribution networks to incorporate fire flow is more expensive than the benefits and savings that would result.

3 Evaluation of firefighting in rural towns in the Western Cape

This chapter deals with the main objective of this thesis i.e. to compare the real fire flows in rural towns in the Western Cape to the requirements specified in the South African National Standards.

As was previously mentioned, incorporating the provision of fire flow into the design of a WDS has a number of consequences, not only does it lead to higher implementation cost but also indirectly results in the loss of water quality, due to longer retention times caused by an over design of the network. When a WDS is designed, RFFs are usually the deciding factor, since these are typically significantly larger than the domestic demands in the network. The ideal would be if the RFF could be kept to a minimum without causing flows or pressures in the network to be insufficient.

The fire flow guidelines of South Africa were discussed in section 2.4.1. It was stated that the RFF in the low risk categories of the SANS: 10090 are relatively high compared to the low risk categories according to the CSIR(2003) and other countries, whereas the high risk categories appears to be more in line with some of the European countries.

3.1 Statistics of Western Cape rural fire flows

Statistics on fires and the fire flows required to extinguish these fires are discussed in this section. The fire flows required for rural towns are determined and compared to the South African standards.

3.1.1 Methodology

In this study water usages and information about extinguishing methods and resources, via the network or via firefighting vehicles, was analysed to provide statistics about the fires in these rural towns. The first step was to obtain data from fire departments in rural towns in the Western Cape. Requests for fire incidents reports as well as additional information on the occurrence of fires were sent to eight fire departments. Of these eight fire departments, three provided fire reports containing information for some, or all, of the fires that occurred over the period of a year. The fire reports contained the following data:

- The time and date of the fire
- The location of the fire
- The estimated volume of water that was used to extinguish the fire

- The time required to extinguish the fire
- The equipment used by the fire department.

Fire incidents stated on the reports were divided into the following categories: structural fires, informal settlement fires, vegetation (grass, veld and refuse) fires, automobile accidents (with fires) and special services. The data was "cleaned" and reorganised by excluding reports where important parameter, e.g. flows or time durations were missing.

After each fire incident, the volume of water that was used to extinguish the fire was estimated and divided by the total time duration. The estimation was done by taking into account the capacities of the firefighting vehicles, the water lines that were used as well as the pumping time. Even though this does not result in exact flow rates, it does provide a good indication of the fire flows that were required to extinguish the fire. Note that when a fire is extinguished it is usually done in two phases, in the first phase the fire is brought under control and in the second phase, care is taken to ensure that the fire does not flare up again. Since additional information on how long each of these phases took was not provided in the fire reports (only the total time duration), the total flow rate is used as constant over the time duration provided (van Zyl et al., 2011). This calculated average flow rate could be lower than the actual flow rates required during the first phase of extinguishing the fire. The flow rates provided to fill shuttling tanks could also be higher since filling these tankers will not be continuous but intermittent.

Part of this study was to determine the importance of the water distribution network and whether there are any alternative methods and resources that could be used for firefighting. This is especially important in areas where the WDS is lacking or not up to standard, e.g. informal settlements.

To determine whether the street hydrants (water distribution network) were utilised to extinguish the fires, the reasoning went as follows:

The fire reports indicated the number of vehicles that responded to the fire and the water capacity for each of the vehicles is known. The incidents were analysed and if the fire flow volumes that were used to extinguish the fire were considerably larger than the combined capacity of all the vehicles responding, it was assumed that water from the WDS was used to augment the water supplies from the firefighting vehicles.

To differentiate between fire flows required by the South African standards and the fire flows sufficient for extinguishing fires in rural towns, as determined in this investigation, the latter is referred to as *rural fire flow* from here on. Note that both these fire flows are supplied by a hydrant at the scene of the fire.

3.1.2 Limitations and shortcomings of this study

During the assembling of data for this thesis, the following problems were encountered:

- Getting fire departments to respond and cooperate was difficult.
- The fire incident reports were confidential, according to some municipalities.
- The fire reports provided were not always complete and relevant data was missing.
- The data provided for Municipality 1 and Municipality 3 was provided for the duration of one year, between January and December. The data for Municipality 2 was provided from July to June the next year.
- The fire departments use different forms to fill in the fire details, making it difficult to compare the data provided.
- It appears that certain fire departments only fill in detailed reports for fires that could result in possible insurance claims, or where injuries and casualties were reported.
- The data categorisation for the type of fire is limited, two of the three fire departments do not have set terms to describe the type of fire and it is left up to the person filling in the form to provide relevant and useful information about the fire using his/her own discretion.
- The fire flows and time durations provided on these forms are mostly estimates
- Due to the large number of assumptions made during the analysis of this study, the results must be considered as approximate.
- The database for this study was limited, with fire incident reports supplied for only one year; for representative results, a more extensive study is required.

3.1.3 Analysis of data

The data obtained from each of the fire departments of three municipalities was analysed separately, since the parameters for each of these municipalities vary. For the municipalities where data was available an analysis of the fire reports, before sorting, was also done to show the difference between reported incidents and the usable data. The information provided by the fire departments was then organised and the data that was not applicable was excluded. This included reports that did not provide important parameters and incidents that were not relevant.

Not all of the fire departments differentiated between low cost housing and informal settlements. Therefore, the term “informal settlement fires” includes both, for the purpose of this study. Structural fires include all types of building fires, e.g. residential, industrial and commercial.

The fire departments that provided data did not always specify whether the water for automobile accidents was required to extinguish fires or to clean the roads of hazardous materials afterwards. For this study, it is assumed that the total volume of water required was for extinguishing fires.

The special services provided by the municipalities are generally the most water consuming service provided by the fire department. Even though these services are not always relevant for this study, they were taken into account to give a more accurate representation of flows and water usages for each month.

Vegetation fires include grass, veld, as well as refuse fires. A high number of these fires are either along roads, on farms or in the vegetation surrounding the town. It is presumed that for most of these fires no water distribution networks were available and that the fire vehicles had to transport water to the scene of the fire.

3.1.4 Municipality 1

According to statistics provided by the fire department of Municipality 1, the fire department responded to approximately 1745 incidents, between the 1st of January 2010 and the 31st of December 2010. A distribution of the original incidents that were reported can be seen in Figure 7 and the flow distributions according to the original data for each of the months are shown in Figure 8.

According to original statistics most of these incidents (50%) were veld, grass and refuse fires, followed by automobile accidents with 32%. Structural fires, special services and informal settlements were lowest with 9%, 5% and 4% respectively. Figure 8 shows a definite seasonal trend for fires according to the fire flows required, with low fire flows in the winter and significantly higher flows in the summer, as a result of a higher number of vegetation fires in the warmer, drier months.

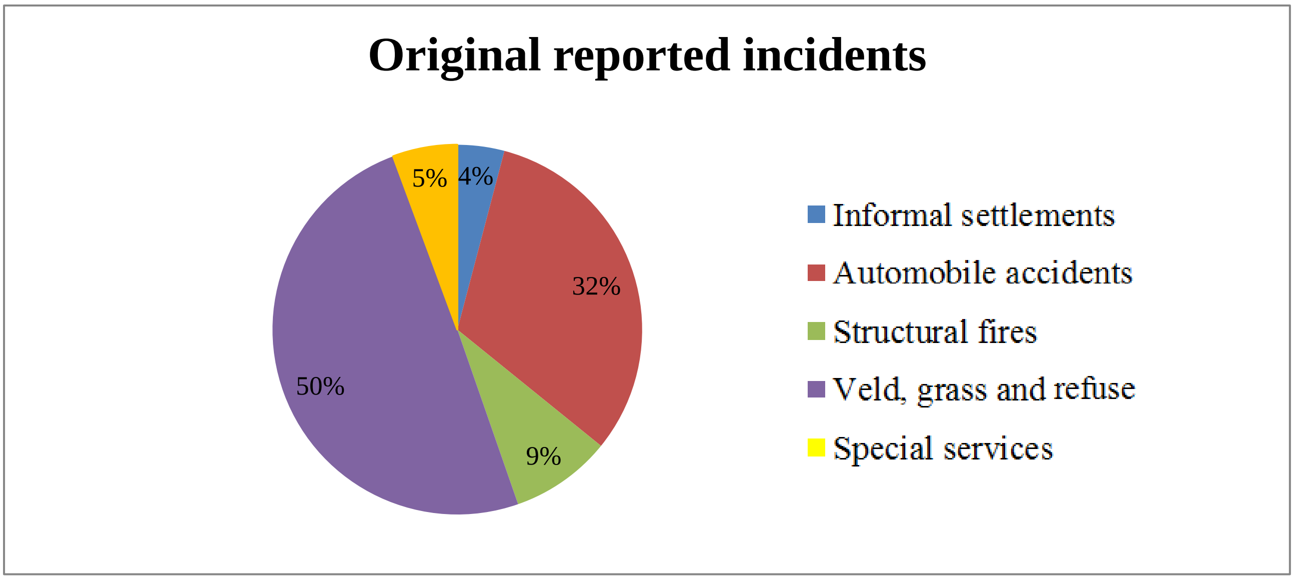

Figure 7: Distribution of fire categories based on the original data set for Municipality 1

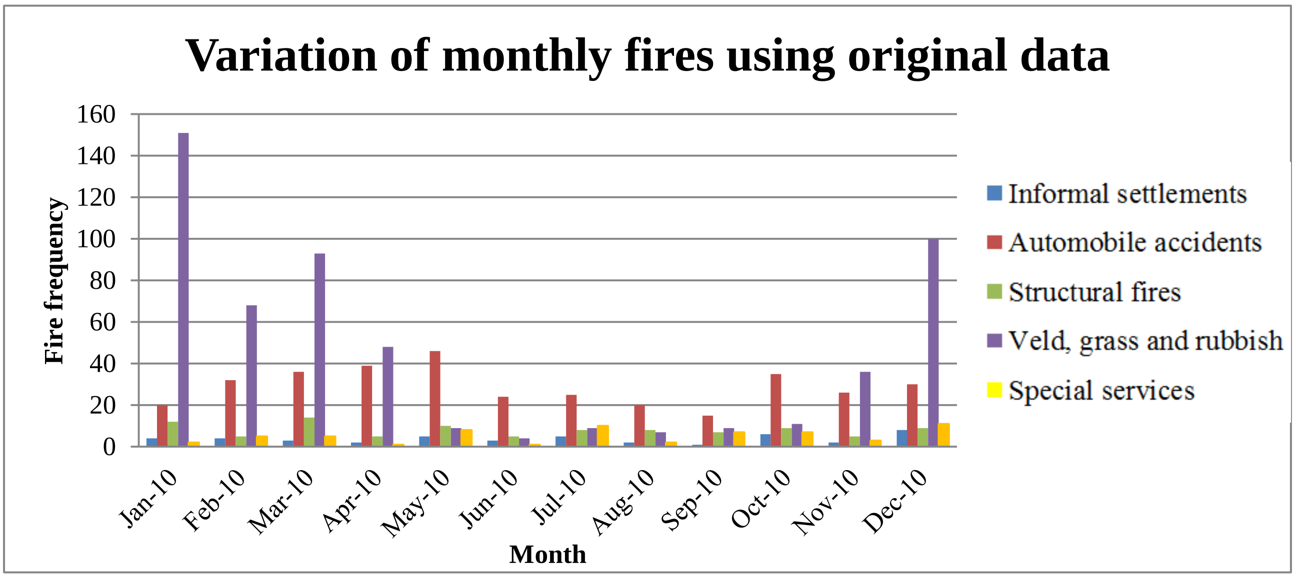

Figure 8: Monthly fire distribution for original data for Municipality 1

The rest of the data obtained from this municipality, in contrast with the statistics provided and discussed previously, provided only 80 usable fire reports for the analysis, which contained all the required parameters. A representation of the organised data is presented in Figure 9 and a more detailed listing is provided in Appendix F, Table F.1.

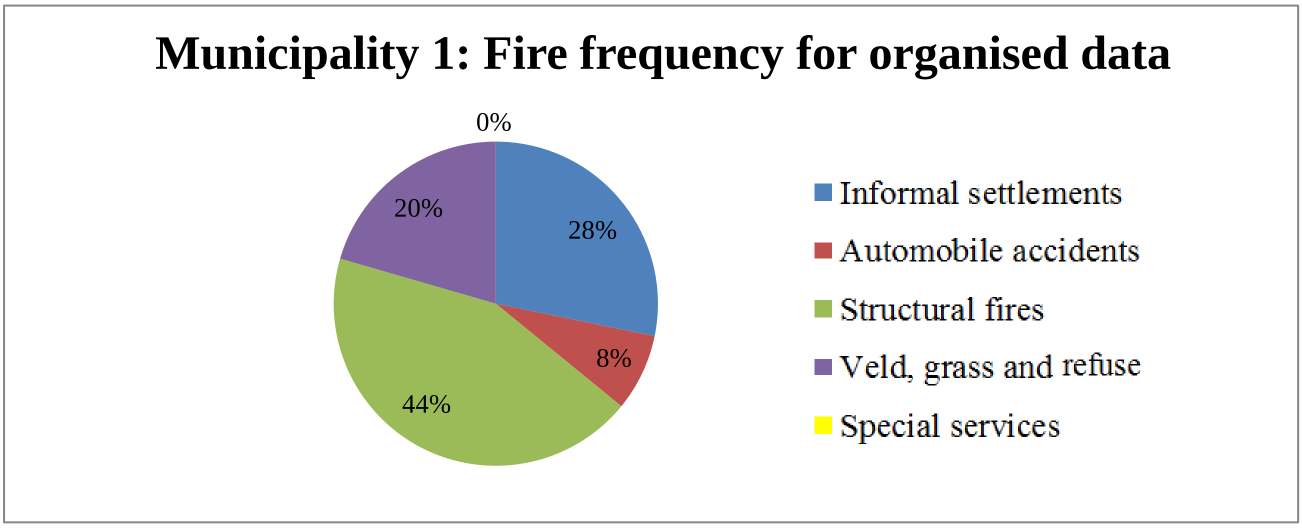

Figure 9: Distribution of fire categories based on data after cleaning and re-categorisation

3.1.4.1 *The fire flow distribution*

The contribution of the remaining fires, according to their categories, can be seen in Figure 9. The number of reports that could be used to obtain data was relatively small. A possible explanation for this is the filing system of the municipality; it appears as if detailed reports were completed for only certain fires.

According to the data presented in Table F.1 in Appendix F and Figure 9, no reports were provided for incidents where special services were required. Figure 9 also shows that the number of reports on structural fires and informal settlement fires are higher than the reports on veld, grass and refuse fires, unlike the percentages provided in Figure 7. A possible explanation for this, along with the fact that reports are only completed for certain fires, is the presence of a wildfire unit aiding in the extinguishing of most of the vegetation fires, resulting in a lower attendance on veld fires than is expected.

Figure 10 depicts the total water volumes of fire flow that were used for each month during the time period. Note that relatively large volumes of water were used in May, July and September due to the occurrence of fires that required relatively high fire flows to extinguish, see

Figure 11. Observe that the fires for this municipality according to the organised reports, unlike the fires according to the original data, do not illustrate a distinct seasonal pattern; mainly because of the low percentage of veld fires (which has the highest seasonal influence) compared to the other municipalities.

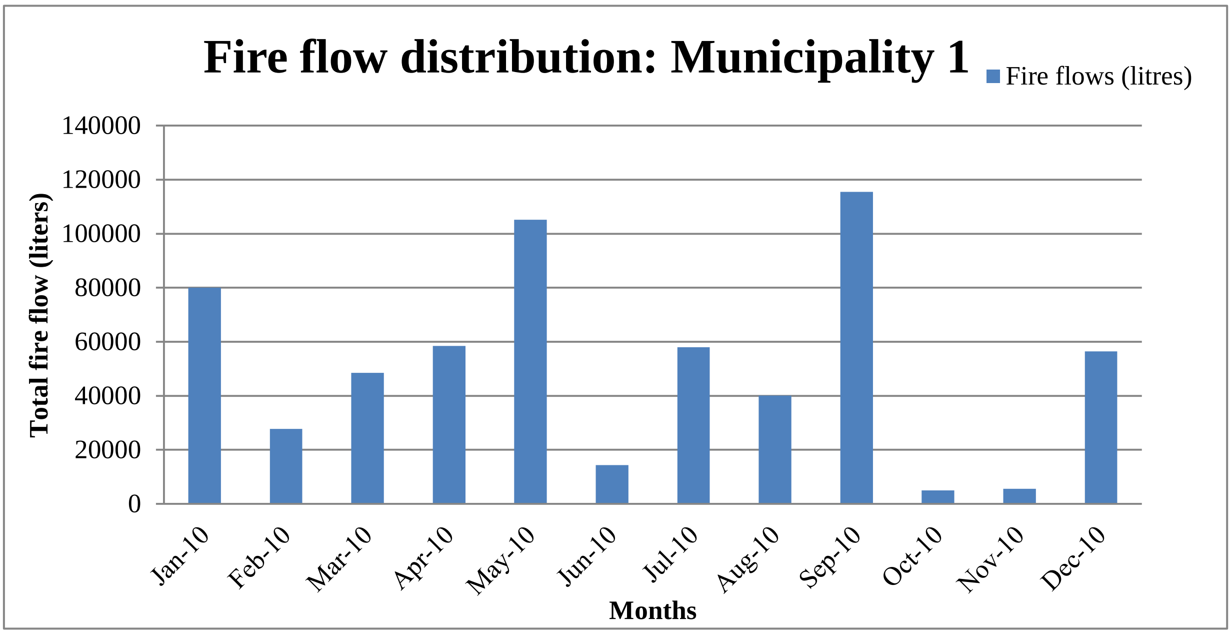

Figure 10: Water volume fire flow distribution for Municipality 1

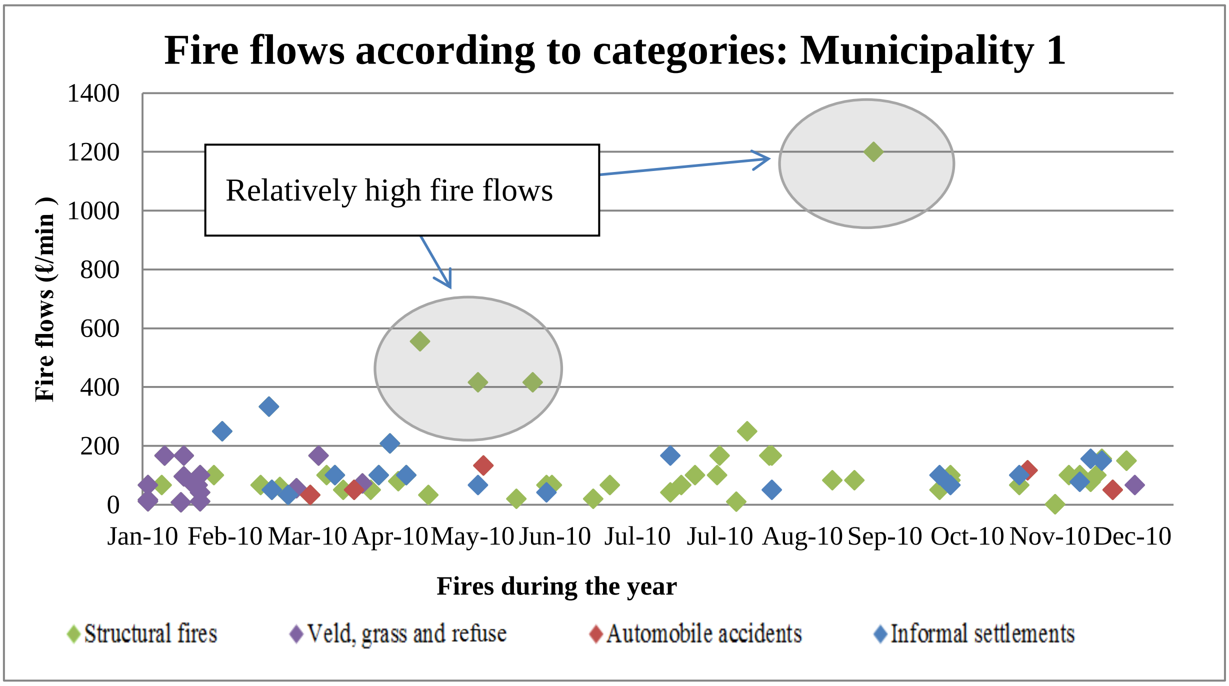

Figure 11: Fire flow distribution for Municipality 1

The average of the fire flows required for each of the categories is shown in Table 27. Structural fires required the highest flow rates with an average of 144 ℓ/min. The highest fire flow that was required during the year was also for a structural fire, where 1 200 ℓ/min was required to extinguish the fire. This specific flow is indicated in Figure 11.

Table 27: Average fire flows for each category

Type of Fire	Average fire flow (ℓ/min)
Structural fires	143.9
Informal settlements	130.4
Veld, grass and refuse	74.2
Automobile accidents	96.7

To determine whether it was necessary to utilise the water distribution network, the method mentioned in paragraph 3.1.1was used and 21 fires fitted the criteria. Two of these fires were on farms and two were extinguished using buckets, therefore 17 of the fires (21.2 % of the total number of fires) were assumed to have been extinguished using water from the network.

3.1.5 Municipality 2

According to the data provided for this municipality, the fire department provided services for 705 incidents between the 1st of July 2010 and the 30th of June 2011. Unlike the previous municipality, the data obtained from this fire department did not include statistics for all the incidents that occurred over the year and a monthly distribution of these incidents could not be done. The available reports were organised and reports that did not provide important parameters were excluded. Only 340 reports provided sufficient data and could be used for further analysis. A summary of the organised data is shown in Appendix F, Table F.2.

3.1.5.1 *The fire flow distribution*

A distribution of the cleaned and reorganised fire reports according to their categories is illustrated in Figure 12 and the monthly incident frequency for the different categories throughout the year in Figure 13.

These figures show a high rate of vegetation fires (61%) compared to other categories. Informal settlements are second highest, at 12%, followed by automobile accidents and structural fires at 11% and 10% respectively. Special services are the lowest, with merely 6%. The significant impact of the climatic conditions on vegetation fires is evident in Figure 13, with the number of vegetation fires considerably greater in the summer months and smaller in the winter.

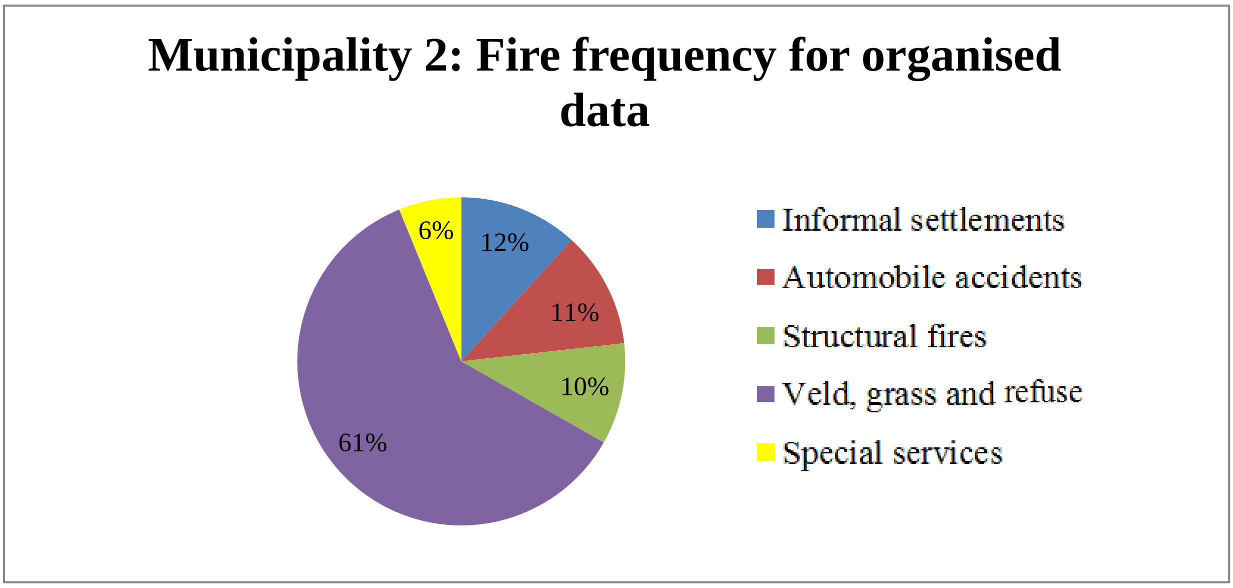

Figure 12: Distribution of fire categories based on data after cleaning and re-categorisation

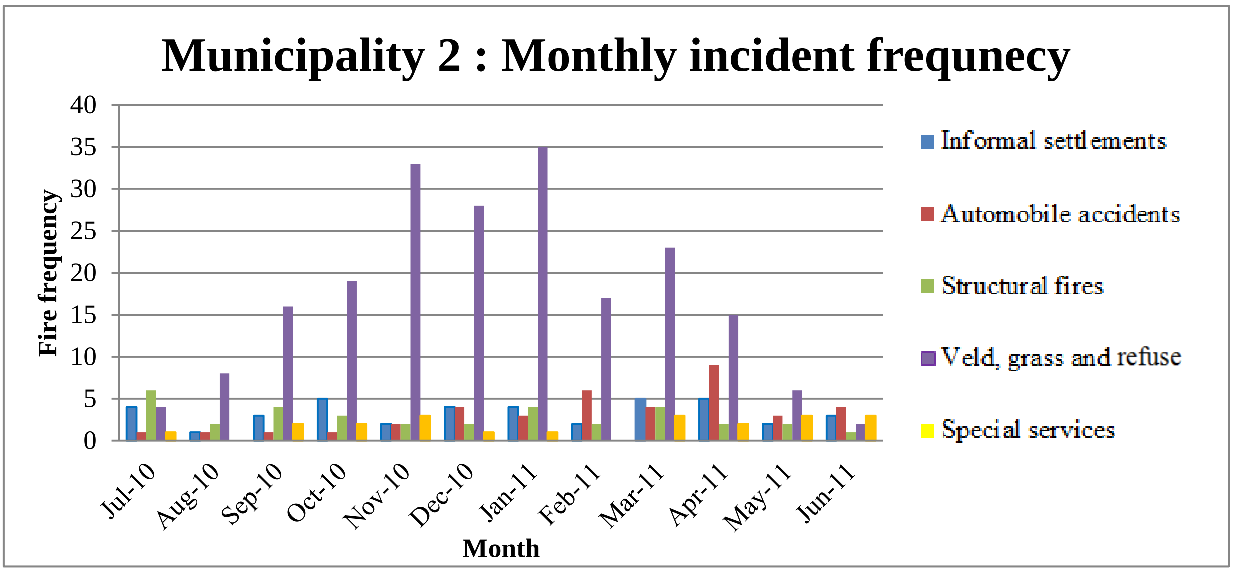

Figure 13: Frequency of incidents per category for organised data

The total volumes of fire flows that were used for each month can be seen in Figure 14 and the RFF distribution of all the fires throughout the year is illustrated in Figure 15. For this municipality the monthly fire flows are relatively demonstrative of the number of fires each month, except for September and March where the flows are higher than one would expect, considering the number of fires that occurred in those months. This is caused by a number of incidents that required relatively high flows, as is also illustrated in Figure 15.

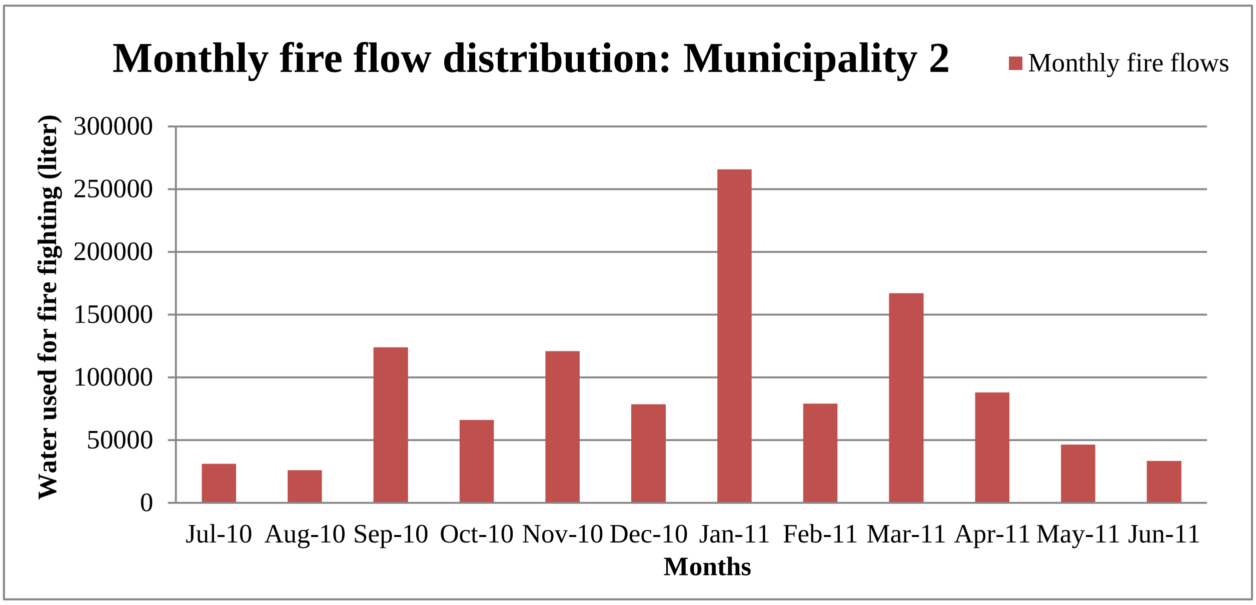

Figure 14: Fire flow volume distribution for Municipality 2

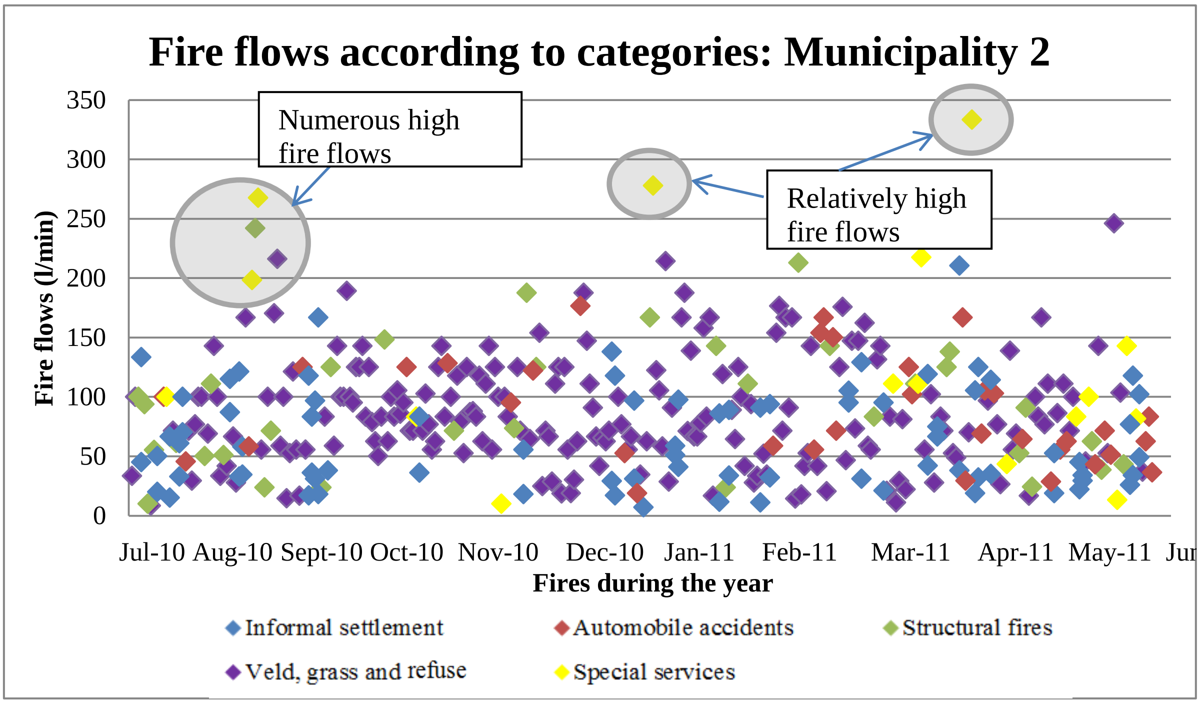

Figure 15: Fire flow rate distribution according to categories for Municipality 2

Figure 15 also shows that three of the highest flows are for special services. Even though these services are provided by the fire departments, they are not fire incidents and can therefore be excluded when determining the real RFF for a WDS.

The average fire flows that were used for each of these categories are shown in Table 28. Note that the three highest categories, special services, informal settlements and vegetation are the three categories that either do not require urgent flows at high volumes (special services) or do not necessarily have access to a sufficient network (informal settlements and vegetation fires).

Table 28: Average fire flows for each category

Type of fire	Average fire flow (ℓ/min)
Structural fires	75.02
Informal settlements	90.21
Veld, grass and refuse	87.26
Automobile accidents	74.30
Special services	169.60

To determine whether it was necessary to utilize the water distribution network, the method explained in section 3.1.1was applied, 16 fires were possible candidates for augmenting their fire flow supplies from the network. However, five of these fires occurred on farms and four were special services, leaving only seven fires (2% of the fires) assumed to have used water from the distribution network to extinguish fires.

3.1.6 Municipality 3

The data obtained from this fire department was only fire reports, no additional information was provided on incidents that occurred. A summary of the 146 fire reports with relevant information for incidents that occurred between the 1st of January 2010 and the 31st of December 2010 can be seen in Appendix F, Table F.3. The distribution of the fires according to their categories can be seen in Figure 16 and the monthly incident frequency of the different categories during the year for Municipality 3 is shown in Figure 17.

Figure 16 shows a high rate of grass, veld and refuse fires (58%) compared to other categories. Informal settlements are second highest (13%), with automobile accidents and structural fires following closely, and special services being the lowest with an incidence of merely 5%. The impact of the climatic conditions on vegetation fires is not as evident in Figure 17 as was the case in Municipality 2, with a high number of vegetation fires in June. Nevertheless seasonal influences are still visible with a high number of fires occurring during January and February.

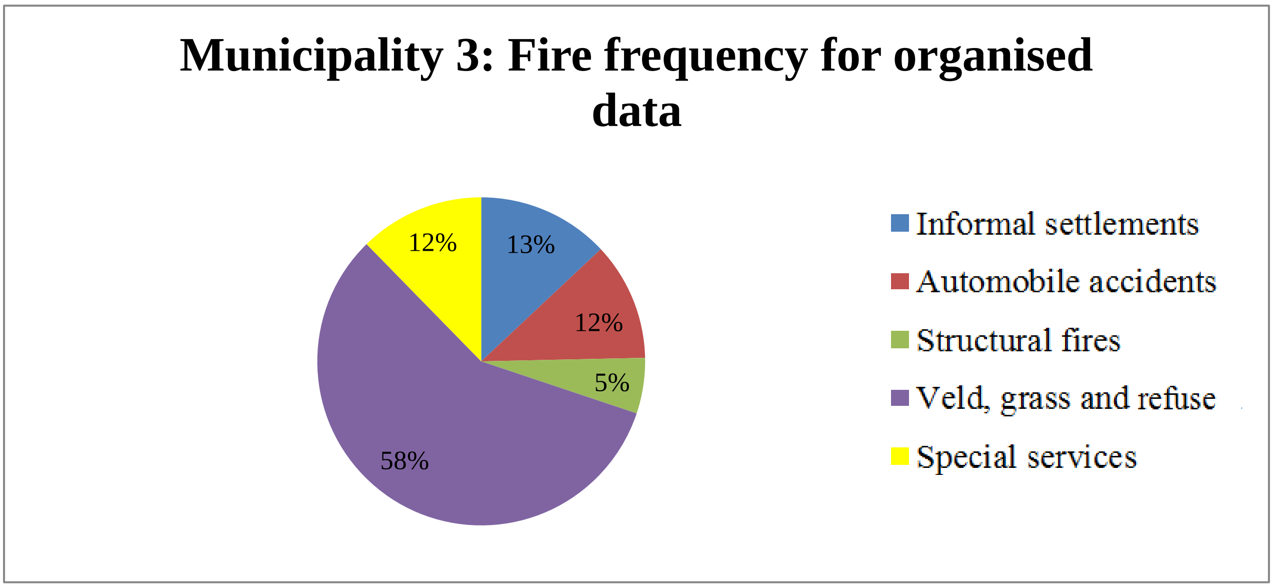

Figure 16: Distribution of fire categories based on data after cleaning and re-categorisation

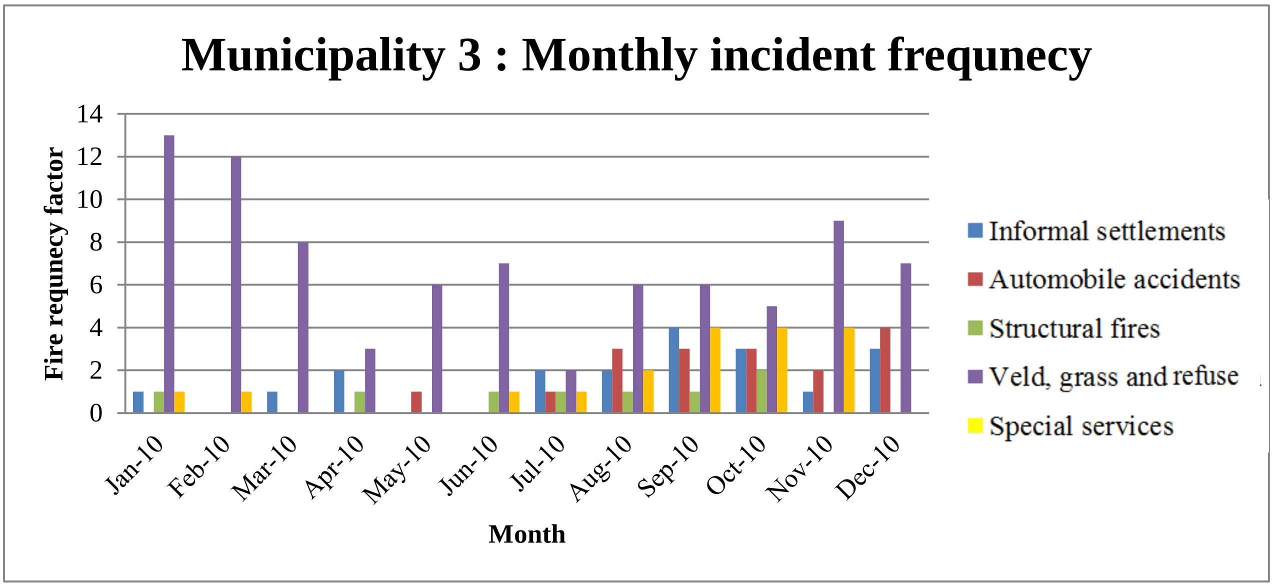

Figure 17: Frequency of fire incidents per category for Municipality 3

3.1.6.1 *The fire flow distribution*

The total fire flow volumes that were used during each month can be seen in Figure 18 and the RFF distribution for all the fires can be seen in Figure 19. Similarly, to Municipality 2, the monthly fire flows are also relatively representative of the number of fires each month, except for September and October, which have much higher flows compared to the other months. Both these high monthly flows are a result of large fire flows that were provided by the fire department.

The high fire flows that were provided in September and October are shown in Figure 19. The figure shows that the abnormally high flow demands are once again special services and therefore provide no indication of the flows required to fight fires.

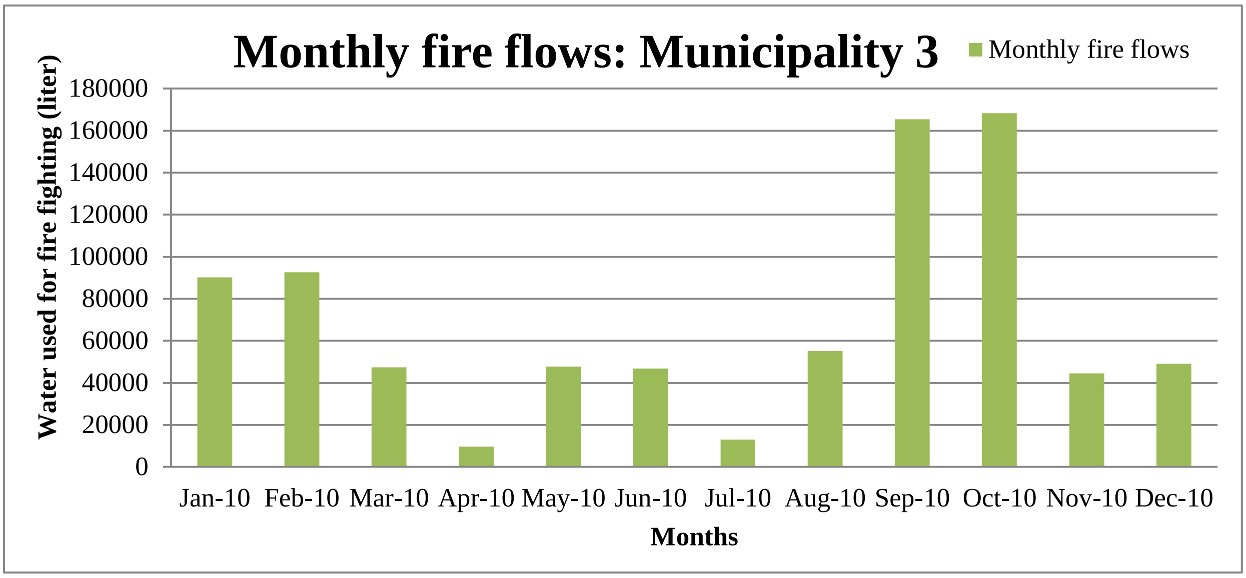

Figure 18: Fire flow volume distribution for Municipality 3

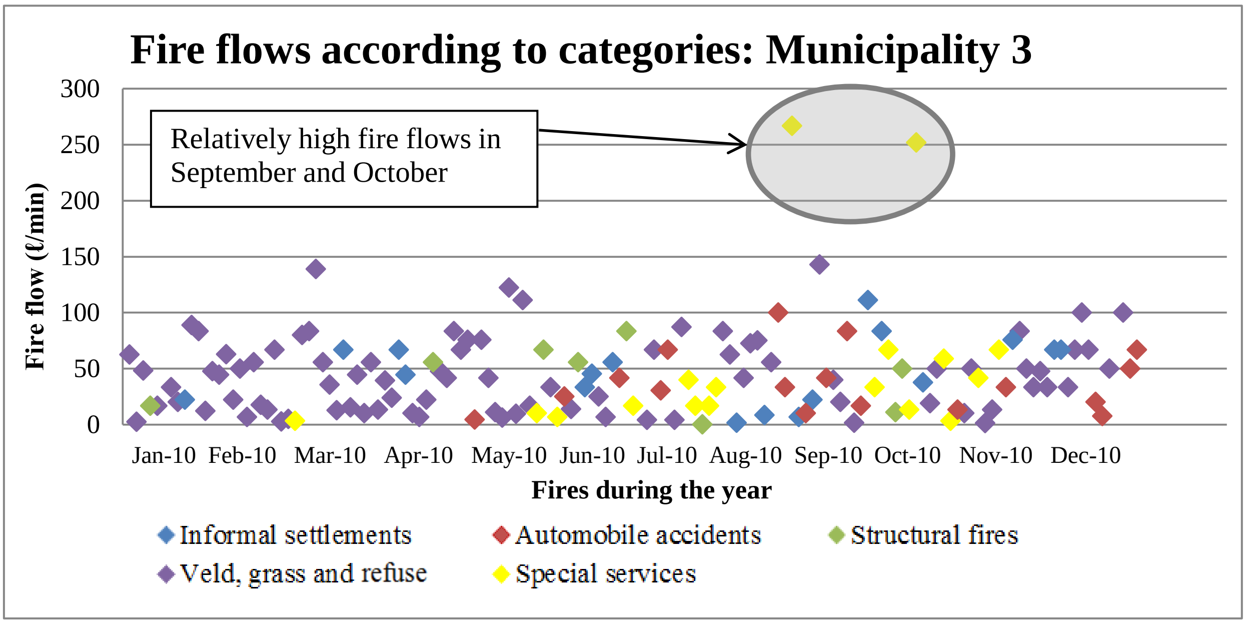

Figure 19: Fire flow rate distribution according to categories for Municipality 3

The average fire flows that were required for each of the different fire categories are shown in Table 29. Once more the highest average RFF are for special services (58.4 ℓ/min) and the second highest flow requirements for informal settlements (57.2 ℓ/min), followed by structural fires with 53.7 ℓ/min.

Table 29: Average fire flows for each category

Type of Fire	Average Fire Flow (ℓ/min)
Structural fires	53.7
Informal settlements	57.2
Veld, grass and refuse	44.6
Automobile accidents	37.9
Special services	58.4

To determine whether it was necessary to utilise the WDS, the method explained in section 3.1.1 was applied and 27 fires were possibilities for utilising the distribution system, according to the water demands and the responding vehicles. Fourteen of these fires were either on farms or on roads outside the town or special services, leaving 13 fires (9% of the fires) assumed to have used water from the distribution network for extinguishing purposes.

3.1.7 Results and discussion

The data discussed in this section in conjunction with Table 30, shows that the highest number of fires (54.3%) that occurred was vegetation fires, followed by informal settlement fires representing 14.4% of the fires.

Table 30: Summary of fire categories for different municipalities

	Informal settlements	Automobile accidents	Structural fire (residential and industrial)	Veld, grass and refuse	Special services
Municipality 1	22	6	34	16	0
Municipality 2	40	39	34	206	21
Municipality 3	19	17	8	84	18
Percentages	14.4%	11.0%	13.5%	54.3%	6.9%

The informal settlements are usually located on the outskirts of an existing WDS and generally do not have an adequate WDS. However, informal settlements still indirectly depend on a WDS for fire flow since firefighting vehicles transport water from predetermined hydrants on the WDS to fires in these areas. Although the informal settlement fires do not essentially result in high property losses and insurance claims, these fires are potentially most threatening to humans due to the close proximity of the residences to one another. The structural fires are third highest at 13.5% of the fires. These fires usually lead to high property losses and can result in burn injuries and casualties.

The average of the fire flow rates used for each of the different fire flow categories is shown in Table 31. According to the analysis of the fire flows, the informal settlement fires required the highest fire flows, followed by structural fires. Special services also require relatively high flows, especially for Municipality 2 and Municipality 3; however, these flows are usually not fire related and, therefore, not relevant when determining the required fire flows. The three highest flows that were required at these municipalities over the duration of one year according to the data provided, were 1 200 ℓ/min, followed by 555 ℓ/min and 416 ℓ/min all of which were structural fires.

The informal settlements do not necessarily have networks to provide potable water, and rarely water for firefighting. It is interesting to note that, even though a large number of fires (14.4%) occur in informal settlements, the CSIR (2003) does not provide fire flow requirements for these areas.

Table 31: Average RFF for each category in ℓ/min

	Informal settlements	Automobile accidents	Structural fire (residential and industrial)	Veld, grass and refuse	Special services
Municipality 1	130.40	96.70	143.9	74.20	0
Municipality 2	90.21	74.30	75.02	87.26	169.6
Municipality 3	57.20	37.90	53.80	44.60	58.40
Total:	277.80	208.90	272.70	206.06	228.00

In light of the analysis that was done for each of the municipalities, it was determined that the water distribution network is seldom used to extinguish a fire. For Municipality 1, 21.2% of the fires were extinguished using the network, for Municipality 2, 2% of the fires and for Municipality 3 only 9% of the fires. This leads to an average of a mere 11% of fires being extinguished in these rural towns using the WDS.

3.1.7.1 *Comparing rural and urban fire flows*

According to previous studies done for urban areas, such as Johannesburg (Van Zyl & Haarhoff, 1997) and Cape Town (Van Zyl et al., 2011), fire flow requirements for high-risk areas were determined to be unnecessarily high, whereas the requirements for low risk areas are inadequate. For the city of Johannesburg, 99.4% of the fires in high risk areas could be extinguished using 3 100 ℓ/min or less. In our study for rural areas, 99.8% of the fires could be extinguished using 1 200 ℓ/min or less, 98.6% of the fires could be extinguished using 600 ℓ/min or less and 97.7% of the fires could be extinguished with less than 400 ℓ/min.

3.1.7.2 *Comparing rural fire flows to standards*

The statistics mentioned in the previous section indicates that flows required for *rural fire flows* are much lower than the fire flows required in the South African standards. According to standards provided by the CSIR (2003) more than 99.8% of the *rural fire flows* were lower than flows recommended for moderate risk areas and more than 97.7% of the flows required were less than flows recommended for the low risk category (group 3). Note that the flows recommended by the CSIR are already significantly lower than the flows recommended in the SANS: 10090 for moderate and specifically low risk areas.

3.2 **Impact of Western Cape rural fire flows on a water distribution system**

As was discussed earlier in chapter 2, the Anytown model is a hypothetical town used for the hydraulic modelling of different fire flow conditions in a WDS. Since the fire flow requirements of the rural towns, as per data set compiled in this report, are more in line with the fire flow requirements recommended by the CSIR (2003), this standard was used to provide the fire flow according to the South African standards for the scenarios in the Anytown network.

The case study was done to quantify the reduced cost of a WDS, which has to provide fire flows as required for rural towns as determined in section 3.1 versus that of a WDS, providing fire flow according to the current South African standards.

The effects of different fire flow conditions on the WDS were compared in the following scenarios by determining the optimum pipe diameters and tank sizes with their corresponding costs for each of the fire flow conditions. The Anytown network, as was described in section 2.5.2, was used in this case study for the comparison of the fire flow conditions. The scenarios investigated were as follows:

- Scenario 1: Fire flow requirements

  The total costs for a network designed to provide fire flows according to the South African standards, from here on referred to as *recommended fire flows*, and a network providing the maximum required *rural fire flows*, according to section 3.1, are compared.

- Scenario 2: Fire flow provision methods

  The total costs for a network providing *rural fire flows* at any hydrant in the WDS and a network where water used for firefighting is provided by refilling firefighting vehicles at predetermined hydrants are compared. The flows required for refilling firefighting units will be referred to as *refill fire flows* from here on.

3.2.1 Firefighting vehicles

The average time to fill a 5kℓ pumper tank is derived by determining the estimated discharge at a hydrant based on the following equation, provided by Govender (2011):

$$flow\ at\ hydrant = \frac{d^2\sqrt{P}}{15}$$

Where: d - discharge diameter at hydrant in mm (65mm)

p - pressure supplied at hydrant in bar (assume pressure is 5 bars)

$$flow\ at\ hydrant = \frac{65^2\sqrt{P}}{15} = 630\ \ell/min$$

Therefore, time taken to fill up a tanker: $^{5000}/_{630} = 8\ minutes.$

The calculated time, 8 minutes, does not cater for the length of the connection hose between the hydrant and the tanker or other consequent losses that may be encountered due to friction losses, which might also have an effect on the time. It is therefore suggested, that given the dynamics of fluctuating hydrant pressures in different areas of a town and taking into account the factors mentioned, a more realistic time would be 10 minutes.

A 3kℓ engine pumper would take approximately 6 minutes and a 0.5kℓ rapid intervention unit 2 minutes. For this case study, assume that two pumper tankers, two engine pumpers and one rapid intervention unit are available for extinguishing fires. To refill all of these would take an average of 10 + 10 + 6 + 6 +2 = 34 minutes.

3.2.2 Assumptions and limitations

Assumptions were made concerning numerous parameters for both scenarios 1 and 2. The following general assumptions were made for the Anytown network model:

- The rural towns that provided data are relatively similar to the Anytown model in terms of size, type of network and demands.

- Daily demands were provided as part of the Anytown problem. The hourly, daily and weekly peak factors are consistent with the peak factors provided in the software manual of the Wadiso Software. Note that for the illustration of the effect fire flow has on a network, the accuracy of these factors is irrelevant as long the factors used were consistent for all the models.

- Ensuring that sufficient pressures are available in a system is just as important as providing fire flows. According to the models, adding flows to the nodes with the lowest pressures had a lower impact than adding fire flows to nodes with the highest domestic demands, and they were therefore excluded in further analysis.

- The optimisation tool in Wadiso was used to determine the optimum pipe and tank sizes. The required flows and minimum specified pressure (300 kPa) was provided as input data for the optimisation of the Anytown network.

- GLS Consulting provided theoretical cost functions used for the optimisation tool of Wadiso to determine the optimum tank and pipe sizes. Note that the accuracy of these costs compared to current prices is irrelevant, since the costs are merely used to provide an economically based comparison between the different scenarios and not an accurate cost estimate for the design network.

- If fires are extinguished using firefighting vehicles that are refilled instead of local hydrants, it is assumed that all the firefighting vehicles available would be deployed.

- Fire flows provided by the network at the scene of the fire were added to the two nodes with the highest average daily demand. To provide for a worst-case scenario, the fire flow was provided during the time of day when the daily peak factors were highest. The nodes with the highest flows were both in industrial (high risk) areas. A *recommended fire flow* of 12 000 ℓ/min was provided. This method of determining the impact of fire flow on a WDS was discussed in section 2.5.4.1.

- Two centralized locations were specified for the two hydrants (nodes 14 and 17) utilized for refilling the firefighting units. For the design and upgrading of a system, the designers should take particular care to provide a refill-hydrant near informal settlements, or any other areas without an adequate water distribution network.

- The emergency storage volume, according to the guidelines in the CSIR (2003) is 24 – 48 hours of the average daily demand. Considering that part of the emergency storage is generally stored as fire flow and that fire flow has already been added to the average daily demands, the additional storage capacity was calculated as the total output of the tanks over 12 hours.

- For the modelling of the network, the pipe sizes are divided into groups of the same diameter, since pipe sizes do not change every few metres. The division was roughly based on the distribution area of the pipe. Pipes providing large areas were grouped together and pipes supplying a small area were grouped together, etc.

The primary limitation of the case study is the small database (one year) from which *rural fire flows* were obtained. More accurate fire flow requirements could be determined if data over longer time periods was used.

3.2.3 Methodology

3.2.3.1 *Scenario 1*

For the first scenario, the fire flow simulations were executed by simultaneously abstracting fire flow from the two nodes with the highest demands, nodes 17 and 19, see Figure 20.

Adding fire flows to the nodes with the lowest pressures had a lower impact on the system than adding fire flows to the nodes with the highest demands, and was consequently excluded. The duration of the RFF, depending on the risk category, were assigned according to the CSIR (2003) for the *recommended fire flows* and the *rural fire flows*.

To illustrate the influence of *rural fire flow* on the network, the highest RFF for any of the three municipalities in section 3.1, was used. The total fire flow, 108kℓ, was supplied over a duration of 90 minutes (1 200 ℓ/min). Note that because of the limited database, it is likely that higher flows could occur in the future. For this case study however, 1 200 ℓ/min was used.

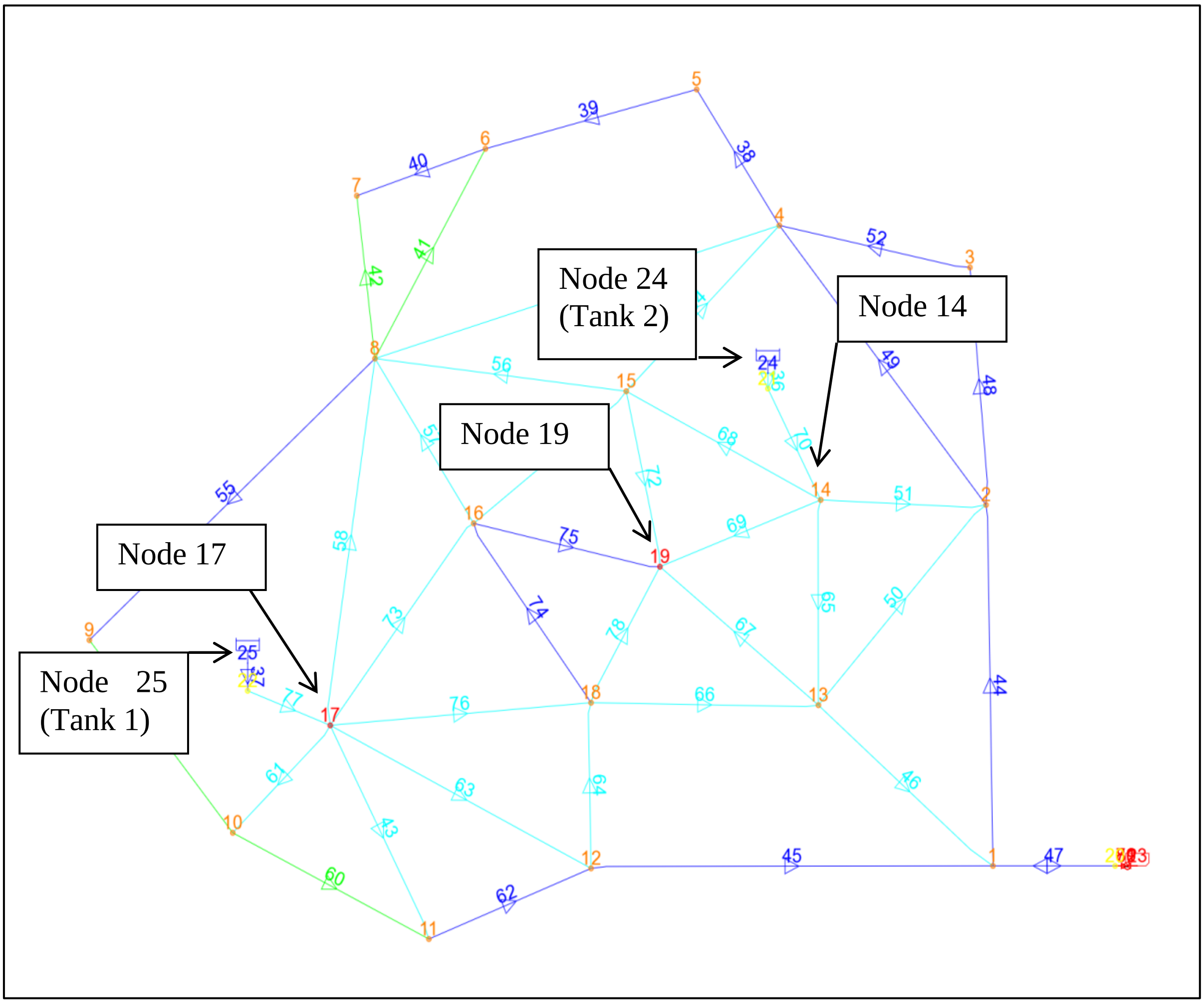

Figure 20: Anytown network model

3.2.3.2 *Scenario 2*

For this scenario, the fire flow simulation for flows in rural towns was the same as for the first scenario. The maximum RFF (1 200 ℓ/min), as was determined in section 3.1, was provided at the nodes with the highest demands to ensure that the rest of the network would also be capable of supplying fire flow.

To illustrate the influence on the network if flows required for refilling firefighting units are provided at predetermined hydrants instead of fire flows being available at all hydrants, *refilling fire flows* were provided at centrally located nodes 17 and 14, see Figure 20. The flows must be sustained for a total of 34 minutes (the time it would take to refill all the units used in this case study) every hour for 6 hours. Centrally located nodes were chosen to ensure that all areas are within practical reach of a hydrant.

According to the data in section 3.1, the fire that required the highest flow (1 200 ℓ/min) were extinguished using a total of 108 kℓ. If this volume of water were to be provided using firefighting vehicles (all the units with a total capacity of 18 kℓ) it would take at least 6 hours, with the units refilling for 34 minutes of every hour. Note that not all of the units are refilled at once; the units take turns being refilled while the other units extinguish the fire.

3.2.4 Results and discussion

Wadiso was used to optimise the Anytown water distribution network model for different scenarios. The modelling was done for the provision of average daily demands as well as different fire flow scenarios. The only parameters used for the modelling were the loads of each node and the minimum specified pressure, 300 kPa (30 m).The optimised network solutions, along with the network costs, were used to compare the different fire flow scenarios on an economic basis.

3.2.4.1 *Modelling results*

The modelling provided estimated costs for the network under the different fire flow conditions, as shown in Table 32.

Table 32: Cost comparison for different fire flow conditions

	Pipe costs(R million)	Tank costs (R million)		Total costs (R million)
		Node 24	Node 25	
Fire flow according to CSIR (2003)	20.627	2.967	3.847	27.441
Fire flow according to rural town requirements [1]	17.712	2.266	3.363	23.340
Fire flow required to fill firefighting units [2]	17.388	2.383	2.926	22.697

1. Fire flow is provided via the network at the scene of the fire.
2. Fire flow is provided at predetermined hydrants to refill firefighting units.

A bar chart illustrating the difference in costs is shown in Figure 21.

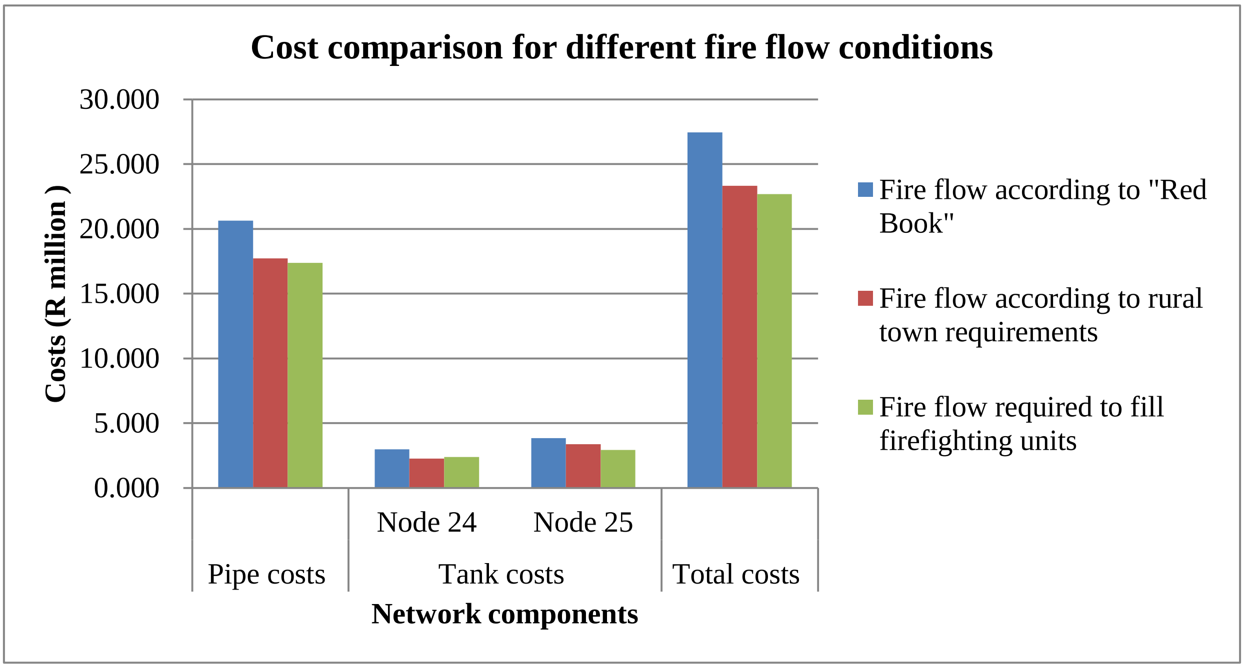

Figure 21: Cost comparison for different fire flow conditions

3.2.4.2 *Discussion*

The comparison of the costs showed the following:

- Scenario 1

  The costs of designing a network to provide the *recommended fire flow* of 12 000 ℓ/min for a high-risk area, is 14.94% (R 4.1 million) higher than the costs required to provide *rural fire flow* (1 200 ℓ/min). Note that even though the *recommended fire flow* is 10 times higher, the costs are only 1.5 times higher. The reason for this is that a large percentage of pipe and tank costs are “fixed”, the actual cost of the pipes, depending on the size, does not have a significant influence on the total costs. This shows similar results to a study by Snyder et al. (2001), discussed in section 2.5.1.

- Scenario 2:

  The costs of designing a network that is able to provide *rural fire flow* is 2.4% (R 643 161) higher than the costs of a network providing *refill fire flows*. Even though

> the design costs for *refill fire flow* are not significantly lower than the design costs for *rural fire flow*, there are numerous other factors adding to the feasibility of this method of fire flow provision. Providing fire flows for informal settlement areas and other areas with inadequate water supplies already depends on this method of provision.
>
> Due to the close proximity of the nodes used in this model to the tanks providing water to the town, they would inherently be ensured of sufficient water supplies, even if there are disruptions in the network, e.g. pipe bursts or maintenance. It would not always be practical to place hydrants close to the water storage, but measures can be taken to situate hydrants on main distributions lines and locations where disruptions would not affect the ability of the hydrants to provide water for fire flow.

The case study showed that the costs of a network that is able to provide fire flows according to the South African guidelines are 15% higher than designing a network able to provide *rural fire flow*. The data set compiled for this study was limited and further studies would be necessary to define more accurate *rural fire flows*. The more detailed and accurate fire flows then determined, could then be used for a re-evaluation of the fire codes, possibly modifications could be made to specifically accommodate smaller rural towns.

The costs for different methods of providing fire flow, via the water distribution network or via predetermined hydrants for refilling fire units, were also compared in this case study. The models showed that developing a system that is able to provide rural fire flow at all hydrants is more expensive than providing fire flow for refilling fire units at a predetermined hydrant. Aside from the cost difference, the *refill fire flow* method also provides a solution for areas where the WDS is inadequate or when the water distribution network is disrupted.

Note that if the method of designing networks with predetermined hydrants to be used for refilling fire vehicles is implemented, the regulations for the firefighting vehicles required for fire departments, see section 2.4.1.1.3, should be adjusted accordingly.

3.3 Evaluation of firefighting techniques and technologies used in rural towns in the Western Cape

The evaluation of the different firefighting techniques and technologies were done using the Pugh method consisting of decision matrices. Stuart Pugh invented this method to aid engineers in their decision making process (Ullman, 2010). Note that this method is subjective and thereby limited. This method provides a robust estimate of the feasibility of each of these techniques/technologies and is suitable only in the initial stages of a design.

3.3.1 Evaluation of firefighting techniques for rural towns

According to the reports provided by the fire departments, the following methods were used to extinguish fires: manual extinguishment using buckets, water from the network at the location of the fire, water transported via firefighting vehicles from a predetermined hydrant and a helicopter.

3.3.1.1 *Decision matrix*

The different techniques were evaluated using a decision matrix. The following parameters were assessed:

1. Practicability:	Is the method practical and executable?
2. Affordability:	Is the method cost effective?
3. Efficiency:	Is the method effective in extinguishing fires?
4. Advanced methods:	Is the method advanced and utilising new technology?
5. Impact:	What is the impact on the water resources/network?
6. Availability:	Is the method readily available in rural towns?

In the first part of the process, Table 33, these parameters are scored against one another on a scale of 0-10 to determine the significance of each of the parameters.

Table 33: Decision matrix for extinguishing methods - weighted means

Criteria for comparison	**1**	**2**	**3**	**4**	**5**	**6**	
1	*	4	6	3	6	6	
2	6	*	7	4	6	6	
3	4	3	*	4	6	5	
4	7	6	6	*	6	6	
5	4	4	4	4	*	6	
6	4	4	5	4	4	*	
Total	**25**	**21**	**28**	**19**	**28**	**29**	**150**
% Weight	16.67	14.00	18.67	12.67	18.67	19.33	

For the second part, Table 34, the parameters are scored and evaluated in relation to one of the methods (helicopters) which is used as a datum. In this process, the methods were compared to the datum and a "+" was assigned if the method scored higher for the specific parameter and a "-" was assigned if the method scored less. If the method were on the same level as the datum an "S" (same) was assigned.

As can be seen in Table 34, using the network for fire flow and using vehicles to transport water to the scene of the fire have the same level of viability.

Table 34: Evaluation of methods using decision matrix

	Weight	**Bucket**	**Network**	**Vehicles**	**Helicopters**
Practicability	16.67%	+	+	+	D
Affordability	14.00%	+	+	+	A
Efficiency	18.67%	-	-	-	T
Utilising of advanced new methods	12.67%	-	+	+	U
Availability	18.67%	+	+	+	M
Impact	19.32%	S	-	-	
Total %	100.00%				
Total +		3	4	4	0
Total -		2	2	2	0
Overall total		1	2	2	0
Weighted total		**18.00%**	**24.02%**	**24.02%**	

A supplementary decision matrix was therefore required to determine which of these two methods would be most suitable, see Table 35.

Table 35: Supplementary evaluation methods using decision matrix

	Weight	**Network**	**Vehicles**
Practicability	16.67%	-	D
Affordability	14.00%	-	A
Efficiency	18.67%	+	T
Utilizing of advanced new methods	12.67%	S	U
Availability	18.67%	-	M
Impact	19.32%	-	
Total %	100.00%		
Total +		1	0
Total -		4	0
Overall total		3	0
Weighted total		**-49.99%**	

This matrix shows that using vehicles to transport water to the fires is a more viable option to extinguish fires than using water from the water network at the location of the fire.

Taking into account the cost comparisons from the case study in section 3.2, it is evident that using vehicles to transport water to the fires is not only a practical but also a cost effective method as long as the transport distance is not too far.

3.3.2 Evaluation of firefighting technologies used in rural towns

According to the literature review in Chapter 2, a number of technologies and new methods could be used to reduce the reliance on the water distribution network for non-potable purposes. These methods aid by either providing alternative water resources or making water more effective as a fire-extinguishing agent.

3.3.2.1 *Decision matrix*

The different methods and technologies were evaluated using a decision matrix.

The following parameters were assessed:

1. Initial costs: Are the initial implementing costs high?
2. Long-term costs: Is the method cost effective in the long-term?
3. Efficiency: Is the method effective in extinguishing fires?
4. Water saving potential: Does the water reduce the use of potable resources?
5. Availability: Is the method readily available?
6. Environmental impact: Does this method have an impact on the environment?

Similar to the process used in section 3.3.1, the parameters mentioned above are scored against one another on a scale of 0-10 to determine the significance of each of the parameters, see Table 36.

The second part is similar to the process explained in section 3.3.1; the parameters are scored and evaluated in relation to one of the methods (water additives) which is used as a datum, see Table 37. According to this decision matrix the most effective technology available to aid in firefighting, as well as the conservation of our natural water resources, is the use of Class A foams in conjunction with CAFS.

Table 36: Decision matrix - weighted means

Criteria for comparison	**1**	**2**	**3**	4	5	**6**	
1	*	6	6	7	7	6	
2	4	*	5	6	7	6	
3	4	5	*	4	7	5	
4	3	4	6	*	6	5	
5	3	3	3	4	*	4	
6	4	4	5	5	6	*	
Total	**18**	**22**	**25**	**26**	**33**	**26**	**150**
% Weight	12.00	14.67	16.67	17.33	22.00	17.33	

Even though the initial costs of installing a CAFS system are high and the long-term effect on the environment has not yet been determined, the enduring benefits and significant savings in potable water resources would make it economically and environmentally feasible.

Table 37: Evaluation methods using decision matrix

	Weight	Dual systems	Non-potable resources	Class A foams and CAFS	Water additives
Initial costs	12.00%	-	-	-	D
Long term costs	14.67%	-	-	+	A
Efficiency	16.67%	-	+	+	T
Water saving potential	17.33%	+	+	+	U
Availability	22.00%	-	-	-	M
Environmental impact	17.33%	+	+	S	
Total %	100.00%				
Total +		2	3	3	0
Total -		4	3	2	0
Overall total		-2	0	1	0
Weighted total		**-30.68%**	**2.66%**	**14.67%**	

4 Conclusion

4.1 Literature survey

The literature study discussed in Chapter 2 reported numerous different methods of providing fire flow, of which water from the WDS is currently the most commonly used method. Water additives that improve the extinguishing capabilities of water were discussed in section 2.2.5. Using class A foam in combination with CAFS is the most effective way to make water more efficient in extinguishing fires, increasing the extinguishing capabilities of water by ten times or more.

Alternative methods of providing water for firefighting, to reduce the reliance on the potable water system, such as the implementation of dual systems and using surface water as a resource were discussed in sections 2.2.6 and 2.2.7. In areas where the WDS is inadequate, water for firefighting is provided by firefighting vehicles transporting the water from predetermined central abstraction points or non-potable water supplies, e.g. lakes and rivers.

The fire flow standards, as well as the methods of providing fire flow in the United States of America, Canada and a few European countries were discussed. In most of these countries, it is left to the local authorities to determine and provide fire flow.

Germany use a different method than most of these countries. In Germany the authorities are responsible for supplying only a basic level of fire flow, called the “base flow”, whereas the owner of the property is responsible for ensuring that sufficient water supplies would be available for firefighting if the “base flows” were insufficient. The advantage of this method is that if a high risk building were built in a low risk area, it would not be the responsibility of the authorities to provide sufficient fire flows, but the property owner’s.

A comparison of South African and other international standards showed that the standards for high risk areas in South Africa are significantly higher than most countries, with the exception of the United States of America and Canada. The comparison also showed that the fire flow recommended by the CSIR (2003) is more in line with the minimum required fire flows of other countries, whereas the minimum required fire flow recommended in the SANS: 10090 is higher than that of most countries. It was also noted that there are no fire flow regulations for low risk areas (group 4), or any other areas lacking a WDS in the CSIR (2003).

The design of a WDS would be more realistic if the potential fire risk damages were also taken into account when designing the most economically feasible network.

4.2 Evaluation of firefighting in rural towns in the Western Cape

4.2.1 Fire flow requirements

According to the analysis of the data done in section 3.1, the fire flows actually required to extinguish fires in rural areas are significantly lower than the fire flows recommended according to the South African standards. The case study done in section 3.2 showed that designing a water distribution network in a rural town to provide fire flows according to the standards, instead of modified flows tailored for a rural area, could result in costs up to 15% higher. The over design of a WDS could also lead to a decrease in the water quality, as a result of longer retention times, in addition to possible sediment deposition caused by low velocities in the pipes.

Considering the significant differences between the fire flows required for cities and *rural fire flows*, including the differences in costs, it might be of value to consider separate fire flow requirements for rural and urban towns. Urban areas are more densely populated than rural towns, with a larger number of high rise buildings and industrial areas, resulting in an increased risk of the spreading of fires and therefore requiring higher fire flows when fires do occur.

The codes do not provide guidelines and regulations for informal settlements and other areas where distribution networks are not available.

4.2.2 Firefighting techniques

In light of the analysis that was done for each of the municipalities, it was determined that the water distribution network is seldom used to extinguish a fire. An average of a mere 11% of fires in these rural towns is extinguished using the WDS.

These results lead to the question of how important the water distribution network really is for the provision of fire flow and whether there are other, more suitable, methods to fight fires possibly at lower costs and with greater efficiency.

As was determined by the evaluation done in section 3.3.1, using firefighting vehicles to transport water to the scene of the fire and refilling at nearby predetermined hydrants suited specifically for firefighting purposes is the most viable option for fighting fires in rural towns in the Western Cape.

The case study in section 3.2 showed that the costs of a network designed to supply fire flow from predetermined hydrants to refill firefighting units are 2.4% lower than the costs of a network designed to provide rural fire flow from hydrants at the location of the fire. Instead of spending money on upgrading the water distribution network to provide the required flows and pressures the money could be used to ensure that the hydrants are adequate for refilling fire units and are available within a practical distance of any area. Systems that are not over-designed would most likely have higher quality water, due to shorter retention times, and the deposition of sediments would be avoided due to higher flow velocities in pipes.

Besides the cost and water quality differences, providing *refill fire flow* also offers a solution for extinguishing fires in areas where the WDS is inadequate, as is often the case in informal settlements. Since some of the firefighting vehicles are smaller and more mobile than the standard tankers used to pump water from the network, it would be easier for them to reach densely populated areas where decent roads are not available, to extinguish fires and then to return to the predetermined hydrant for a refill.

Providing fire flow from predetermined hydrants could also increase the reliability of the network in providing fire flow. If disruptions were to occur on the network near the fire, causing a shortage of water, water could be transported from predetermined central abstraction points not affected by the disruption.

The success of providing fire flow at predetermined, central abstraction points is highly reliant on the organizational abilities of the fire departments, the maintenance and availability of firefighting equipment, as well as the maintenance of the central abstraction points. A re-evaluation of the number of firefighting vehicles required in a fire brigade according to SANS: 10090 (2003), previously discussed in section 2.4.1.1.4 of Chapter 2, would be necessary if the method of refilling firefighting vehicles to transport water to the location of the fire is implemented.

4.2.3 Firefighting technologies

The evaluation of the firefighting technologies showed that there are numerous advanced methods available to increase the efficiency of water in extinguishing fires and correspondingly to reduce the reliance on potable water resources for firefighting. The use of foams and CAFS are the most viable options according to the decision matrix done in section 3.3.2. By adding these elements to regular water from the WDS, the firefighting abilities would increase by 10 times or more, as was mentioned in the literature survey.

Using foams and CAFS together with firefighting vehicles transporting water from predetermined hydrants would be the most effective method of firefighting in rural towns in the Western Cape.

5 Recommendations for further studies

The execution of similar analyses to those of Chapter 3 is suggested, using a more extensive database over a longer time duration, to determine whether these results are an accurate reflection of fires in rural towns. It is recommended also that this study should be conducted in other provinces. Specifically provinces such as the Northern Cape, with less vegetation surrounding the towns. According to the data analysed, climate and vegetation has a substantial impact on the occurrence of fires. Limited vegetation could result in a significant reduction in the number of fires, and therefore the fire flows required, in small rural towns.

As a result of the differences in the fire flows required in rural towns and the flows provided in the South African standards it is recommended that the South African design codes are revisited and re-evaluated. It is also suggested that a distinction be made between the flows required for rural areas and the flows required for urban areas. The difference in fire flow guidelines for low risk areas should also be reviewed and similar flows recommended in the SANS: 10090 and the CSIR (2003).

The lack of fire flow guidelines for the low risk area (group 4) in the CSIR (2003) should also be addressed. It is recommended that accurate fire flow requirements for informal areas are determined and methods for supplying fire flows to these areas, such as shuttling water from predetermined, central abstraction points, are implemented.

The method previously mentioned of transporting water from predetermined hydrants for firefighting, should be reviewed in detail, to determine the economic feasibility and the reliability of implementing this method as the main method of fighting fires in rural towns.

Fire departments as well as engineers should review the use of new technologies, such as firefighting foam and CAFS, in order to determine the feasibility of implementing these methods to increase the efficiency of water as an extinguishing agent and thereby reduce the reliance on potable water resources for firefighting.

Considering all the suggestions mentioned there are numerous possibilities for redefining the way South Africa fights fires. Modifications can be made to the fire flows recommended in the South African standards to ensure that sufficient fire flows are available without over designing a network. The methods used for firefighting can also be reviewed and methods that are more efficient implemented to increase our firefighting abilities and, at the same time, reduce the reliance on our potable water resources.

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Appendices

APPENDIX A: ISO method

Table A1: Type of construction factor as determined by range in effective area (ISO, 2008)

Class	1		2		3 & 4		5 & 6	
Factor (F)	2		1		1		1	
(C)	Effective Area (A)		Effective Area (A)		Effective Area (A)		Effective Area (A)	
	At least	Not over	At least	Not over	At least	Not over	At least	Not over
500	0	535	0	1,205	0	1,883	0	3,348
750	536	1,050	1,206	2,363	1,884	3,692	3,349	6,564
1,000	1,051	1,736	2,364	3,906	3,693	6,103	6,565	10,850
1,250	1,737	2,593	3,907	5,835	6,104	9,117	10,851	16,209
1,500	2,594	3,622	5,836	8,150	9,118	12,734	16,210	22,639
1,750	3,623	4,822	8,151	10,852	12,735	16,954	22,640	30,140
2,000	4,823	6,194	10,853	13,937	16,955	21,776	30,141	38,714
2,250	6,195	7,737	13,938	17,409	21,777	27,202	38,715	48,359
2,500	7,738	9,452	17,410	21,267	27,203	33,230	48,360	59,076
2,750	9,453	11,338	21,268	25,511	33,231	39,861	59,077	70,864
3,000	11,339	13,395	25,512	30,140	39,862	47,095	70,865	83,724
3,250	13,396	15,624	30,141	35,156	47,096	54,931	83,725	97,656
3,500	15,625	18,025	35,157	40,557	54,932	63,374	97,657	112,659
3,750	18,026	20,597	40,558	46,344	63,375	72,413	112,660	128,734
4,000	20,598	23,341	46,345	52,517	72,414	82,058	128,735	145,881
4,250	23,342	26,256	52,518	59,076	82,059	92,306	145,882	164,100
4,500	26,257	29,342	59,077	66,020	92,307	103,156	164,101	183,390
4,750	29,343	32,600	66,021	73,350	103,157	114,610	183,391	203,751
5,000	32,601	36,029	73,351	81,066	114,611	126,666	203,752	225,185
5,250	36,030	39,630	81,067	89,168	126,667	139,325	225,186	247,690
5,500	39,631	43,402	89,169	97,656	139,326	152,587	247,691	271,267
5,750	43,403	47,346	97,657	106,529	152,588	166,452	271,268	295,915
6,000	47,347	51,461	106,530	115,788	166,453	295,916		
6,250	51,462	55,748	115,789	125,434				
6,500	55,749	60,206	125,435	135,464				
6,750	60,207	64,836	135,465	145,881				
7,000	64,837	69,637	145,882	156,684				
7,250	69,638	74,609	156,685	167,872				
7,500	74,610	79,753	167,873	179,446				
7,750	79,754	85,069	179,447	191,406				
8,000	85,070	191,407						

Table A.2: Factor for communications (P)

Description of Protection of Passageway Openings	Fire-resistive, Non-combustible, or Slow burning communications				Communications with Combustible Constructions					
	OPEN	ENCLOSED (ft)			OPEN			ENCLOSED		
	Any length	<10	11 - 20	21 - 50	< 10	1 - 20	21 - 50	< 10	11- 20	21 - 50
Unprotected	0	*	0.3	0.2	0.3	0.2	0.1	**	**	0.3
Single Class A[1] fire door at one end of passageway	0	0.2	0.1	0	0.2	0.12	0	0.3	0.2	0.1
Single Class B fire door at one end of passageway	0	0.3	0.2	0.1	0.25	0.2	0.1	0.35	0.25	0.15
Single Class A fire door at each end or double Class A fire doors at one end of passageway	0	0	0	0	0	0	0	0	0	0
Single Class B[2] fire door at each end or double Class B fire doors at one end of passageway	0	0.1	0.05	0	0	0	0	0.15	0.1	0

*For over 50 ft, P = 0

** For unprotected passageways of this length, consider the two buildings a single fire division

1. A door that protects all access communications from fires
2. A self-closing door that protects against fires

Table A.3: Factor for exposure (X)

Construction of Facing wall on Subject building	Distance in Feet to the Exposure building	Length-height of Facing Wall of Exposure Building	Construction of Facing Wall of Exposure building Types			
			1 & 3	2, 4, 5, & 6		
				Unprotected Openings	Semi-protected openings [1]	Blank wall
Frame, metal or masonry with openings	0 - 10	1 -100	0.22	0.21	0.16	0
		101 - 200	0.23	0.22	0.17	0
		201 - 300	0.24	0.23	0.18	0
		301 - 400	0.25	0.24	0.19	0
		>400	0.25	0.25	0.2	0
	11-30	1 -100	0.17	0.15	0.11	0
		101 - 200	0.18	0.16	0.12	0
		201 - 300	0.19	0.18	0.14	0
		301 - 400	0.2	0.19	0.15	0
		>400	0.2	0.19	0.15	0
	31-60	1 -100	0.12	0.1	0.07	0
		101 - 200	0.13	0.11	0.08	0
		201 - 300	0.14	0.13	0.1	0
		301 - 400	0.15	0.14	0.11	0
		>400	0.15	0.15	0.12	0
	61-100	1 -100	0.08	0.06	0.04	0
		101 - 200	0.08	0.07	0.05	0
		201 - 300	0.09	0.08	0.06	0
		301 - 400	0.1	0.09	0.07	0
		>400	0.1	0.1	0.08	0
Blank Masonry Wall	Facing wall of the exposure building is higher than the subject building Use the above table EXCEPT use only the length-height of the facing wall of the exposure building ABOVE the height of the facing wall of the subject building. Buildings higher than five storeys, assume five storeys.					
	When height of facing wall of subject building ≥ height of facing wall of exposure building, X = 0					

1. Wired glass or outside open sprinklers

Appendix B: IFC method

Table B.1 Minimum RFF and flow duration for buildings

Fire Flow Calculation Area (ft^2)[1]					Fire flow (gpm)[3]	Duration flow (hours)
Type IA and IB[2]	Type IIA and IIIA[2]	Type IV and V-A[2]	Type IIB and IIIB[2]	Type V-B[2]		
0-22,700	0-12,700	0-8,200	0-5,900	0-3,600	1,500	2
22,701-30,200	12,701-17,000	8,201-10,900	5,901-7,900	3,601-4,800	1,750	
30,201-38,700	17,001-21,800	10,901-12,900	7,901-9,800	4,801-6,200	2,000	
38,701-48,300	21,801-24,200	12,901-17,400	9,801-12,600	6,201-7,700	2,250	
48,301-59,000	24,201-33,200	17,401-21,300	12,601-15,400	7,701-9,400	2,500	
59,001-70,900	33,201-39,700	21,301-25,500	15,401-18,400	9,401-11,300	2,750	
70,901-83,700	39,701-47,100	25,501-30,100	18,401-21,800	11,301-13,400	3,000	3
83,701-97,700	47,101-54,900	30,101-35,200	21,801-25,900	13,401-15,600	3,250	
97,701-112,700	54,901-63,400	35,201-40,600	25,901-29,300	15,601-18,000	3,500	
112,701-128,700	63,401-72,400	40,601-46,400	29,301-33,500	18,001-20,600	3,750	
128,701-145,900	72,401-82,100	46,401-52,500	33,501-37,900	20,601-23,300	4,000	4
145,901-164,200	82,101-92,400	52,501-59,100	37,901-42,700	23,301-26,300	4,250	
164,201-183,400	92,401-103,100	59,101-66,000	42,701-47,700	26,301-29,300	4,500	
183,401-203,700	103,101-114,600	66,001-73,300	47,701-53,000	29,301-32,600	4,750	
203,701-225,200	114,601-126,700	73,301-81,100	53,001-58,600	32,601-36,000	5,000	
225,201-247,700	126,701-139,400	81,101-89,200	58,601-65,400	36,001-39,600	5,250	
247,701-271,200	139,401-152,600	89,201-97,700	65,401-70,600	39,601-43,400	5,500	
271,201-295,900	152,601-166,500	97,701-106,500	70,601-77,000	43,401-47,400	5,750	
295,901-Greater	166,501-Greater	106,501-115,800	77,001-83,700	47,401-51,500	6,000	
—	—	115,801-125,500	83,701-90,600	51,501-55,700	6,250	
—	—	125,501-135,500	90,601-97,900	55,701-60,200	6,500	
—	—	135,501-145,800	97,901-106,800	60,201-64,800	6,750	
—	—	145,801-156,700	106,801-113,200	64,801-69,600	7,000	
—	—	156,701-167,900	113,201-121,300	69,601-74,600	7,250	
—	—	167,901-179,400	121,301-129,600	74,601-79,800	7,500	
—	—	179,401-191,400	129,601-138,300	79,801-85,100	7,750	
—	—	191,401-Greater	138,301-Greater	85,101-Greater	8,000	

1. Minimum required fire shall be allowed to be reduced by 25% for Group R

2. Type of construction based on the *International Building Code*

3. Measure at 20 psi (140 kPa)

Appendix C: Russian Fire flow

Table C.1: Categories of premises and fire flow for trunk mains (Russian standard)

Population served (x1000)	Theoretical number of simultaneous fires	Fire flow (ℓ/s)	
		Buildings ≤ 2 storeys	Buildings ≥ 3 storeys
< 1	1	5	10
1 - 5	1	10	10
5 - 10	1	10	15
10 - 25	2	10	15
25 - 50	2	20	25
50 - 100	2	25	36
100 - 200	3	-	40
200 - 300	3	-	55
300 - 400	3	-	70
400 - 500	3	-	80
500 - 600	3	-	85
600 - 700	3	-	90
700 - 800	3	-	95
800 - 1000	3	-	100

Table C.2: Categories of premises and fire flows for distribution mains

Building Type	Fire flow (ℓ/s)				
	Based on building volume (1 000m^3)				
Apartment blocks with	<1	1 - 5	5 - 25	25 - 50	50-100
> 2 storeys	10	10	-	-	-
2 - 5 storeys	10	15	15	20	-
5-16 storeys	-	-	20	25	-
16 - 25 storeys	-	-	-	25	30
Public building with					
< 2 storeys	10	10	15	-	-
2 - 6 storeys	10	15	20	25	30
6 - 12 storeys	-	-	25	30	35
12 - 16 storeys	-	-	-	30	35

Appendix D: Calculations for buildings using different methods

Single family residential building

The following input parameters must be taken into account, see Table D.1.

Table D.1: Input parameters for single family residential building

Input factors: Residential single family building		
Description	Value	
Building type	Single family residential	Units
Area	2 000	ft^2
Height	22	ft
Storeys	one	
Type of area	Residential	
Exposures	2 (side and back)	
Exposure distance (side)	16	ft
Exposure distance (back)	40	ft

IITRI Method

$$Fire\ Flow(gpm) = \{9\ x\ 10^{-5}\ x\ (Area[ft^2])^2\} + \{50\ x\ 10^{-2}\ x\ (Area[ft^2])\}$$

$$Fire\ Flow\ (gpm) = \{9\ x\ 10^{-5}\ x\ (2\ 000)^2\} + \{50\ x\ 10^{-2}\ x\ 2\ 000\}$$

$$Fire\ flow = 1\ 360\ gpm$$

ISU method

$$Fire\ Flow(gpm) = (Area[ft^2]\ x\ Height\ of\ building[ft]/100)$$

$$Fire\ Flow(gpm) = (2\ 000\ x\ 22/100)$$

$$Fire\ Flow = 440\ gpm$$

NFA method

Exposure is only taken into account if building is within 30ft

$$Flow(gpm) = [(Area\ [ft^2]) \div 3\ x\ Storeys] + [Exposures\ x\ (Area[ft^2]\ \div 3)\ x\ 0.25]$$

$$Flow(gpm) = [(2\ 000) \div 3\ x\ 1] + [1\ x\ (2\ 000\ \div 3)\ x\ 0.25]$$

$$Flow = 833.3\ gpm$$

The ISO method

Assumption: Type of construction –Jointed Masonry

Construction factor coefficient, see Table 2. F = 1

Assumption: Limited combustible Class (C – 2)

Occupancy factor coefficient, see Table 4. O = 0.85

Assumption: Exposure to back: Frame, metal or masonry with openings, distance - 40 ft, height – 22ft, unprotected openings

Exposure to side: Frame, metal or masonry with openings, distance - 16 ft, height – 22ft, Semi-protected openings

Factor for exposure: 0.16

Assumption: Communications – open, Communication factor - 0

$$Fire\ Flow = (Construction\ factor)(Occupancy\ factor)[1.0 + (Exposure\ factor + Communication\ factor)]$$

Where: $Construction\ factor\ = 18\ x\ Construction\ coefficient\ x\ (Area)^{0.5}$

$$Construction\ factor\ = 18\ x\ 1\ x\ (2\ 000)^{0.5}$$

$$Construction\ factor\ = 805$$

$$Fire\ Flow = (805)(0.85)[1.0 + (0.16 + 0)]$$

$$Fire\ Flow = 794\ \approx 800\ gpm\ (rounded\ to\ nearest\ 250\ gpm)$$

The UNFC method

The building does not have a sprinkler system. The weighted values are attained from table from Table 9 and the fire flow is obtained from Table 10.The following assumptions were made and indicated in Table D.2 the fire flow was attained from Table D.3.

Table D.2: Weighted factors for determining fire flow in unsprinklered buildings

Weighted factors values		
Type	Category	Value
Response time by fire department	On-site fire department (within 1.6km)	1
	On-site fire department (within 1.6km - 4.8km)	2
	On-site fire department (more than 4.8km away)	3
	Off-site fire department (within 3.2km)	2
	Off-site fire department (more than 3.2km away)	3
Type of construction	Type I	1
	Type II	2
	Type III	3
	Type IV	2
	Type V	4
Number of storeys	Single storey	1
	Double storey	2
Separation distance	> 18.3m	1
	6.4m - 18.3m	2
	< 6.1m	4
Building floor area	< 697 m2	1
	697 - 1394 m2	2
	1394 - 2323 m2	3
	2323 - 3716 m2	4
	> 3716	5
Firefighting access	< 55m	1
	55 - 70m	2
	>70m	4

$$Total\ weighted\ values = 3 + 1 + 1 + 2 + 1 + 1 = 9$$

Table D.3: Water demands for unsprinklered facilities

Total Weighted value						
Occupancy hazard classification	Fire flows (ℓ/min) at 137 kPa			Duration (min)		
	6 - 10	11 -15	>16	6 - 10	11 -15	>16
Light Hazard	2 810	4 260	5 680	60	90	120
Ordinary Group 1	3 785	5 680	7 570	90	120	150
Ordinary Group 2	5 680	8 520	11 360	90	120	150
Extra	9 465	14 195	18 930	150	195	240

$$Fire\ flow = 2\ 810\ \ell/min$$

The IFC method

According to IBC and the IFC method: $Fire\ flow\ =\ 1\ 000\ gpm$

FUS method

Assumption: Construction type: brick or masonry walls, combustible floors and interior

Construction factor coefficient, see paragraph 2.3.3.2.1. C = 1.0

Assumption: Occupancy type: Moderate combustibility

Occupancy modifications see Table 11, no change

Assumption: Construction type: brick or masonry walls, combustible floors and interior

Construction factor coefficient, see paragraph 2.3.3.2.1. C = 1.0

Assumption: Exposure modifications: one side - within 10m (+20%)

one side – within 20m (+10%)

$$F\ = 220x\ construction\ coefficent\ x\ \sqrt{Area}$$

$$F\ = 220\ x\ 1.0\ x\ \sqrt{222} = 3278\,\ell/\mathrm{min} +\ \{30\%\ (exposure)\}$$

$$F\ = 4261\ \ell/\mathrm{min}$$

Calculated fire flow

Table D.4: Calculated fire flows for one family residential building

Methods	IITRI inℓ/min (gpm)	ISU in ℓ/min (gpm)	NFA in ℓ/min (gpm)	ISO in ℓ/min (gpm)	UFC in ℓ/min (gpm)	IFC in ℓ/min (gpm)	FUS in ℓ/min (gpm)
Without Sprinklers	5 150 (1 360)	1 670 (440)	3 155 (833)	3 030 (800)	2 810 (1 804)	3 785 (1 000)	4261 (1 125)
With Sprinklers	N.A	N.A	N.A	1 515 (400)	950 (610)	1 892 (500)	2 622 (692)

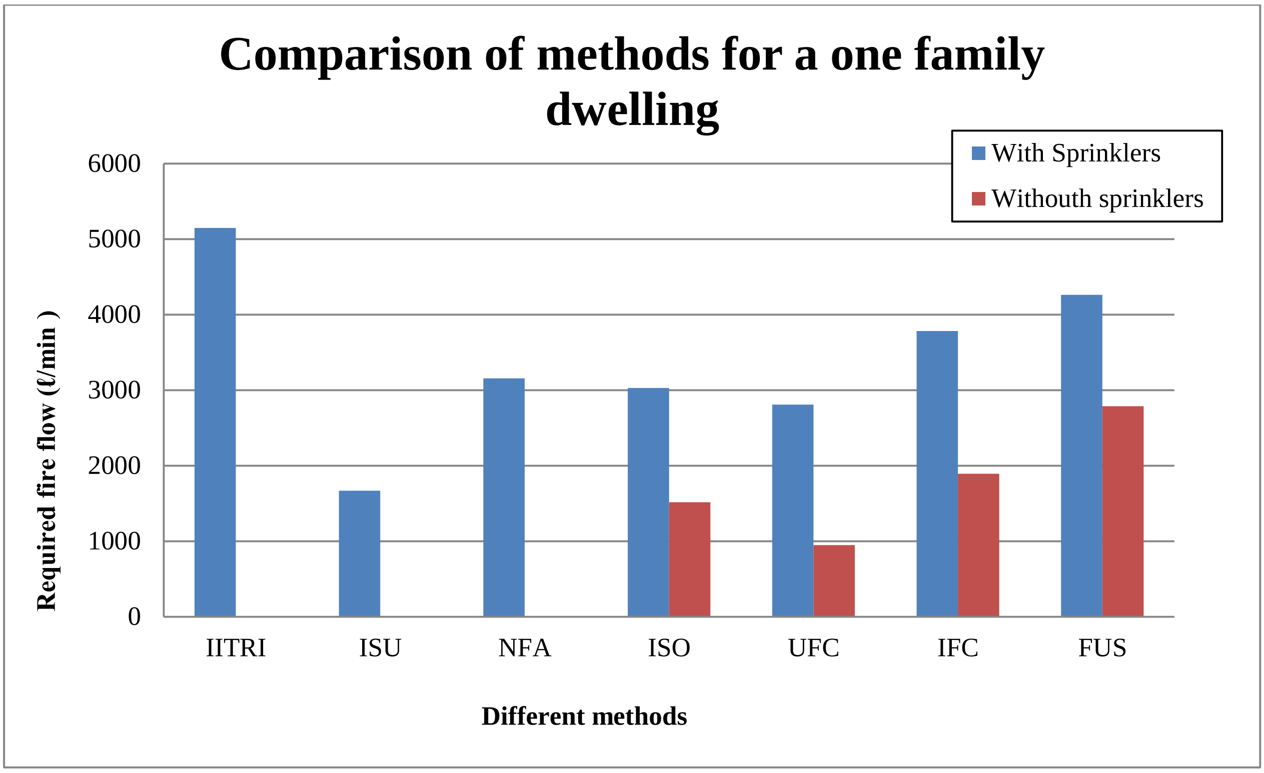


Figure D.1: Comparison of fire flow methods for one family dwelling

Apartment building

The following input parameters must be taken into account, see Table D.5.

Table D.5 Input parameters for apartment building

Example of calculations		
Input factors: Apartment building		
Description	Value	
Building type	Apartment	Units
Area	5 000	ft^2
Height	35	ft
Storeys	3	
Type of area	Heavy residential	
Exposures	2 (side and back)	
Exposure distance (side)	40	ft
Exposure distance (back)	50	ft
Construction type	Wood frame	
IFC construction type	VB	
UFC Construction types	V(000)	
Construction factor (F)*	1.5	
Exposure factor (X)*	0.85	
Communication factor (P)*	0.12	

* Values are obtained in same way as in previous example

IITRI Method

$$Fire\ Flow(gpm) = \{9\ x\ 10^{-5}\ x\ (Area[ft^2])^2\} + \{50\ x\ 10^{-2}\ x\ (Area[ft^2])\}$$

$$Fire\ Flow\ (gpm) = \{9\ x\ 10^{-5}\ x\ (15\ 000^*)^2\} + \{50\ x\ 10^{-2}\ x\ \ 15\ 000^*\}$$

$$*\ The\ area\ of\ all\ three\ storeys$$

$$Fire\ flow = 27\ 750\ gpm$$

ISU method

$$Fire\ Flow(gpm) = \ (Area[ft^2]\ x\ Height\ of\ building[ft]/100)$$

$$Fire\ Flow(gpm) = \ (5\ 000\ x\ 35/100)$$

$$Fire\ Flow = 1\ 750\ gpm$$

NFA method

Exposure is only taken into account if building is within 30ft

$$Flow(gpm) = [(Area\ [ft^2]) \div 3\ x\ Storeys] + [Exposures\ x\ (Area[ft^2]\ \div 3)\ x\ 0.25]$$

$$Flow(gpm) = [(5\ 000) \div 3\ x\ 3] + [0\ x\ (5\ 000\ \div 3)\ x\ 0.25]$$

$$Flow = 5\ 000\ gpm$$

The ISO method

Assumption: Type of construction – Wood Frame

Construction factor coefficient, see Table 2. F = 1.5

Assumption: Limited combustible Class (C – 2)

Occupancy factor coefficient, see paragraph 2.3.3.2.1. O = 0.85

Assumption: Exposure to back: Frame, metal or masonry with openings, distance - 50ft, height – 35 ft, unprotected openings

Exposure to side: Frame, metal or masonry with openings, distance - 40 ft, height – 35 ft, unprotected openings

Factor for exposure: 0.1

Assumption: Communications – open

Communication factor - 0

$$Fire\ Flow = (Construction\ factor)(Occupancy\ factor)[1.0 + (Exposure\ factor + Communication\ factor)]$$

Where: $Construction\ factor\ = 18\ x\ Construction\ coefficient\ x\ (Area)^{0.5}$

$$Construction\ factor\ = 18\ x\ 1.5\ x\ (5\ 000)^{0.5}$$

$$Construction\ factor\ = 1\ 909.2$$

$$Fire\ Flow = (1\,909.2)(0.85)[1.0 + (0.1 + 0)]$$

$$Fire\ Flow = 1\,785 \ \approx 1\,750 gpm\ (rounded\ to\ nearest\ 250\ gpm)$$

The UNFC method

The building does not have a sprinkler system. The weighted values are attained from Table 9 and the fire flow is obtained from Table 10.

The following assumptions were made and indicated in Table D.6the fire flow was attained from Table D.7.

Table D.6: Weighted factors for determining fire flow in unsprinklered buildings

Weighted factors values		
Type	Category	Value
Response time by fire department	On-site fire department (within 1.6km)	1
	On-site fire department (within 1.6km - 4.8km)	2
	On-site fire department (more than 4.8km away)	3
	Off-site fire department (within 3.2km)	2
	Off-site fire department (more than 3.2km away)	3
Type of construction	Type I	1
	Type II	2
	Type III	3
	Type IV	2
	Type V	4
Number of storeys	Single storey	1
	Double storey	2
Separation distance	> 18.3m	1
	6.4m - 18.3m	2
	< 6.1m	4
Building floor area	< 697 m2	1
	697 – 1 394 m2	2
	1 394 – 2 323 m2	3
	2 323 – 3 716 m2	4
	> 3716	5
Firefighting access	< 55m	1
	55 - 70m	2
	>70m	4

$$Total\ weighted\ values = 3 + 4 + 1 + 2 + 3 + 1 = 14$$

Table D.7: Water demands for unsprinklered facilities

Total Weighted value						
Occupancy hazard classification	Fire flows (ℓ/min) at 137 kPa			Duration (min)		
	6 - 10	11 -15	>16	6 - 10	11 -15	>16
Light Hazard	2 810	4 260	5680	60	90	120
Ordinary Group 1	3 785	5 680	7570	90	120	150
Ordinary Group 2	5 680	8 520	11 360	90	120	150
Extra	9 465	14 195	18 930	150	195	240

$$Fire\ flow = 4\ 260\ \ell/min$$

The IFC method

According to IBC and the IFC method: $Fire\ flow\ =\ 3\ 250\ gpm$

FUS method

Assumption: Construction type: Wood frames

Construction factor coefficient, see paragraph 2.3.3.2.1. C = 1.5

Assumption: Occupancy type: Limited combustibility

Occupancy modifications, see Table 11, -15%

Assumption: Exposure modifications: two sides - within 20m (+30%)

$$F\ = 220x\ construction\ coefficent\ x\ \sqrt{Area}$$

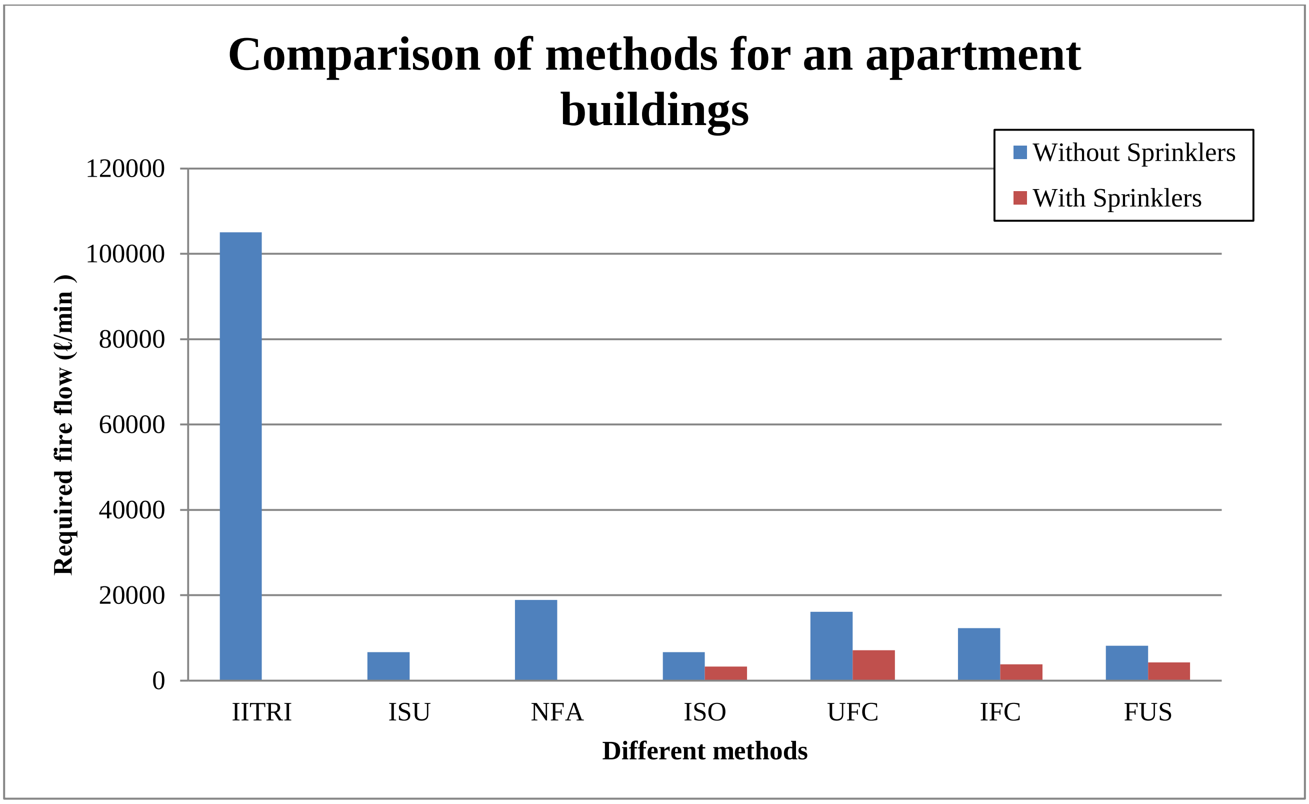
$$F\ = 220\ x\ 1.5\ x\ \sqrt{555} = 7\ 774.3 - \{15\%\ (occupancy)\} + \{30\%\ (exposure)\}$$

$$F\ = 8\ 162\ \ell/\mathrm{min}$$

Calculated fire flow

Table D.8: Calculated fire flows for one family residential building

Methods	IITRI in ℓ/min (gpm)	ISU in ℓ/min (gpm)	NFA in ℓ/min (gpm)	ISO inℓ/min (gpm)	UFC in ℓ/min (gpm)	IFC in ℓ/min (gpm)	FUS in ℓ/min (gpm)
Without Sprinklers	105 033 (27 750)	6 625 (1 750)	18 925 (5 000)	6 625 (1 750)	4 260 (1 125)	12 300 (3 250)	8 162 (2156)
With Sprinklers	N.A	N.A	N.A	3 310 (875)	1 900 (502)	3 785 (1 000)	4 275 (1 130)



*IITRI method is extremely high as result of all three storeys being taken into account for total area calculations

Figure D.2: Comparison of methods an apartment building

Commercial store and warehouse

The following input parameters must be taken into account, see Table D.9.

Table D.9: Input parameters for apartment building

Example of calculations		
Input factors: Commercial store and warehouse		
Description	Value	
Building type	Commercial store and warehouse	
Area	10 000	ft^2
Height	20	ft
Storeys	1	
Type of area	Commercial	
Exposures	2 (side and back)	
Exposure distance (side)	30	ft
Exposure distance (back)	65	ft
Construction type	Metal frame	
IFC construction type	IIB	
UFC Construction types	II(000)	
Construction factor (F)*	0.8	
Exposure factor (X)*	0.17	
Communication factor (P)*	0.12	

* Values are obtained in same way as in previous example

IITRI Method

$$Fire\ Flow(gpm) = \{-1.3\ x\ 10^{-5}\ x\ (Area[ft^2])^2\} + \{42\ x\ 10^{-2}\ x\ (Area[ft^2])\}$$

$$Fire\ Flow\ (gpm) = \{-1.3\ x\ 10^{-5}\ x\ (10\ 000)^2\} + \{42\ x\ 10^{-2}\ x\ \ 10\ 000\}$$

$$Fire\ flow = 2\ 900\ gpm$$

ISU method

$$Fire\ Flow(gpm) = (Area[ft^2]\ x\ Height\ of\ building[ft]/100)$$

$$Fire\ Flow(gpm) = (10\ 000\ x\ 20/100)$$

$$Fire\ Flow = 2\ 000\ gpm$$

NFA method

Exposure is only taken into account if building is within 30ft

$$Flow(gpm) = [(Area\ [ft^2]) \div 3\ x\ Storeys] + [Exposures\ x\ (Area[ft^2]\ \div 3)\ x\ 0.25]$$

$$Flow(gpm) = [(10\ 000) \div 3\ x\ 1] + [1\ x\ (10\ 000\ \div 3)\ x\ 0.25]$$

$$Flow = 4\ 166\ gpm$$

The ISO method

Assumption: Type of construction – Metal Frame

Construction factor coefficient, see Table 2. F = 0.8

Assumption: Limited combustible Class (C – 2)

Occupancy factor coefficient, see Table 4. O = 0.85

Assumption: Exposure to back: Frame, metal or masonry with openings, distance - 65ft, height – 20ft, unprotected openings

Exposure to side: Frame, metal or masonry with openings, distance - 30ft, height – 20ft, unprotected openings

Factor for exposure: 0.17

Assumption: Communications – open Communication factor - 0

$$Fire\ Flow = (Construction\ factor)(Occupancy\ factor)[1.0 + (Exposure\ factor + Communication\ factor)]$$

Where: $Construction\ factor\ = 18\ x\ Construction\ coefficient\ x\ (Area)^{0.5}$

$$Construction\ factor\ = 18\ x\ 0.8\ x\ (10\ 000)^{0.5}$$

$$Construction\ factor\ = 1\ 440$$

$$Fire\ Flow = (1\ 440)(0.85)[1.0 + (0.17 + 0)]$$

$$Fire\ Flow = 1\ 432\ \approx 1\ 500\ gpm(rounded\ to\ nearest\ 250\ gpm)$$

The UNFC method

The building does not have a sprinkler system. The weighted values are attained from Table 9 and the fire flow is obtained from Table 10.

The following assumptions were made and indicated in Table D.10 and the fire flow was attained from Table D.11.

Table D.10: Weighted factors for determining fire flow in unsprinklered buildings

Weighted factors values		
Type	Category	Value
Response time by fire department	On-site fire department (within 1.6km)	1
	On-site fire department (within 1.6km - 4.8km)	2
	On-site fire department (more than 4.8km away)	3
	Off-site fire department (within 3.2km)	2
	Off-site fire department (more than 3.2km away)	3
Type of construction	Type I	1
	Type II	2
	Type III	3
	Type IV	2
	Type V	4
Number of storeys	Single storey	1
	Double storey	2
Separation distance	> 18.3m	1
	6.4m - 18.3m	2
	< 6.1m	4
Building floor area	< 697 m2	1
	697 - 1394 m2	2
	1394 - 2323 m2	3
	2323 - 3716 m2	4
	> 3716	5
Firefighting access	< 55m	1
	55 - 70m	2
	>70m	4

$$Total\ weighted\ values = 3 + 2 + 1 + 2 + 2 + 1 = 10$$

Table D.11: Water demands for unsprinklered facilities

Total Weighted value						
Occupancy hazard classification	Fire flows (ℓ/min) at 137 kPa			Duration (min)		
	6 - 10	11 -15	>16	6 - 10	11 -15	>16
Light Hazard	2 810	4 260	5 680	60	90	120
Ordinary Group 1	3 785	5 680	7 570	90	120	150
Ordinary Group 2	5 680	8 520	11 360	90	120	150
Extra	9 465	14 195	18 930	150	195	240

$$Fire\ flow = 3\ 785\ \ell/min$$

The IFC method

According to IBC and the IFC method,

$$Fire\ flow\ \ =\ 1\ 750\ gpm$$

FUS method

Assumption: Construction type: unprotected metal structures

Construction factor coefficient, see paragraph 2.3.3.2.1. C = 0.8

Assumption: Occupancy type: Limited combustibility

Occupancy modifications, see Table 11, -15%

Assumption: Exposure modifications: one side - within 10m (+20%)

One side - within 30m (+10%)

$$F\ = 220x\ construction\ coefficent\ x\ \sqrt{Area}$$

$$F\ = 220\ x\ 0.8\ x\ \sqrt{1\ 110} = 5863 - \{15\%\ (occupancy)\} + \{30\%\ (exposure)\}$$

$$F\ = 7\ 615\ \ell/\text{min}$$

Calculated fire flow

Table D.12: Calculated fire flows for one family residential building

Methods	IITRI in ℓ/min (gpm)	ISU in ℓ/min (gpm)	NFA in ℓ/min (gpm)	ISO in ℓ/min (gpm)	UFC in ℓ/min (gpm)	IFC in ℓ/min (gpm)	FUS in ℓ/min (gpm)
Without Sprinklers	10 980 (2 900)	7 570 (2 000)	15 765 (4 166)	5 677 (1 500)	3 785 (1 000)	6 623 (1 750)	7 615 (2 012)
With Sprinklers	N.A	N.A	N.A	750	1 900 (502)	3 785 (1 000)	4 683 (1 240)

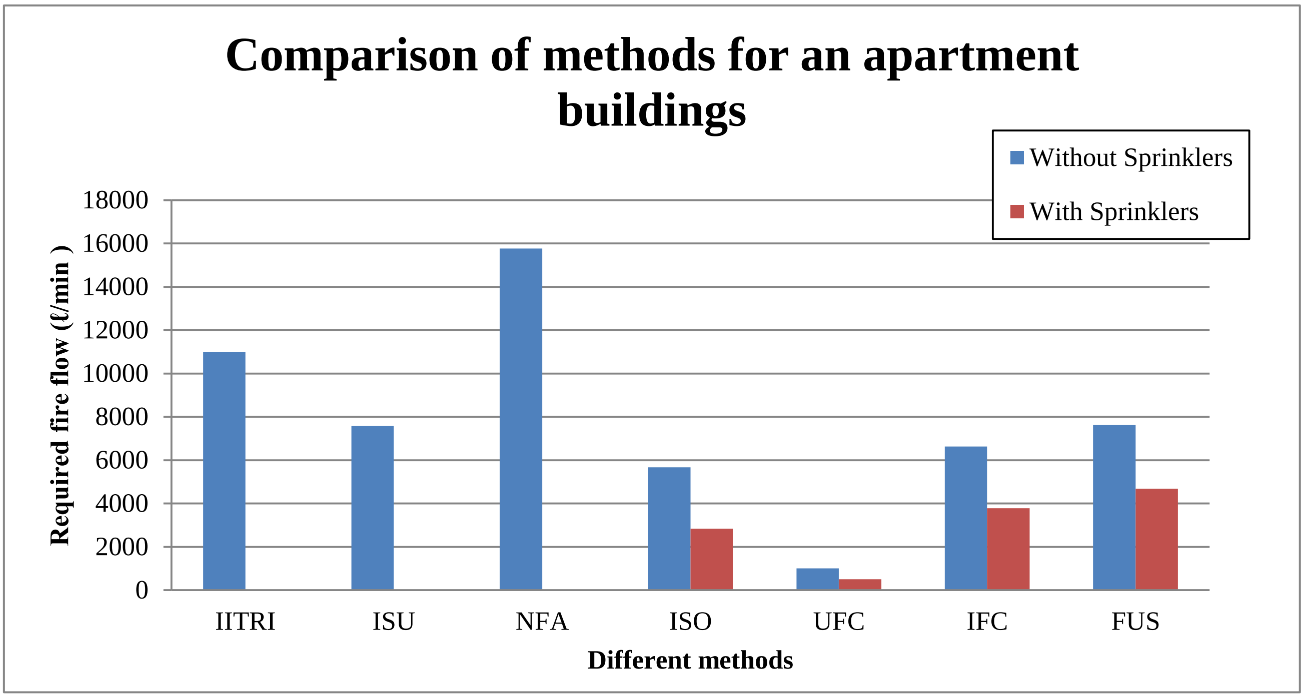


Figure D.3: Comparison of methods for Commercial Store and Warehouse

Appendix E: Summary of international fire codes

Country	Governing Requirements	Fire Flow Calculation Method	Description	Parameters considered	Legality and Liability	Design Considerations		
						Residual pressures	Duration (h)	Fire flow (l/min)
The United States of America	Fire codes adopted by local municipalities	The Insurance Services Office (ISO) method	Rate of fire flow necessary to extinguish fire in a building	type of construction, type of occupancy, type of exposure, communicaiton factors	Determined and enfroced by local authorities	140	1 - 4	1 900 - 45 200
		Illinois Institure of Technology Research Institute (IITRI) method	Based on data from actual fires	type of occupancy , area of fire				
		Iowa State University (ISU) method	Based on available oxygen and tempo of vaporization of water into steam	fire floor area, height of building				
		National Fire Academy (NFA) method	Method used for buildings with four or less floors	fire floor area potential exposures				
		National Fire Protection Agency (NFPA) method	NFPA suggests fire departmetns determine fire for all areas	occupancy hazard, construction type, total area				
		The Uniform Fire Code (UFC)	Sprinklered buildings: based on occupancy type Unsprinklered buildings: Calcultions based on different parameters	type of occupancy, type of construction, number of storeys, seperation distance, fire floor area, firefighting access				
		The International Fire Code (IFC)	Based on construction type classification by IBC	type of construction, fire floor area				
Canada	Provinces and regions adopt fire codes	The National Building Code (NBC)	Recommend that sufficient fire flow is provided for all buildings	N.A	Responsibility for buliding codes and fire prevention regulation rests with provinicial and territorial governments	N.A	N.A	1 900 - 45 400
		The Fire Underwriters Survey (FUS) method	Based on building characteristics	fire floor area,number of storeys , type of occupancy,exposures , sprinkler system				

Country	Governing Requirements	Fire Flow Calculation Method	Description	Parameters considered	Legality and Liability	Design Considerations		
						Residual pressures	Duration (h)	Fire flow (l/min)
Greece	National Standards	National standards for fire flow	Fire flow is assigned based on the classification of the type of building	type of building	N.A	420	0.5	700 - 7 200
France	National standards	National standards for fire flow	Fire flow determined according to fire risk areas, modifications by authorities	fire risk areas, number of storeys	Established by local authorites and fire departments. No legal liability	N.A	2	1 000
Germany	National Standards	National standards for fire flow	Standards are based on risk assigned to type of building and potential spread risk	type of building , fire spread risk	Based on agreement between fire departments and local authorities. No legal liability	140	2	760 - 3 200
United Kingdom	National Codes	National codes for fire flow	Fire flow is assigned based on the classification of the type of building	type of building	Private water companies responsible for providing water	N.A	N.A	450 - 4 500
Spain	National Standards	National standards for fire flow	Minimum fire flow of 1m3/min	fire risk area	N.A	110	2	1 000
Russia	Russian Standards	Russian standards (SNIP 19)	Based on very detailed fire risk categories for buildings, standards distinguish between trunk and distribution mains	type of building, area of fire, degree of fire protection	Municipalities are responsible for supplying adequate fire flow, no legal liability	110	3	600 - 9 000
Netherlands	National guidance documents (KIWA)	National documents (KIWA)	Fire flow determined according to fire risk areas	fire risk areas	Municipalities are responsible for supplying adequate fire flow	N.A	0.5	1 500 - 6 000
South Africa	"Red Book" SANS:2003	ISO methods, Standards	Fire flow determined according to fire risk areas	fire risk areas	Based on standards, no legal liability	"Red Book - 150 SANS:2003 - 200	0.5	Red Book: 350 - 12 000 SANS: 2003: 1 500 - 13000

APPENDIX F: Fire flow data for municipalities

Table F.1: Frequency of incidents per category for Municipality 1

Categories	Informal settlements	Automobile accidents	Structural fire (residential and industrial)	Veld, grass and refuse	Special services		Fire flows (litres)
Jan-10	3	1	4	12	-		80 050
Feb-10	2	-	2	-	-		27 800
Mar-10	3	2	3	3	-		48 450
Apr-10	2		3	-	-		58 500
May-10	2	1	4	-	-		105 200
Jun-10	1	-	2	-	-		14 350
Jul-10	1	-	4	-	-		58 000
Aug-10	1	-	3	-	-		40 100
Sep-10	-	-	3	-	-		115 500
Oct-10	2	-	1	-	-		5 000
Nov-10	1	1	2	-	-		5 600
Dec-10	4	1	3	1	-		56 500
Total	22	6	34	16	0	78	615 050
Percentage	28.2	7.7	43.6	20.5	0.0	100	

Table F.2: Frequency of incidents per category for Municipality 2

Categories	Informal settlements	Automobile accidents	Structural fire (residential and industrial)	Veld, grass and refuse	Special services		Fire flows (litres)
Jan-10	4	1	6	4	1		31 100
Feb-10	1	1	2	8	0		26 000
Mar-10	3	1	4	16	2		124 000
Apr-10	5	1	3	19	2		66 000
May-10	2	2	2	33	3		121 050
Jun-10	4	4	2	28	1		78 500
Jul-10	4	3	4	35	1		265 875
Aug-10	2	6	2	17	0		79 000
Sep-10	5	4	4	23	3		167 000
Oct-10	5	9	2	15	2		88 000
Nov-10	2	3	2	6	3		46 486
Dec-10	3	4	1	2	3		33 383
Total	40	39	34	206	21	340	1 126 394
Percentage	11.8	11.5	10.0	60.6	6.2	100	

Table F.3: Frequency of incidents per category for Municipality 3

Categories	Informal settlements	Automobile accidents	Structural fire (residential and industrial)	Veld, grass and refuse	Special services		Fire flows (litres)
Jan-10	1		1	13	1		90 250
Feb-10				12	1		92 600
Mar-10	1			8			47 400
Apr-10	2		1	3			97 00
May-10		1		6			47 700
Jun-10			1	7	1		64 800
Jul-10	2	1	1	2	1		13 000
Aug-10	2	3	1	6	2		55 100
Sep-10	4	3	1	6	4		165 400
Oct-10	3	3	2	5	4		168 350
Nov-10	1	2		9	4		44 440
Dec-10	3	4		7			39 000
Total	19	17	8	84	18	146	837 740
Percentage	13.0	11.6	5.5	57.5	12.3	100	