University of Canterbury Fire Engineering Conference
M. J. Gannon,
Christchurch, New Zealand, April 14, 2015

UNDERSTANDING THE IMPACT ON SPRINKLER SYSTEMS DUE TO REDUCED SUPPLY WATER PRESSURE

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Keywords: Sprinkler, Pressure, Reduction, Impact, Fire.

Abstract. *Sprinkler systems are designed and installed to control the spread of fire. They are designed based on information including the supply water flow and pressure availability to meet the hydraulic demand of the system design. One of the challenges facing sprinkler systems currently designed and installed in New Zealand is the trend of mains town supply water pressures being reduced by water supply companies to mitigate leaks in the water supply pipe work caused by ageing infrastructure and continued urban expansion; the main reason being ageing infrastructure. This presents the results from analysis related to the effectiveness of sprinklers on activation in a fire scenario and results from computer modelling of a sprinkler system to determine what the impact of reducing the pressure in a sprinkler system below the original design parameters is.*

1 INTRODUCTION

Sprinkler systems are designed and installed to control the spread of fire. They are designed based on information which includes the supply water flow and pressure availability to meet the hydraulic demand of the system design. Based on NZS4541 [1], water supplies to sprinkler systems are categorised into 4 different types of classes.

This paper discusses the results and analysis related to the effectiveness of sprinklers on activation in a fire scenario and results from computer modelled 'exemplar scenarios' where the supply water pressure is reduced. The sprinkler system modelled is an Ordinary Hazard 3 (OH3) sprinkler system, with an unboosted town's main water supply (Class C1 water supply). An OH3 sprinkler system was selected for the model in this project as it is considered to be indicative of the sprinkler system used for protection of buildings containing the type of commodity classes in warehouses [1].

This paper uses B-RISK fire modelling software. B-RISK is developed by BRANZ and it is a risk based Monte Carlo fire simulation software with the ability to simulate the activation of multiple sprinklers within an enclosure.

All hydraulic modelling in this paper has been undertaken using HYENA software which is developed by ACADS-BSG using the Hazen Williams formula and 2-D sprinkler layout configurations. The Hazen Williams formula is the formula used to undertake the hydraulic design calculations for the sprinkler systems in NZS454. In NZS4541, designs of OH3 sprinkler systems must operate at a minimum pressure of 50kPa.

One of the challenges facing sprinkler systems currently designed and installed in New Zealand is the trend of mains town supply water pressures being reduced by water supply companies to mitigate leaks in the water supply pipe work caused by ageing infrastructure and continued urban expansion; the main reason being ageing infrastructure [2], [3]. Figure 1 shows an example of a town's main water supply pressure-flow curve that was measured over a

4 year period [4] for an .ordinary hazard (OH) system as 1,200 l/min operating at a pressure of 240 kPa. As shown, in 2002 the system hydraulic demand was adequately provided for by the available town's main water supply at the time, however in 2006 the hydraulic demand of the system was greater than the available water supply. This is an example of the effects of reduced water pressure due to ageing infrastructure over time.

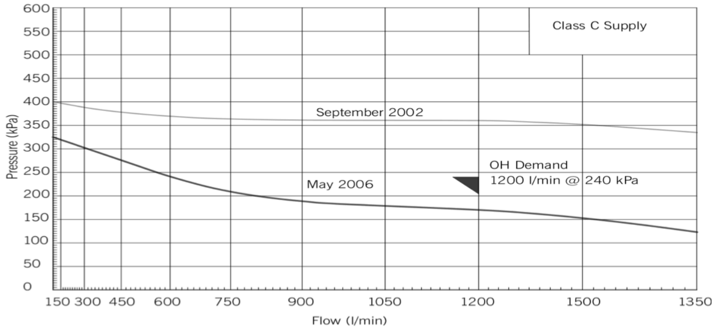

Figure 1: Reduced pressure in town's main water supply to sprinkler system measured over 4 years [4]

There is concern that reduced pressure in town's water supply over time will compromise the effectiveness of sprinkler systems and specifically those that are designed to operate with sole reliance on the town's main supply and without any means to boost the pressure. However, there is very little known as to how much or if at all reducing the water supply pressure has on sprinklers.

This paper presents the findings from analysis undertaken to help further understand what the impact of reducing the pressure in a sprinkler system below the original design parameters and identifies some of the key variables that can impact on the effects of reducing the supply water pressure to a town's main dependant sprinkler system.

1.1 Assumptions of the models and analysis

It was assumed that the reliability and effectiveness of the sprinkler activation within the B-RISK models was 100%. Previous research and guidance [2], [5], [6] would indicate that this assumption is optimistic and that the reliability of sprinklers can vary for different building types. However, the database set for which this same research [5] is based acknowledges that unreported fires or fires to small to activate sprinklers might distort the concluded reliability values.

It was also assumed that when sprinklers activate they do not impact neighbouring sprinklers by cooling them with water spray and hence extending the times for activation of successive sprinklers.

1.2 Limitations of the models and analysis

The design density values used in the B-RISK models where reduced to less than 4.2 mm/min which is outside the smallest design density of the B-RISK sprinkler suppression algorithm (based on Evans sprinkler fire suppression algorithm) [7], [8].

2 METHODOLOGY

2.1 Background

Circa 1990, sprinkler experiments focusing on the interaction of sprinkler systems and smoke vents were conducted by the UK Building Research Establishment at the Multifunctioneel Trainingcentrum in Ghent, Belgium. Subsequent to that work, Frank et al (2012) [9] used this experimental work to further understand the reliability of sprinklers by modelling sprinkler activation times. This paper builds on the further work by Frank (2013) [2] with consideration to sprinkler system configuration type, pipe diameter sizes and alternating the supply water pressure.

2.2 Sprinkler Supply Water Pressure-Flow Curve

2.2.1 Background

One of the key design parameters for any sprinkler system is the hydraulic demand requirement. This determines the minimum total flow rate (l/min) and pressure (kPa) in order for the system to meet the minimum performance specifications of NZS4541 or the standard to which the system was designed to. It also identifies if the water supply to the sprinkler system represented by the 'Hydraulic Flow Curve' is sufficient to meet the hydraulic demand of the system.

A qualitative hydraulic flow curve shown in Figure 2 is based a private discussion from the New Zealand sprinkler industry and shows the differences between the supply water pressure and flow relationship when the supply pressure is altered due to water supply network deterioration or increased draw-off due to town expansion.

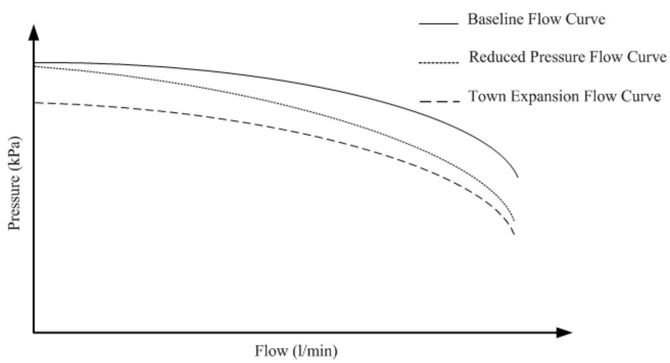

Figure 2: Sprinkler system Pressure versus Flow curves compared to base line flow curve

2.2.2 Simulation pressure-flow curve

The supply water flow curve for the two systems (the End and Loop type systems) was selected from sample data shown in Figure 3 which was obtained from 5 sprinkler biennial survey reports for installations located in Wellington (town's main sample 1 and sample 2), Christchurch (town's main sample 3 and sample 4) and Queenstown (town's main sample 5).

The pressure-flow curve selected for the simulations was town's main sample 2 (Wellington), this pressure-flow curve was selected to ensure that the sprinkler pressure requirements of NZS4541 to achieve no less than 50 kPa for each sprinkler within the area of operation were met in the baseline simulation (the initial simulation).

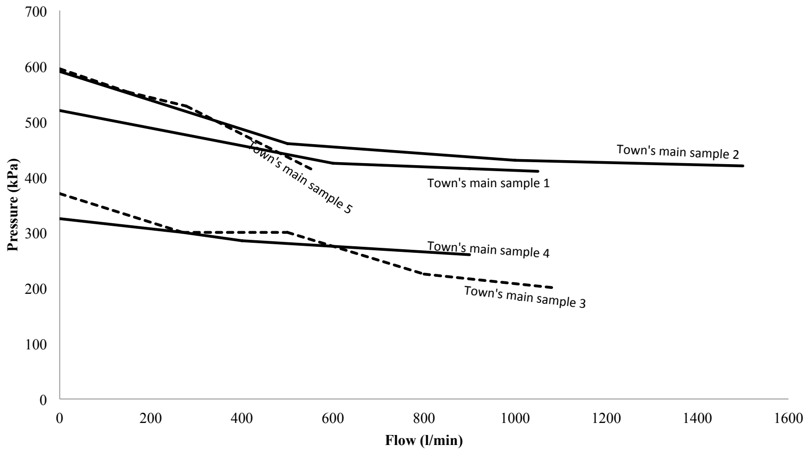

Figure 3: Graph of Flow/Pressure sample data from five New Zealand sites

To simulate a reduction in town main water pressure the ‘Town’s Main Sample 2’ Curve was reduced at intervals of 10% for each simulation run within HYENA and BRISK until a noticeable change in the sprinkler system performance to suppress the fire was observed form the output results. The supply water flow/pressure curves used for modelling are shown in Figure 4. The reduction in pressure is denoted by the 10% increment reductions.

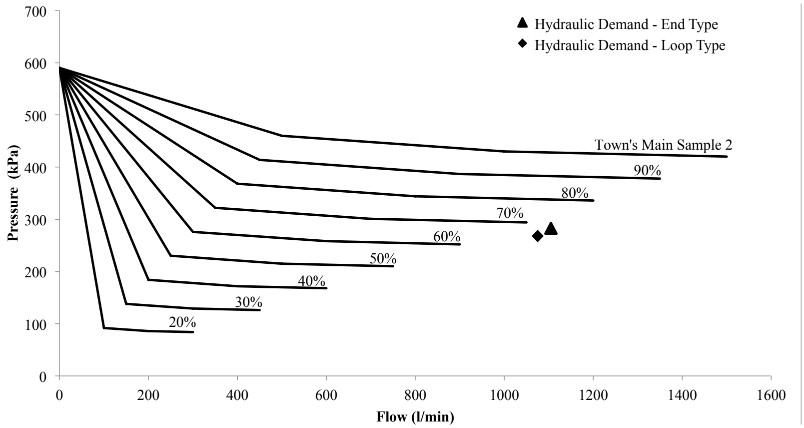

Figure 4: Graph of an incrementally reduced Flow/Pressure design curves used in the HYENA modelling component of the analysis.

2.3 Sprinkler system enclosure

Investigating a component of the work completed by Frank (2013) and also using the Ghent sprinkler test layout design as discussed in Frank’s research. The sprinkler set up and enclosure design comprised of a 55-sprinkler head grid spaced at 3.35 m by 2.45 m within an enclosure 27 m long by 18 m wide by 10 m high with an opening in the wall of 1 m wide by 2 m high (representative of a doorway which was always open). Each sprinkler head was positioned upright and 150 mm from the ceiling underside.

2.4 Sprinkler system selection

Three types of sprinkler layout systems were considered as representative of a sprinkler system installed in commercial buildings in New Zealand today. They are the end-type; loop-type used circa post1970's and an older version of the loop-type used circa pre 1970's in saw tooth roof profile buildings.

Based on the resources and timeframe available for the project, the end-type and loop-type (post circa 1970's) sprinkler systems were selected to be modelled in HYENA and BRISK using the same sprinkler grid layout similar to the Ghent sprinkler experiment as used by Frank (2013).

Figure 5 and Figure 6 shows the two alternate locations of the design fire (modelled separately) in the end and loop type sprinkler systems. The shaded zones denote the hydraulically most demanding area (A) and hydraulically least demanding area (B) of the sprinkler systems. These zones are referred to in NZS4541 as the area of operation, which comprise up to 18 sprinkler heads for an OH3 sprinkler system.

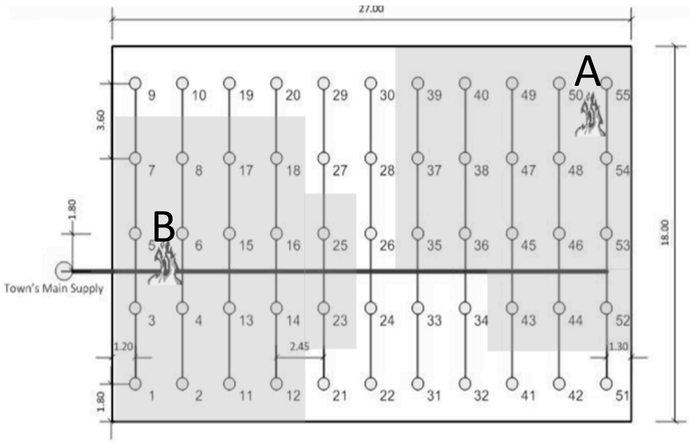

Figure 5: End-Type sprinkler system layout.

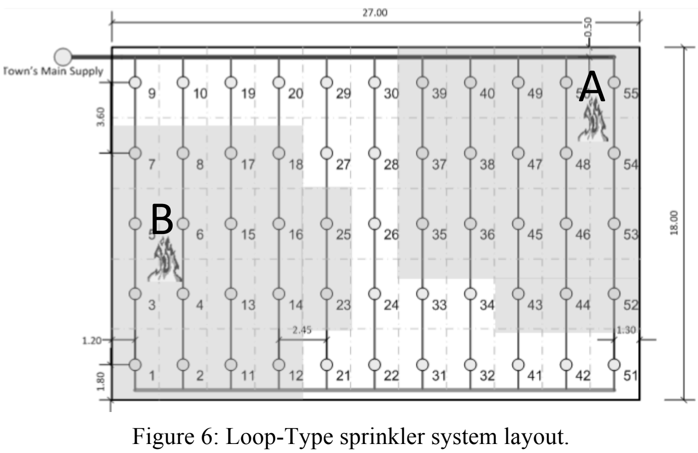

Figure 6: Loop-Type sprinkler system layout.

2.5 Areas of Operation for an OH3 sprinkler system

The areas of operation, as shown by the shaded regions in Figure 5 and Figure 6, comprise of 18 sprinklers per zone as defined by NZS4541. The guidance of NZS4541 requires that the hydraulic demand for all 18 heads operating simultaneously in either zone must be met by providing a minimum pressure of no less than 50 kPa to each sprinkler head during operation. In practice this can be met very easily for the activation of the first 4 sprinkler heads however initial hydraulic modelling and research [2] showed that this becomes more onerous to meet this requirement as successive sprinklers are activated. One of the assumptions made in the modelling was that all sprinkler heads, regardless of their activation time, would have the design density as determined by the hydraulic analyses for the activation of 18 sprinkler heads simultaneously. This conservative assumption was due to one of the limitations of BRISK in not having a 'dynamic sprinkler activation' function.

2.6 Sprinkler system pipe sizes

The pipe sizes used for the hydraulic modelling are shown in Table 1. Pipe sizes have been sized, with consideration to the town's main sample 2 pressure-flow curve used, to ensure that the baseline model meets the hydraulic requirements for the area of operation (18 sprinklers heads) in accordance with NZS4541.

The pipe material used in the hydraulic modelling was steel with a pipe material constant used in the Hazen Williams calculation, C = 120.

Table 1:Sprinkler system pipe sizes

Description	**Nominal Bore diameter (mm)**
Distribution Pipe	100
Distribution Pipe (loop system)	100
Range Pipe	50

2.7 Sprinkler head characteristics

The sprinkler head characteristics used in the models [10] was similar to that used in previous research [2]. It is recognised that the RTI of the sprinkler head used in previous research [2] was 200 $(m.s)^{1/2}$ and is slower than quick response sprinklers available today (50 $(m.s)^{1/2}$ and 135 $(m.s)^{1/2}$, based on B-RISK default values [7]). As such, altering the RTI for the models that are produced in this project may influence that the impact of reducing the supply water pressure from that of the designed pressure suppressing the fire earlier. At this stage, based on project time constraints, varying the RTI as one of the variables was considered further work following this project. Table 2 shows the comparison of previous research sprinkler head data and that used in this project.

Table 2: Sprinkler head characteristics used in the fire simulations

	Ghent Experiment*	This Project Model
Type	Wormald, Type A	Wormald, Type TY-FRB**
Thread Size	15mm	15mm
K-Factor	Unknown	8.0 $l/min.kPa^{-1/2}$
Operating Temperature	68°C	68°C
Location	150 mm below the ceiling	150 mm below the ceiling
Orientation	Upright	Upright

*Cited in previous research [2]

**Although this sprinkler head is a quick response sprinkler [10], the RTI is set at 200 $(m.s)^{1/2}$ for the B-RISK models.

2.8 Design Fire Selection

The design fire that was selected for use in the modelling was a fast growth 5.3 MW fire as it was considered, from the Society of Fire Protection Engineering (SFPE) handbook, to be representative of the fuel load for type for a commercial premises [11], [12]. Furthermore, the 5.3 MW design fire was initially confirmed to activate a number of sprinkler heads exceeding the 18 sprinklers within the area of operation. Frank et al work (2012) used a larger fire (up to 14MW).

2.9 Design Fire Location

The End-Type and Loop sprinkler configurations were modelled with the design fire located in one of two locations; Within the Hydraulically Most Demanding Area of Operation or the Hydraulically Least Demanding Area of Operation denoted by A and B, respectively, and as shown in Figure 5 and Figure 6.

2.10 Selection of Exemplar Scenarios

Once the baseline models of the End-Type and Loop-Type sprinkler configurations were modelled in HYENA and BRISK, the sprinklers were subjected to the different exemplar scenarios shown Table 3.

Table 3: Scenario modelling matrix

System Type	Fire Location*	%Model Water Supply
End	A	100% reducing in increments of 10% until a significant change in the BRISK outputs is observed
	B	
Loop	A	
	B	

*A= Hydraulically most demanding Area, B = Hydraulically least demanding area

The following B-RISK output results were used to determine the impact of reducing the supply water pressure to the sprinkler system by comparing the output data for different scenario models against the baseline model;

- Design Fire Heat Release Rate (kW) – If suppression of the design fire Heat Release Rate (HRR) was not achieved the system was considered to have been overcome and subsequently failed.
- Link Temperature (°C) or the Number of sprinkler heads activated – If the number of activated sprinkler heads exceeded the area of operation (18 sprinkler heads) the system was considered to have been overcome and subsequently failed.

3 RESULTS

3.1 Fire modelling results using BRISK

Figure 7 shows, from the BRISK model results, the impact on the sprinklers performance to suppress the design fire heat release rate when the water supply pressure was reduced in increments of 10% until a significant change or impairment was observed. As expected, as the availability of supply water pressure decreased, the ability of the sprinkler system to suppress the heat release rate (HRR) decreased.

In Figure 7, the ‘no suppression’ curve shows a sharp reduction just before 1800 seconds; this is due to the fire becoming ventilation controlled. If the width or height of the opening to the enclosure was increased, this effect would occur later, depending on the vent area increase.

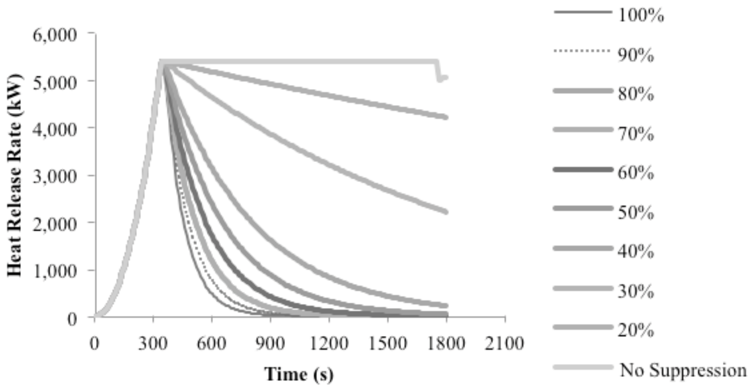

Figure 7: HRR rate results for End-Type configuration and the 5.3 MW design fire located in the Hydraulically Most Demanding Area of Operation.

Both system configurations (end and loop type) and both fire locations of the design fire (hydraulically most and least demanding areas) showed very similar results as shown in Figure 7.

Table 4 shows from the BRISK model results, the impact on the number of sprinkler heads activated in order to suppress the design fire heat release rate when the water supply pressure was reduced in increments of 10% until a significant change or impairment was observed. When the model was run with no suppression activated, the number of sprinklers activated within the Hydraulically least demanding area and hydraulically most demanding area differed by 6 sprinkler heads. This was due to the radial distance of the sprinkler heads relative to the fire. The were more sprinkler heads closer to the fire when the fire was located in the hydraulically least demanding area.

Table 4: Number of sprinkler head activated relative to reduction in water pressure

System Type	Zone	Percentage of Actual Supply Pressure	Percentage of System Hydraulic Demand Pressure	Number of Sprinklers Activated
End	Hydraulically Least Demanding	0%	0%	29
		20%	34%	21
		30% to 100%	45% to 148%	4
	Hydraulically Most Demanding	0%	0%	23
		20%	35%	17
		30%	45%	8
		40% to 100%	59% to 148%	4

Loop	Hydraulically Least Demanding	0%	0%	29
		20%	36%	21
		30%	47%	6
		40% to 100%	63% to 157%	4
	Hydraulically Most Demanding	0%	0%	23
		20%	37%	17
		30%	47%	6
		40% to 100%	63% to 157%	4

4 DISCUSSION

The town's main sample pressure-flow curve that was used meant that the water supply pressure exceeded the hydraulic demand pressure of the baseline model by approximately 57%.

The relationship between the percentage of actual supply pressure and the percentage of system hydraulic demand pressure will be unique to individual sprinkler systems and may have bigger or smaller differences to that shown in the model in this project.

So, for this particular model reducing the water supply curve from 100% by increments of 10% doesn't start to impact on the system hydraulic demand pressure of the end and loop sprinkler configurations until a decrease of 80% and 70%, respectively, of the supply water pressure occurs.

Furthermore, the point at which the modelled sprinkler systems are considered to be impaired (or have failed) is when the percentage of actual supply pressure is reduced to 20% of the original water supply pressure.

The performance of the sprinkler with respect to the HRR and number of sprinklers activated for the end and loop type configurations, as well as the fire being located in the hydraulically most demanding and hydraulically least demanding areas, was very similar.

It was also observed that the HRR graph outputs from BRISK as shown in Figure 7 to show a smooth line curve in the graphs. As the sprinkler heads activate and the design density changes (due to multiple heads activating) this type of curve would be expected to look more 'staggered' as result of the change in the fire area. This is considered one of limitations of the BRISK modelling software where it essentially combines all the sprinklers that activate into one 'equivalent' sprinkler and monitors the performance of the 'equivalent' sprinkler.

5 CONCLUSION

The conclusions drawn from the analysis of the modelled exemplar scenarios indicates that the system configuration and fire location in the hydraulically most demanding or least demanding areas of operation do show significant difference in the sprinklers system performance when the supply water pressure is reduced.

The initial ratio (or margin) of the actual supply pressure and the system hydraulic demand dictates the maximum percentage decrease in supply water pressure before the sprinkler system becomes impaired. Therefore based on the analysis contained in this report, a 'nominal' figure for which supply water pressure can be decreased before impairment occurs cannot be applied as a general rule for all sprinkler systems. Instead the analysis and results indicate that working towards developing a 'Framework' or 'Procedure' as well as developing the current analytical/modelling tools could improve being able to further understand the impact of reducing the water supply pressure to a sprinkler system based on the unique characteristics of the sprinkler system.

A development of the BRISK tool could be to incorporate a ‘dynamic sprinkler activation’ function into BRISK which could potentially improve the resolution of the model output results especially the HRR graphs by showing a staggered curve that would be expected from the successive activation of the sprinkler heads.

Although the models used in this analysis only varied the supply water pressure, system configuration and fire location; the model matrix as shown in Table 3 should be considered to include variables such as change in Response Time Index (RTI) of the sprinkler heads used in the model, alternative design fires (to include; different growth curves, different peak HRR value/size and adjust location relative to the sprinkler head i.e. reduce the radial distance of the nearest sprinkler head to the centre of the fire), alternative system configurations, alternative ceiling heights, sprinkler head spacing.

Suggested further work would include 1) Expanding the model matrix in Table 3 to include additional variables as previously discussed; 2) Expand the modelling analysis to work towards developing a Framework/Process; 3) To consider developing a BRISK to incorporate a ‘dynamic sprinkler activation’ function.

6 REFERENCES

[1] Standards New Zealand, "NZS4541:2013 Automatic fire sprinkler systems", NZ, 2013.

[2] Frank, K. M., "Fire Safety System Effectiveness for a Risk-Informed Design Tool", Department of Civil and Natural Resources Engineering, University of Canterbury, 2013 p 411.

[3] New Zealand Institute of Economic Research (NZIER), "Water management in New Zealand A road map for understanding water value", public discussion paper, p59, ISSN:1176-4384

[4] O'Brien, T, "Fire sprinklers need water", BUILD, February/March 2008, page 53 to 54, DOI: Unknown

[5] Koffel, W. E., "Reliability of automatic sprinkler systems", *Paper commissioned by the Alliance for Fire and Smoke Containment and Control, Inc.*, 2005, p8.

[6] British Standards Institution, "PD 7974-7:2003 - The application of fire safety engineering principles to fire safety design of buildings, Probabilistic Risk Assessment", 2003.

[7] Wade C., Baker G., Frank K., Robbins A., Harrison R., Spearpoint M. and Fleischmann C., "B-Risk User Guide and Technical Manual", BRANZ, 2013.

[8] Evans, D. E., "Sprinkler fire suppresion algorithim for HAZARD", *in proceedings of the 12th Joint Panel Meeting of the UJNR Panel on Fire Research and Safety*, Oct 27 - Nov 2.,1994, cited in [7].

[9] Frank, K., Spearpoint, M.J., Fleischmann, C.M. and Wade, C.A., "Modelling the activation of multiple sprinklers with a risk-informed design tool", *Hong Kong: 9th International Conference on Performance-Based Codes and Fire Safety Design*, 20-22 Jun 2012, p12.

[10] Tyco Fire Protection Products, "TF Series TY-FRB, 5.6 K-Factor, upright pendent and recessed pendent sprinklers quick response, standard coverage", February 2014, p4.

[11] New Zealand Centre for Advanced Engineering (CAENZ), "Fire Engineering design guide", p41-55, 2008.

[12] National Fire Protection Association (NFPA), "SFPE - Handbook of fire protection engineering", Third edition, pages 3-1 to 3-37, 2002.