Fire-fighting Flow-rate

Fire-fighting Water Flow-rates
SFPE (NZ) TP 2004/1 – UKWIR Consultation

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Part 1 – Review of Fire-fighting Water Requirements in the UK

1.1 The current national guidance[1] for the provision of water for fire-fighting offers limited information to fire authorities in estimating the *optimum water flow-rates* needed for fire control or final suppression in building fires. However, this guidance document does provide an engineering based methodology for *grading hydrant flows in line with the risks* they serve, although the source of this information is not clear. Both of these topics are now subject to review through a national consultation process.

1.2 In the UK, some guidance for estimating needed flow-rate exists in the Fire Service Manual[2] although the 'Iowa methodology' referred to therein is inappropriate for UK Fire Services. Such an approach cannot be used in this way as the associated fire-fighting tactics are extremely limited in scope and are rarely used. Therefore, there is no current guidance that may be used to estimate flow-rate requirements for building fires of variable fire load other than the basic data provided in the UK Water/LGA document referred to above.

1.3 The consultation process currently being undertaken by the UKWIR[3] is prompting response from fire authorities in relation to a range of issues surrounding water provisions for fire protection and fire-fighting, including that of needed fire-fighting flow-rates. This issue is tabled via proposals from Dorset Fire & Rescue Service, through a task briefing paper initiated by CFOA (Chief Fire Officers Association).

1.4 The Dorset proposals recommend ways that building fires may be dealt with, based on minimum needed fire-fighting water flow-rates. The proposals lay out guidelines whereby it is suggested that fires of a limited size may be controlled and suppressed without any need to supplement the fire appliance water tank.

1.5 The Dorset briefing paper makes further recommendations to review the existing provision of fire hydrants in order to scale the number of hydrants down in certain parts of the county as a means of diverting any financial savings to areas where water provisions are limited. This is now tabled for national consideration and response.

1.6 The Dorset proposals also make recommendations that a particular New Zealand methodology[4] for estimating fire-fighting water flow-rates be implemented nationally. This author would wish to point out that this methodology is based on the combination of two research projects into fire-fighting flow-rate requirements (TFR 1989: Grimwood & SFPE (NZ) TP 2004/1: Barnett) following many months' joint work between the two fire engineers.

1.7 This author believes the methodology provided in the New Zealand approach TP 2004/1 for estimating *minimum* fire-fighting water flow-rates offers the most accurate of all known methods. There have been many other similar engineered solutions around the world based solely on scientific theory, whilst very few have used empirical evidence of actual flow-rates used at real building fires upon which to base their final formulae. The solutions that are based solely on the physical attributes of water as a cooling agent generically provide gross over estimates in needed flow-rates.

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[1] The National Guidance Document for the Provision of Water for Fire-fighting 2007; Water UK; Local Government Association
[2] Fire Service Manual; Hydraulics, Pumps & Water Supplies 2001; HM Inspectorate of Fire Services
[3] UK Water Industry Research Limited
[4] SFPE (NZ) TP 2004/1; Barnett C

1.8 In the UK there have been just two research studies into fire-fighting flow-rates used at building fires in the past four decades. These are (1) this author's (Grimwood) 'TFR 1989' study of 100 serious working fires in London and (2) Sardqvist's (SWE) 1993 study of 307 fires in London. However, the latter research was mainly based on a large number of very small fires and the data inputs used for flow-rates, using SRDB codes, were flawed to the point that a gross over-estimate in needed flow-rate estimates resulted. As an example, flows in excess of 800 Litres/min were assumed for specific main line jets and yet, flows to this extreme from one jet were/are rarely (if ever) used offensively in London.

Part 2 – SFPE (NZ) TP 2004/1
Fire-fighting Water Flow-rate

2.1 Cliff Barnett was a renowned fire engineer in New Zealand and around the world until he passed away in 2008. He is a past president of the Society for Fire Protection Engineers (SFPE) (New Zealand) and his professional contribution to fire engineering is held in high esteem. His work is constantly referenced through hundreds of technical papers every year.

2.2 Cliff had worked for many years engineering fire-fighting water supply networks and water storage facilities throughout the world. In 2004 he was tasked to establish an engineered solution through the SFPE (NZ) for estimating needed flow-rates at building and enclosure fires in New Zealand.

2.3 He sourced over 700 pages of calculations he had used to develop a simple computer programme[5] for evaluating fire growth and flow-rate requirements to produce the draft document TP 2004/1. At this stage his work was solely limited to the physics associated with the mechanisms of fire suppression, coupled with the cooling attributes of water.

2.4 The flow factor originally used in the draft paper was 0.58 which was commonly referred to by fire engineers, based on established efficiency factors used at the time (0.33), for water as applied to structural fires. This suggested that 0.58 Litres/second was required to suppress each MW of heat output from a building or enclosure fire.

2.4 Based on theory alone and using the 0.58 flow factor, the flow charts produced in the draft document demonstrated a range of flow curves based around a flow-rate of 8.7 Litres/m^2 for 250 kW/m^2 of involved fire load.

2.5 In the early part of 2004 Cliff Barnett approached this author and requested a coordinated approach in combining the theoretical research from TP 2004/1 with the empirical research recorded through TFR 1989 (100 serious fires in London) in order to provide a more rounded methodology for estimating flow-rate needs with a far greater level of accuracy.

[5] FireSys Fire Engineering Tools; MacDonald Barnett Partners; Auckland NZ; 2004

Part 3 – TFR 1989 (Grimwood)
Fire-fighting Water Flow-rate

3.1 In 1989, as part of the London Fire Brigade Fire Investigation Team (North & Central Area), this author (Grimwood) undertook practical research into the water flow-rates used to suppress 100 serious working fires in London.

3.2 The 100 fires were all 'make-up' fires requiring the assistance of four pumps or more, involving a wide range of occupancies, mostly residential flats and houses but also including offices, restaurants, schools, factories, warehouse and industrial units where fire damage areas up to 1,720m^2. The research was validated by comparing needed flow-rates as used at a further twenty serious fires in offices, in the USA.

3.3 In all cases the author attended the fires (UK) whilst they were in progress and utilised hand calculations, based on recognised flow and pressure loss hydraulic formulae, to estimate the flow-rate used to control and suppress the fires. The 20 additional fires in the USA were reviewed using first-hand face to face interviews with fire officers, commanders and on-scene pump operators to again calculate, using hydraulic formulae, the flow-rates in use at each fire.

3.4 The objectives of the research were to record the actual fire-fighting water flow-rates used by firefighters to control and suppress structural fires. This entailed a generic range of fire stream applications that included 87% interior offensive and 13% exterior defensive operations, utilising a mix of solid-bore straight stream attacks and some constant flow fog patterns used mainly for operator protection, cooling hot surfaces or extinguishing flaming gaseous combustion.

3.5 A primary purpose of the research, which was published in 1990[6], was to develop an 'easy to use' fire-ground method (formula) that would enable fire-ground commanders to estimate water-flow requirements with a reasonable level of accuracy.

3.6 The research demonstrated flow-rates that clearly correlated with the extent of fire damage in buildings. Where the applied flow-rate was below 2 Litres/min/m^2 (83% of fires) then fire suppression was achieved after a struggle and well into the decay stages (burn-out) of fire development on 53% of occasions.

17% fires	3.75 LPM/m2	Effective Suppression
Critical Flow Rate 2 LPM/m2	**Critical Flow Rate 2 LPM/m2**	**Critical Flow Rate 2 LPM/m2**
21% Fires	1.87 LPM/m2	Difficult Suppression
21% Fires	1.34 LPM/m2	Late Stage Suppression
25% Fires	1.25 LPM/m2	Late Stage Suppression
16% Fires	0.62-1.25 LPM/m2	Late Stage Suppression

Grimwood's 100 fire TFR 1989 research into Fire-fighting Flow-rates (London Fire Brigade)

3.7 From this assessment it was considered impractical and potentially unsafe to extinguish fires during later stages on the fire development curve as compartment fires might well attack the structural elements during this phase and risk structural collapse. Therefore for this reason, flow-rates below 2 LPM/m^2 were seen as 'critical' and potentially unsafe for future use.

[6] Grimwood P.T; Fog Attack 1990; FMJ International Publications (Fire Magazine), UK

3.8 In fact, flow-rates around 3.75 LPM/m^2 were seen as a far safer and more practical option. By rounding the 3.75 to 4.0 LPM/m^2 a useful target flow-rate fire-ground formula was produced as;

F = A x 4

Where;
F = Flow required in Litres/minute
A = Area of floor fire involvement in square metres
4 = Flow factor based on an optimum target flow of 4.0 LPM/m^2

This formula became known as the Tactical Flow-rate (TFR 1989)

3.9 The fire-ground formula was well used and successfully peer reviewed at subsequent fires by fire officers in London and around the UK, during the following years. The formula does appear in some fire authorities' water strategy documents.

3.10 Although the flow of 4.0 LPM/m^2 provided a safe approach in most situations it was always proposed by the author that in situations where a high fire load existed; or where the compartment boundaries had been breached and structural elements were becoming involved; or where the fire development was influenced by increasing ventilation factors; then the applied flow-rate should be increased to 6.0 LPM/m^2 per 250 kW/m^2 of involved fire load under such circumstances.

F = A x 6

3.11 This factor became particularly relevant as lightweight construction forms became common, where structural elements may add a percentage to the involved fire load, or where energy efficient compartments with high levels of insulation may increase the risk of energy rich gases in under-ventilated fires suddenly becoming ventilated.

3.12 These rule of thumb fire-ground formulae offered fire officers a simple and accurate means of estimating needed flow-rate requirements for almost any given structural fire scene involving floor area or occupancies to 1,720 m^2. This remains the case despite the higher level of accuracy now provided in TP 2004/1.

3.13 As an example, a 25 x 40 metre single storey building is 25 percent alight (250m^2 of fire involvement). Therefore 250 x 6 = 1500 Litres/min flow requirement. This would suggest three main hose-lines or possibly four, depending on the branch capacities. Additional considerations might deploy back-up hose-lines to protect interior fire-fighting egress routes.

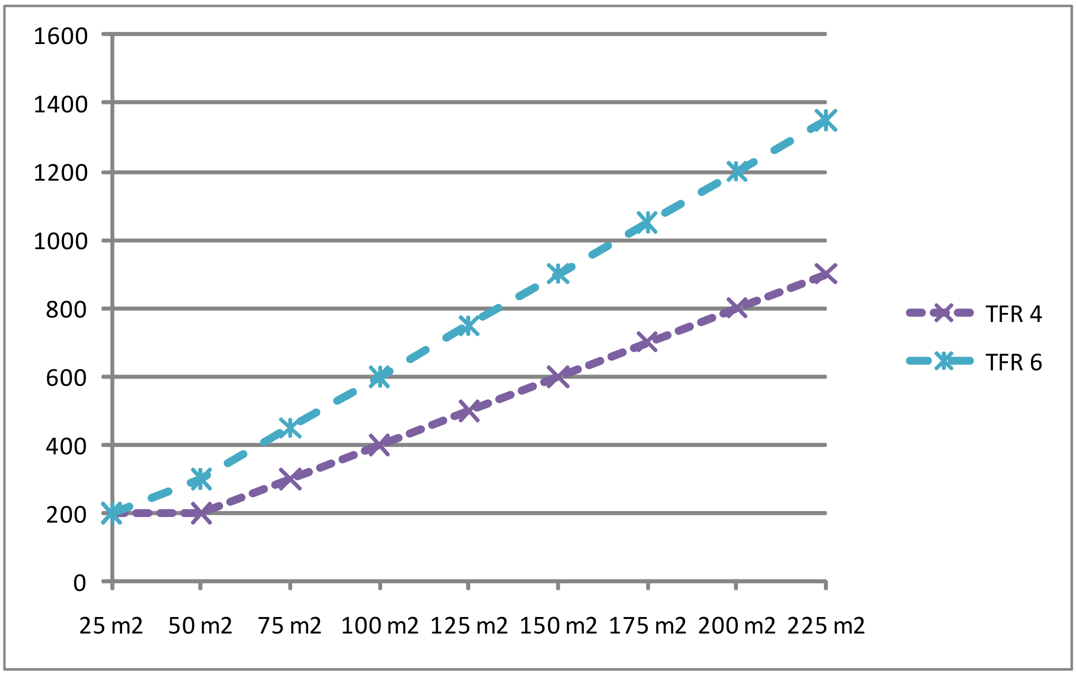

Chart 1: The recommended Tactical Flow-rates (TFR) for fire involvement to 225m2 in floor area (note the TFR 6 L/m2 higher flow-rate requirements where additional fire loads or ventilation increase the burning rate of a fire).

3.13 It was further established from the author's practical research[7] that a primary fire-fighting flow-rate below **200 Litres/min** may be detrimental to safe fire-fighting operations, even in small enclosures or rooms, where the potential for involved fire loads exceeded 150 MJ/m^2.

3.14 Because of this, several UK fire authorities, including London, are now evaluating the use of 22mm or 25mm high-pressure hose-reels, as 19mm hose-reel cannot flow ≥120-150 LPM. However, the use of a 200 LPM hose-reel still has limitations in anything more than a one or two room residential fire and transporting fire loads in heavy smoke will suggest that flow-rates should be higher still.

Part 4 – Combining TFR 1989 With SFPE TP 2004/1

4.1 The data from TFR 1989 was closely analysed by Cliff Barnett and it's insertion into TP 2004/1 caused an amendment to the flow-rate factor where a greater efficiency factor had been noted with flow-rates used at actual building fires in London. These 100 fires were all serious in nature with some fire involvements up to 1,720 m^2 in floor area.

4.2 A new efficiency factor of 0.50 was used to produce a flow factor of 0.38 which resulted in core flow rates of 5.7 Litres/min per 250 kW/m^2 of involved fire load for optimum suppression of enclosure fires. This was consistent with the A x 6 'rule of thumb' formula (6 Litres/min) suggested by TFR 1989.

[7] Grimwood P.T.; EuroFirefighter 2008; Jeremy Mills Publishing Limited, UK

4.3 The TP 2004/1 approach compares favourably with flow-rate derivations as follows;

- 6.0 LPM/m^2 – TFR 1989/1
- 6.3 LPM/m^2 – UK Water/LGA National Guidance for 76m^2 House
- 6.5 LPM/m^2 – BS 9990:2006 (derived) for 70m^2 Flat
- 6.25 LPM/m^2 – National Fire Academy (USA); plus back-up line of same

4.4 The flow efficiency factor of 0.50, derived from TFR 1989 data, was also carried over to the FireSys computer programme introduced by Barnett and incorporated into module '8e' of the Universal Fire Model.

4.5 This improvement in fire stream efficiency led to major reductions in the needed flow rates detailed through the modified flow charts in TP 2004/1.

4.6 However, it should be noted that the TP 2004/1 methodology is based on Fire Load Energy Densities (FLEDS) as detailed in established CIB W14 guidance. Whilst this source is commonly referenced globally throughout the fire engineering profession there are other codes and guidance that may conflict with this data. For example, Eurocode offers data that differs in respect of estimated fire loads for residential and office premises.

4.7 The TP 2004/1 FLEDS relate to fire loading – 400 (Low fire load such as dwellings, hotels, schools etc); 800 (Medium fire load such as offices, some shops, factories and department stores); and 1200 (High fire load occupancies such as Libraries, industrial processes, pharmacies etc). In Eurocode a modern dwelling might fall into the 800 (Medium) range.

4.8 This variance in fire load estimations should not be allowed to depreciate the value of the SFPE (NZ) TP 2004/1 methodology in calculating needed flow-rate for as any engineering analysis of occupancy fire loads becomes more accurate in future years, it will be a very simple process to update the FLEDS and 400-800-1200 references used by TP 2004/1.

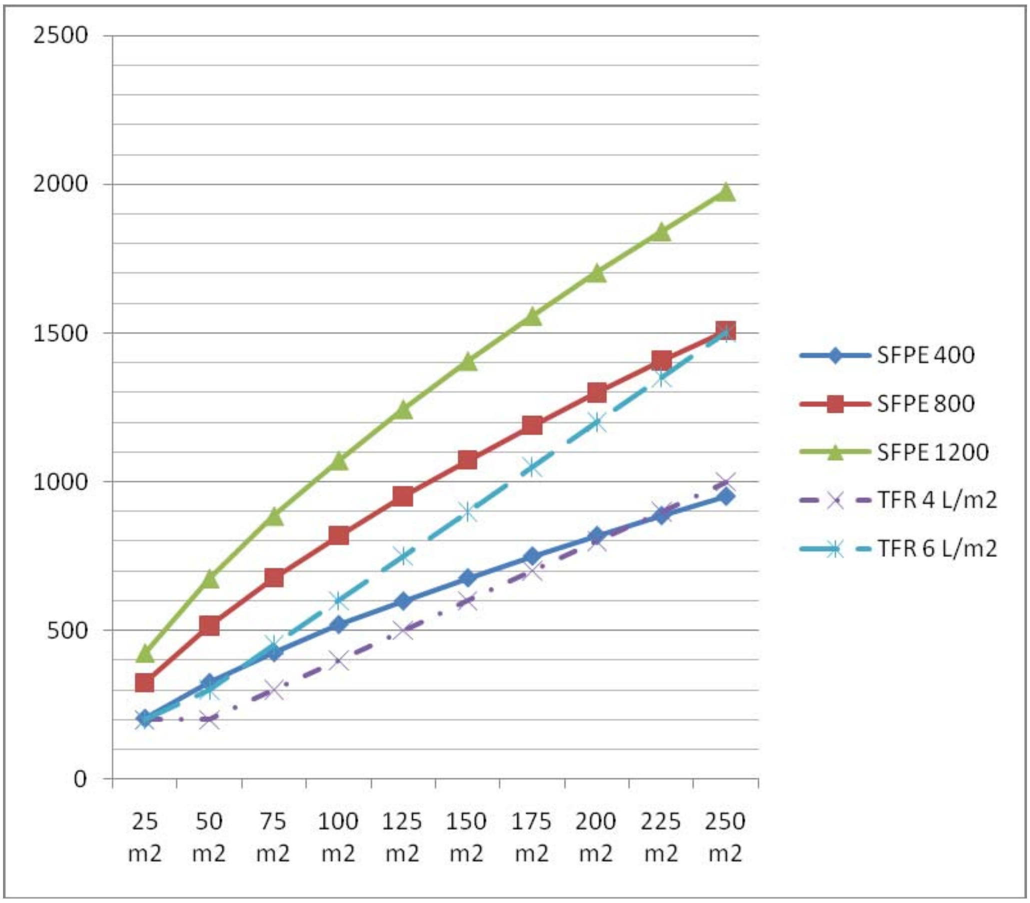

Chart 2: The flow-rate curves for SFPE (NZ) TP 2004/1 compared with the TFR fire-ground 'rule of thumb' formulae based on the 100 fire study by Grimwood. The theory curves of TP 2004/1 conform closely with the empirical curves of TFR 1989/1. The vertical axis displays LPM requirements for control and suppression of building and enclosure fires, prior to reaching the decay stages of the fire development curve.

	SFPE 400	SFPE 800	SFPE 1200	TFR 4 L/m2	TFR 6 L/m2
25 m2	205	325	426	200	200
50 m2	325	516	676	200	300
75 m2	426	677	886	300	450
100 m2	520	819	1073	400	600
125 m2	599	951	1245	500	750
150 m2	677	1073	1406	600	900
175 m2	750	1189	1558	700	1050
200 m2	819	1300	1703	800	1200
225 m2	886	1406	1842	900	1350
250 m2	951	1508	1976	1000	1500

Note: The flow charts in this document may differ slightly from those in TP 2004/1 which are rounded up with less precision at the L/s stage.

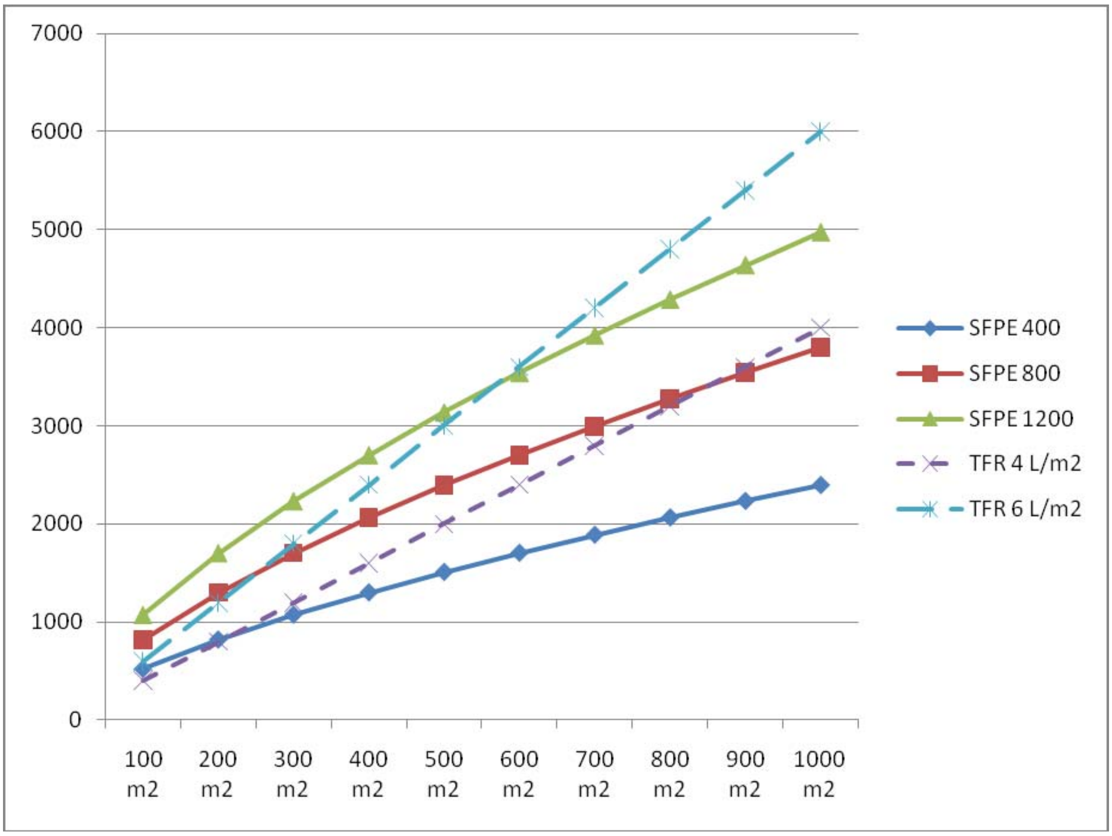

Chart 3: The flow-rate curves for SFPE (NZ) TP 2004/1 compared with the TFR fire-ground 'rule of thumb' formulae based on the 100 fire study by Grimwood for fires ranging between 100-1000m^2. It is seen that the TP 2004/1 methodology becomes more representative of larger fires where the fire load mass is reducing with time in a longer duration fire than those which may occur in smaller enclosures. The A x 6 fire-ground 'rule of thumb' becomes inaccurate beyond 300m^2 of fire involvement.

	SFPE 400	SFPE 800	SFPE 1200	TFR 4 L/m2	TFR 6 L/m2
100 m2	520	819	1073	400	600
200 m2	819	1300	1703	800	1200
300 m2	1073	1703	2231	1200	1800
400 m2	1300	2063	2702	1600	2400
500 m2	1508	2393	3135	2000	3000
600 m2	1703	2702	3540	2400	3600
700 m2	1887	2994	3922	2800	4200
800 m2	2063	3273	4287	3200	4800
900 m2	2231	3540	4637	3600	5400
1000 m2	2393	3797	4974	4000	6000

Note: The flow charts in this document may differ slightly from those in TP 2004/1 which are rounded up with less precision at the L/s stage.

Part 5 - Conclusions and Operational Considerations

1. The vast majority of fires are confined to the compartment or origin.

2. Most building fires only require a very small amount of water to achieve control and final suppression.

3. The features associated with modern lightweight construction and energy efficient compartments suggest that fire development may involve more of the gas-phase than in the past.

4. Whilst the rapid deployment of a hose-reel may achieve some rapid knockdown of fire in the gas-phase, it may struggle to prevent a fast developing fire situation where the fuel-phase fire continues to grow. It has been noted that where a fixed fire load exceeds 270 MJ/m^2, the deployment of a single 19mm hose-reel must remain questionable.

5. The flow concept of TP 2004/1 is based upon 50/50% suppression/exposures. However, this was a topic that was debated to some great extent by this author with Cliff Barnett during the final draft and it was mutually agreed that the term 'exposure' included the potential for a large percentage of the fire load to transport in smoke and ignite in surrounding areas of a structure, or to become involved in gas-phase combustion where exterior winds were forcing additional oxygen into the fire zone.

6. For example, where the area of involvement (fire) is just $20m^2$ but the area of involvement (heavy smoke) is $70m^2$ in a low fire load (office) then the overall potential for sudden energy release is around 17.5 MW. This situation would demand a minimum safe deployment of two hose-lines (attack and back-up) with a combined minimum flow-rate of around 900 LPM.

7. This author also undertook research in 2002 into the estimated average flow-rate used by firefighters at UK building fires. A series of flow tests with 58 UK brigades demonstrated that the average primary attack lay-flat hose-line was being pumped to just 290 Litres/minute.

8. There is a clear need to train firefighters in the need for effective flow-rate and also to equip them with branches, nozzles and effective hose sizes that are able to deliver the required flow-rate for any specific situation, within reasonably practical limits. Ideally, all fire appliances should be fitted with flow meters as pressure gauges provide extremely limited information on their own.

9. The concepts of *optimum fire-fighting flow-rate for enclosure fires* and *water provisions from the hydrant grid* are two separate issues and whilst they are inherently linked, they should not be confused. It is suggested that Appendix 5 of the current national guidance document should not be replaced with TP 2004/1 but rather that the current guidance should be retained until a detailed engineering analysis of water provisions is undertaken and a suitable means of grading the hydrant grid is developed.

10. Further, that TP 2004/1 should be added to any future revision of the national guidance document and that any engineered solution to grading water provisions be based around this methodology.

11. It is worth noting that there are a number of engineered grading systems of fire-fighting water provisions that also take account of the service delivery of a local fire authority, in their ability to effectively meet their requirements in applying water to fires at pre-determined capacities and time scales.

12. It may still be the case that the current national guidance for water provisions will remain effective to form the basis of water provision arrangements, in support of the TP 2004 flow-rate methodology.

13. Great care must be taken in addressing issues associated with the removal of fire hydrant stock; depletion of hydrant grids and mains; and any proposals to place greater reliance on water tank supplies as carried on fire appliances. These are matters that must again be closely analysed from an engineering and operational perspective.

14. Any belief that building fires ≤100m^2 are not in need of fire-fighting flow-rate assessment or that appliance water tank supplies are nearly always enough is strictly flawed. With Health & Safety concerns, the trend in the UK Fire Service is now for back-up hose-lines and higher flow-rates than previously used and we must address any planned reduction in hydrant stock with a critical eye.

Appendix One – TP 2004/1 Flow Rate Charts

Floor Area SqM	400 MJ/SqM	800 MJ/SqM	1200 MJ/SqM
	LPM	LPM	LPM
0	0	0	0
100	540	840	1080
200	840	1320	1680
300	1080	1680	2220
400	1320	2040	2700
500	1500	2400	3120
600	1680	2700	3540
800	2040	3300	4260
1000	2400	3780	4980
1200	2700	4260	5640
1400	3000	4740	6240
1600	3300	5220	6780
1800	3540	5640	7380
2000	3780	6000	7920
2200	4020	6420	8400
2400	4260	6780	8940
2600	4500	7200	9420
2800	4740	7560	9900
3000	4980	7920	10320

Table 2: Required flow-rates according to TP 2004/1

400 MJ/m2 Occupancies	800 MJ/m2 Occupancies	1200 MJ/m2 Occupancies
Bakery	Car Paint Shop	Candle Factory
Cafe	Carpet Store	Pharmacy
Sweet Shop	Exhibition Hall (Loaded)	New Stand
Car Accessories	Food Store	Library
Car Repair Shop	Loading Ramp & Goods	
Church	Offices	
Cinema	Paint & Varnish	
Doctors and Dentists	Rubber Goods	
Hairdressers	Railway Station	
Dwellings		
Hospital		
Hotel		
Restaurant		

Table 4: Typical 400/800/1200 MJ/m2 occupancies (source TP 2004/1 ref: CIB W14 data)