

# CHANGING STATE TECHNOLOGIES

## Urban Water Reticulation Booster Pumping Use Case

A Technical White Paper

The Engineering and Commercial Case for MPR Pump Technology over Traditional Urban Reticulation  
Pumping – Efficiently Meeting Firefighting Requirements

October 2026



## Executive Summary

Urban water reticulation networks in New Zealand must comply with SNZ PAS 4509, the Firefighting Water Supplies Code of Practice, which requires that any water main serving a firefighting point sustains a minimum residual pressure of 100 kPa with a flow of 12.5 to 25 litres per second — maintained without warning at the point of greatest hydraulic disadvantage in the network, which in an elevated supply zone is invariably the highest point.

For any booster station serving such a zone, this creates a threefold engineering conflict: sustain compliant pressure at the top of the zone under any fire flow demand; respond to that demand the instant it appears; and do so without over-pressurising the lower parts of the same network that the booster also serves. A conventional centrifugal pump resolves this conflict sub-optimally because it is constrained to a single, fixed head-flow (H-Q) curve — a pump sized to guarantee the minimum head at peak fire flow will over-pressurise the lower network at normal domestic flowrates, while a pump sized for domestic efficiency will fail to maintain the required head as fire flow rises. The standard industry response is to add plant: pressure-reducing valves, variable-speed drives held to a narrow control band, duty/assist/standby pump sets, and the SCADA infrastructure to coordinate them — each an additional failure point and maintenance obligation, all in service of what is, in engineering principle, a single control problem. A further structural weakness emerges at high fire flow: net positive suction head required rises steeply with flow in a centrifugal pump, and once the available NPSH can no longer satisfy what the pump demands, achievable head collapses from the published curve and cavitation risk increases at precisely the moment full performance is most needed.

Changing State Technologies' MPR™ (Multi-Phase Rotor) pump resolves this conflict directly, without much of the additional plant a conventional solution requires. Rather than being constrained to a fixed H-Q curve, the MPR™ operates on a pump plane — a broad two-dimensional operating envelope within which flow and head can be adjusted largely independently and efficiency tuned at each duty point. In the elevated-zone booster application, a single pressure sensor installed at the highest, most hydraulically disadvantaged point of the network feeds directly back to the MPR™ control PLC, which holds the required 100 kPa residual at that point continuously, tracking demand across the full range from overnight domestic minimum through to peak simultaneous fire flow, without leaving a preferred operating region, without over-pressurising the lower network, and reducing the requirement of a downstream pressure-reducing valve or separate fire-duty pump set. Because NPSH does not collapse the achievable operating envelope in the same way at high flow, the required head remains available through the upper end of the fire demand range without cavitation risk. The result is that a single MPR™ pump set unit (duty and stand-by) — controlled solely from the critical-point pressure sensor — could deliver SNZ PAS 4509 compliant performance across the complete domestic-to-fire-flow duty range, as a direct replacement for the conventional multi-pump, multi-valve booster configuration, at materially lower system complexity, capital cost, and maintenance burden.

A second reason to hold network pressure at the minimum compliant level is the cost surplus pressure imposes on the network itself. Leakage, bursts and pipe deterioration all rise with pressure: a 10% cut in average pressure typically removes 10–15% of leakage, and a 10% cut in maximum pressure roughly 10–27% of new bursts, although long-term field data show the burst benefit is largest in the first few years and partly rebounds afterwards. New Zealand networks lose a conservatively estimated 20–22% of treated water. Fire-flow requirements are why little of this benefit is captured, because a fixed setting must suit the worst-case fire draw; dynamic pressure control has delivered three to five times the leakage reduction in a fire-constrained network. The MPR™ pump provides that dynamic control at source, holding the minimum 100 kPa at the critical point and no more at peak fire demand (Section 5). **Note:** Benefits are network-specific and need confirming by modelling and pilot measurement.

## 1. Regulatory Context

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In New Zealand, the flow and pressure that a public water supply must sustain for firefighting purposes are governed principally by SNZ PAS 4509, the Firefighting Water Supplies Code of Practice. Equivalent performance-based standards apply throughout most of the developed world, and the operating challenge we describe in this use case is common to any reticulated network with elevated supply zones.

SNZ PAS 4509 requires that, in order to sustain adequate flow and pressure for firefighting, the pressure in the residential water main must not fall below 100kPa, with a residual flow of between 12.5 and 25 litres per second depending on the local risk classification — for example, a low-risk area of urban dwellings compared with a high-hazard commercial or industrial area. Network operators must demonstrate that this performance can be maintained at the point of greatest hydraulic disadvantage, typically the highest point of an elevated zone, under fire flow conditions that arrive with no warning and can vary considerably in magnitude and duration.

## 2. The Operating Challenge

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It is common practice, in cities and towns with elevated zones, to install booster pumps to maintain PAS 4509 compliant pressure and flow to those higher elevations. The underlying challenge is threefold:

- Sustain a compliant residual pressure at the highest, most hydraulically disadvantaged point of the zone, under any fire flow demand that might arise.
- Respond to that demand as it appears, since fire flow is intermittent, unpredictable in magnitude, and superimposed on normal domestic demand.
- Avoid over-pressurising the lower parts of the network while doing so, since the same booster station typically serves properties much closer to the source head.

This paper discusses below why a conventional centrifugal booster pump, or set of pumps, is not ideally suited to reconciling these three requirements simultaneously, and how the MPR™ pump from CST resolves the conflict directly. Section 5 then sets out why avoiding over-pressurisation matters well beyond fire code compliance.

## 3. Limitations of a Conventional Centrifugal Solution

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A conventional centrifugal pump is constrained to operate along a single, fixed H-Q curve. For any given flow, there is one head the pump can produce; the operator cannot select flow and head independently. This has direct consequences for a firefighting booster duty:

- Sizing conflict: a pump sized to deliver the required head at low, everyday domestic flow will not, on the same curve, deliver adequate head once a large fire flow is drawn — the operating point simply slides down the curve as flow increases. Conversely, a pump sized to guarantee head at peak fire flow will over-pressurise the network at normal domestic flow.
- Efficient operation is confined to a narrow preferred operating region around the best efficiency point (BEP). Any duty imposed by a fire event that falls outside that region is served inefficiently, and, in the more extreme cases, very poorly, or not at all.

- NPSH required (NPSH<sub>r</sub>) rises steeply with flow. Once available NPSH can no longer meet what the pump requires at high fire flow, the achievable head falls away from the published curve, increasing cavitation risk at precisely the moment full performance is needed most.
- Preventing over-pressurisation of the lower network typically requires additional plant — a pressure-reducing valve, a throttled control valve, or a variable-speed drive constrained to a narrow control band — each of which is an additional critical failure point, and an additional item of plant to maintain and calibrate.
- Meeting the full domestic-to-fire-flow duty range often requires duty/assist/standby pump sets and associated control philosophy, adding capital cost and operational complexity to what is, in principle, a single control problem: hold the pressure at one critical point on the network.

## 4. The MPR™ Solution

The MPR™ pump from CST is an ideal solution for this application. Rather than being constrained to a single characteristic curve, the MPR™ pump operates on a pump plane: a broad, two-dimensional Q-H operating envelope within which flow and head can be set largely independently, and efficiency can be tuned at each duty point.

In the elevated-zone booster scenario, a pressure sensor is installed at the highest, most hydraulically disadvantaged point of the network — one of the points PAS 4509 compliance is judged against. The MPR™ pump uses feedback from this sensor to hold the required residual pressure at that point directly, regardless of the flow demanded by fire appliances drawing on hydrants elsewhere in the zone. Because the pump is not confined to a fixed curve, it does not need to trade head for flow as fire demand rises and falls, and because NPSH does not collapse the achievable operating region in the same way as it does for a conventional centrifugal pump, this holds true through the higher end of the required fire flow range.

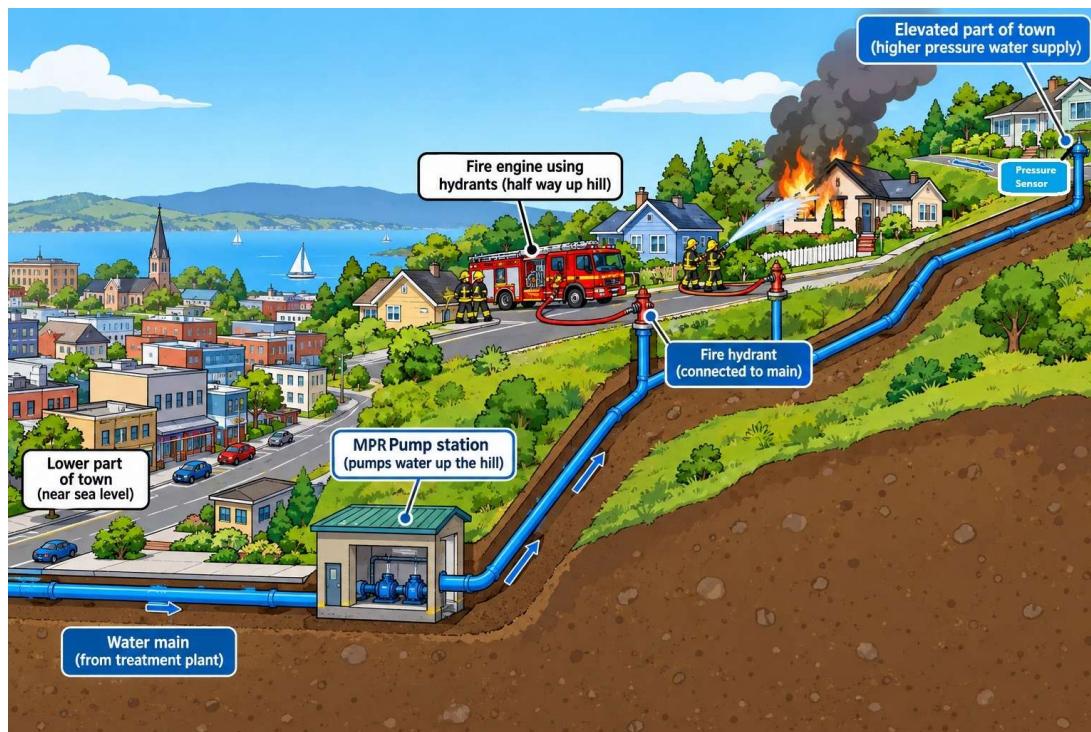


Figure 1: MPR™ booster pump station maintaining PAS 4509 compliant residual pressure at the elevated zone during a fire flow event.

The practical result is that one MPR™ set, controlled from the critical-point pressure sensor, can serve normal domestic demand efficiently and step seamlessly into a fire flow event, sustaining compliant pressure at the top of the zone without over-pressurising the lower parts of the network below the pump station. Downstream pressure-reducing valves on lower lying service connections may be avoided or reduced, as can throttled control valves. The need for varying pump sets to cater for fire-duty and normal demand is eliminated and replaced with a simplified Duty / Stand By MPR™ pump set configuration to reconcile the two duties — the same unit, tuned within its operating envelope, does both. Section 5 explains why holding pressure at the minimum compliant level also delivers leakage, asset-life and energy benefits beyond compliance.

## 5. Benefits of Reducing Pressure in Urban Reticulated Networks

Sections 2 to 4 treat over-pressurisation of the lower network as a problem to be avoided in order to meet PAS 4509 efficiently. The pressure-management literature treats it as a cost. Every metre of head that a booster delivers above what the network needs at its critical point is dissipated somewhere — through leakage and pipe-wall stress in the lower network, across pressure-reducing valves, or as wasted pumping energy — and three decades of international experience show that removing that surplus delivers measurable gains in leakage, pipe failures, asset life and energy use [24–33]. This section summarises those benefits, the New Zealand context in which they matter, and why fire-flow requirements have limited how much of the benefit utilities capture.

### 5.1 Lower leakage

Leak flow does not follow the simple square-root orifice law once the behaviour of real pipe defects is taken into account. Cracks, split joints and longitudinal splits widen as internal pressure rises, so leak flow varies with pressure raised to a leakage exponent,  $N_1$ :  $L_1/L_0 = (P_1/P_0)^{N_1}$ . This is the Fixed and Variable Area Discharges (FAVAD) concept [24, 25, 30].  $N_1$  typically lies between 0.5 and 1.5, with values of about 1.0–1.15 common in mixed metal and plastic networks and higher values reported for longitudinal splits in flexible plastic pipe. A 10% reduction in average pressure therefore removes roughly 10–15% of pressure-dependent leakage (Table 1).

A network fed at a fixed source pressure or set-point is at its highest pressure overnight, when demand and friction losses are lowest and little of the water being pushed through the pipes is being used. In one Turkish district metered area (DMA), real-time control that cut maximum inlet pressure from 70 m to 45 m reduced the recorded loss rate from 49% to 30% over a year, reduced the volume supplied by 12% for the same billed consumption, and cut recorded network failures from 39 to 23 [36]. A 2025 simulation study found that controlling pumping-station pressure alone reduced modelled leakage from 33% to 23% of supply, with pressure-reducing valves at boundary pipes bringing it to 17% [37].

### 5.2 Fewer bursts and lower repair costs

Burst frequency responds to pressure more strongly than leakage does, because bursts are driven by peak pressures and pressure transients acting on already weakened pipe rather than by average operating pressure. The empirical relationship is  $B_1/B_0 = (P_{1,max}/P_{0,max})^{N_2}$ , where  $N_2$  has been reported from about 0.5 to well above 3 and is highest in networks that already have high break rates [26–29]. The IWA Water Loss Specialist Group's analysis of 112 pressure-managed zones in 10 countries found mostly significant reductions in new burst frequency after moderate reductions in maximum pressure [28]. An  $N_2$  of 1.2 to 3.0 means that each 1% reduction in maximum pressure reduces bursts by 1.2% to 3.0% (Table 1). Recent New Zealand research using Auckland pipe-failure data notes that the burst reductions observed after

pressure management are often significantly larger than steady-state theory predicts, pointing to the role of transients and pressure cycling [34].

Long-term field evidence adds an important qualification. Ghasemi, van Zyl and Gong analysed six pressure-managed areas (nine material-specific datasets) in Barwon Water's Geelong network for 2006–2023. Every dataset showed an immediate drop in failure rate, forming a “shadow period” of 2.1–4.5 years, after which failure rates rebounded in eight of the nine datasets (statistically significant in five, all asbestos-cement). In eight of nine datasets, however, the long-term failure-rate slope stayed below the pre-pressure-management level, and Lambert's static burst relationship agreed well with the first phase but underestimated the later phase, particularly for cast-iron mains [40]. The authors conclude that pressure management is best evaluated as a time-dependent intervention rather than a permanent step change in failure rates [40].

### 5.3 Longer asset life and deferred capital expenditure

Lower peak pressure and less pressure cycling reduce the stress amplitude on corroded pipe walls and joints, delaying the point at which those assets reach failure. Lambert and co-workers describe this with a “straw that breaks the camel's back” model: a pipe fails when its residual strength is exceeded by the combination of static load, pressure cycling and an occasional surge, so trimming the peaks takes load off the assets most at risk [30]. The economic significance is that avoided bursts save renewal spend as well as repair cost. A Melbourne utility reported that 215 fewer mains bursts saved about \$0.37 million in repairs and about \$2.75 million in deferred renewals [30]. Asset-decay analyses link active pressure control directly to longer operating life [32]. For New Zealand water organisations facing substantial renewal needs, deferring capital works without compromising service is a benefit in its own right. The Geelong data point to a retained but smaller long-term benefit after an initial shadow period, so deferral benefits in a business case should be modelled as time-dependent rather than permanent [40].

### 5.4 Lower energy use and supply cost

Pumping power is proportional to flow multiplied by head [10]. Every metre of surplus head the booster delivers is paid for in electricity and, where a pressure-reducing valve then removes it, dissipated as heat across the valve. Reducing leakage also reduces the volume that must be sourced, treated, pumped and delivered in the first place; the Turkish study above supplied 12% less water with no change in service [36]. Where surplus pressure cannot be avoided, throttling combined with energy recovery can recover part of it [33], but the more direct route is not to generate the surplus.

### 5.5 The New Zealand context

The Water Services Authority — Taumata Arowai's Network Environmental Performance Report 2024/25, published on 27 July 2026, found that around one-third of councils report at least one drinking water network with very high leakage by international standards, and recommended that operators continue to reduce leakage and improve pressure management where appropriate [38]. Water networks lost about 57 million m<sup>3</sup> in 2022, roughly 20% of the water supplied [34], and an independent estimate puts national leakage at about 22% against around 5–6% in the Netherlands and Germany [39]. Pressure management aligns with this regulatory attention and with the sector's funding constraints because it reduces loss without new source, treatment or trunk capacity.

### 5.6 The fire-flow constraint — and why dynamic control matters

Network designers have been cautious about pressure reduction because fire-flow requirements set a floor beneath which pressure cannot fall at the critical point, and because a fixed-setting valve must be set for

the worst-case fire draw. Rokstad's study of Trondheim, Norway, whose fire-flow requirements of 20–50 L/s exceed the 12.5–25 L/s of PAS 4509, shows how large the effect is [35]. Average network pressure there was about 667 kPa (68 m) against a minimum service requirement of about 294 kPa (30 m), yet managers were reluctant to apply pressure management for fear of compromising fire-fighting capacity. When pressure reduction was optimised subject to the fire-flow constraint, fixed-outlet (static) reduction was found to be tightly limited, because the setting must preserve fire-flow capacity at every node. Flow-modulated (dynamic) regulation, which lowers pressure during normal demand and lets it rise when a fire flow is drawn, was typically three to five times as effective in reducing leakage and yielded about five times the net present value (NOK 106.5 million against NOK 21.2 million). About 85% of the predicted leakage reduction came from dynamically controlled zones [35].

The same study identifies, as an open engineering problem, robust control of pressure regulation under abrupt demand changes such as hydrant openings, without hydraulic instability [35]. That is the operating condition the MPR™ pump is designed around.

## 5.7 Implications for the MPR™ use case

Sections 3 and 4 present the MPR™ booster as a solution to a compliance problem. The evidence above indicates that it is also a route to capturing the pressure-management benefits that the fire-flow constraint has historically put out of reach:

- **Head set to what is needed.** The MPR™ is controlled from the pressure sensor at the critical point, so its head at any flow is the head required to hold the residual there and no more. There is no excess head for the lower network to absorb, reducing or removing the need for pressure-reducing valves to dissipate.
- **Dynamic by design.** The pump plane allows head to fall with demand overnight and rise only when a fire flow is drawn. This is the flow-modulated behaviour found to be the most effective in [35], delivered at source by the pump rather than by additional valves.
- **Fewer sources of transients.** Reducing the number of downstream pressure-reducing or throttling valve, and the staging of duty/assist pump sets, removes “valve hunting” and the step changes in flow and head that can generate the pressure transients associated with bursts [26–29]. Confirming the size of this effect is a pilot objective.
- **Energy matched to duty.** Head follows demand, and efficiency can be tuned at each duty point (Section 4), so the pump does not run away from its best efficiency point simply to deliver head the network does not need.
- **Compliance preserved.** The PAS 4509 residuals at the critical point remains the controlling constraint. Pressure is lowered everywhere else, not at the point where fire flow is minimum pressure is judged.

**Clarification:** The percentages quoted in this section are drawn from published pressure-management studies of networks generally, not from MPR™ installations. The benefit in any given zone depends on its leakage and burst exponents, pipe materials and condition, and the gap between the pressure now delivered and the minimum compliant pressure, and should be quantified for a candidate zone by hydraulic modelling before it is claimed. Because burst reductions appear to be largest in the first few years and partly rebound thereafter [40], any pilot should track burst records over several years, not months. A pilot installation with before-and-after night-flow, burst-record and energy measurements would provide the MPR™-specific evidence that published figures cannot.

| Pressure reduction | Leakage, N1 = 1.0 | Leakage, N1 = 1.5 | Bursts, N2 = 1.0 | Bursts, N2 = 2.0 | Bursts, N2 = 3.0 |
|--------------------|-------------------|-------------------|------------------|------------------|------------------|
| 10%                | 10.0%             | 14.6%             | 10.0%            | 19.0%            | 27.1%            |
| 20%                | 20.0%             | 28.4%             | 20.0%            | 36.0%            | 48.8%            |

Table 1: Illustrative reduction in leakage (average pressure) and new bursts (maximum pressure), calculated as  $1 - (1 - r)^{N1}$  from the power-law relationships in [24–28]. Reported N1 is typically 0.5–1.5 and reported N2 spans 0.5 to above 3, so actual results are site-specific.

| Benefit                       | Mechanism                                                                                  | Reported benchmark                                                                                                                                                                                                                                                                                               | Contribution of the MPR™ pump                                                                      |
|-------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Leakage volume                | Leak area and flow rise with pressure (FAVAD): $L \propto p^{N1}$                          | 10% lower average pressure $\approx$ 10–15% less leakage; loss rate 49% $\rightarrow$ 30% in a Turkish DMA [36]; modelled 33% $\rightarrow$ 23% from pump-station pressure control alone [37]                                                                                                                    | Head held at the required critical-point residual at every flow; no fixed high set-point overnight |
| Burst frequency               | Peak pressures and transients act on weakened pipe: $B \propto P_{max}^{N2}$               | 10% lower maximum pressure $\approx$ 10–27% fewer new bursts for N2 = 1–3, more where N2 is higher [26–29]; failures 39 $\rightarrow$ 23 in a Turkish DMA [36]; long-term, a 2.1–4.5-year shadow period followed by a partial rebound that stayed below the pre-management level in 8 of 9 Geelong datasets [40] | Lower peaks; no valve hunting or pump-staging steps (to be confirmed in pilot)                     |
| Asset life and renewals       | Less cyclic fatigue and joint movement delays failure                                      | 215 fewer mains bursts in a Melbourne utility saved $\sim$ \$0.37M in repairs and $\sim$ \$2.75M in deferred renewals [30]                                                                                                                                                                                       | Continuously matched pressure reduces stress on lower-zone pipes                                   |
| Energy and supply cost        | Pump power $\propto$ flow $\times$ head; less leakage means less water sourced and treated | 12% less water supplied for the same billed consumption [36]                                                                                                                                                                                                                                                     | Head matched to duty; efficiency tuned at each duty point; no dissipation across a valve           |
| Fire-flow compliance retained | Static reduction is capped by the worst-case fire draw; dynamic reduction is not           | Flow-modulated control 3–5 $\times$ as effective as fixed-outlet in a fire-constrained network [35]                                                                                                                                                                                                              | One unit tracks the critical-point pressure from overnight minimum to peak fire flow               |

Table 2: Benefits of reducing pressure in urban reticulated networks and the contribution of the MPR™ pump.

## 6. Comparative Summary Against PAS 4509 Requirements

| PAS 4509 requirement                                          | Conventional centrifugal booster pump                                             | MPR™ pump (Changing State)                                                      |
|---------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Sustain $\geq 100$ kPa residual pressure at the highest point | Fixed H-Q curve means head falls as fire flow rises; a single unit sized for peak | Operates across a broad Q-H operating envelope rather than a single curve; head |

| PAS 4509 requirement                                                                                                                     | Conventional centrifugal booster pump                                                                                                                                                                           | MPR™ pump (Changing State)                                                                                                                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| of the elevated zone under any fire flow demand                                                                                          | demand will over-deliver head at low flow, and under-deliver at the top of a large fire flow event once past its duty point                                                                                     | at the critical point is held to the pressure sensor set-point at any flow within the envelope                                                                                                                                       |
| Deliver 12.5-25 L/s residual flow depending on risk classification, without warning                                                      | Response to a sudden hydrant draw is a shift along the fixed curve; if the new duty point falls outside the preferred operating region, efficiency and pressure control both degrade                            | Duty point is tunable in real time; flow and head can move independently within the envelope, so the pump tracks the new demand without leaving a preferred operating region                                                         |
| Avoid over-pressurising the lower parts of the network while boosting the elevated zone                                                  | Typically requires a pressure-reducing valve, throttled discharge valve, or a variable-speed drive tuned to a narrow band to prevent over-pressure downstream; each adds a failure point and maintenance burden | Head is set directly to the required residual pressure at the control point; reliance on downstream throttling or PRVs can be reduced or eliminated to prevent over-pressurisation of the lower zone (to be confirmed by modelling). |
| Maintain adequate NPSH margin across the full range of flows demanded during a fire event, including multiple simultaneous hydrant draws | NPSHr rises sharply with flow; once available NPSH falls short at high flow, published head is not achievable and cavitation risk increases at the worst possible moment                                        | NPSH does not collapse the achievable operating region in the same way, so the required head is available through the higher end of the fire flow range without cavitation risk                                                      |
| Return to efficient, low-cost duty once normal (non-fire) demand resumes                                                                 | Best efficiency point (BEP) is fixed; operating away from BEP for day-to-day demand after being sized for fire flow wastes energy                                                                               | Efficiency can be tuned at each duty point, so day-to-day domestic demand and peak fire demand can both be served efficiently from the same unit                                                                                     |
| Provide firefighting flow without additional standby units or complex control philosophy                                                 | Achieving both duty ranges often requires duty/assist/standby pump sets, VSDs, and PRV stations working together                                                                                                | A single MPR™ pump set, controlled from the pressure sensor at the critical point, can cover the full domestic-to-fire-flow range with less complexity                                                                               |
| Minimise excess pressure in the lower network (not a PAS 4509 requirement, but a driver of leakage, burst and energy cost — Section 5)   | A fixed set-point or narrow-band control tends to hold the lower network at fire-duty pressure through low-demand periods; surplus head is dissipated across a valve or lost through leakage and pipe stress    | Head follows the critical-point sensor: lower pressure through most of the day, rising only when fire flow is drawn; less or no surplus head to dissipate                                                                            |

## 7. Conclusion

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Meeting SNZ PAS 4509 at an elevated zone is fundamentally a problem of sustaining a compliant residual pressure at one critical point under an unpredictable and highly variable flow demand, without over-pressurising the rest of the network. A conventional centrifugal pump, constrained to a single H-Q curve and a narrow efficient operating region, resolves this only by adding plant: pressure-reducing valves, variable-speed drives held to a narrow band, or duty/assist/standby pump sets sized around the extremes of the demand range.

The MPR™ pump resolves the same problem directly. Because it operates on a pump plane rather than a pump curve, and because NPSH does not constrain the achievable operating envelope in the same way, a single MPR™ unit can sustain the required residual pressure at the critical point across the full range of domestic and fire flow demand, efficiently, and without much of the additional plant a conventional solution would require. This makes the MPR™ pump a well-matched, lower-complexity solution for elevated-zone booster pumping in urban water reticulation networks that must demonstrate PAS 4509 compliance.

Beyond compliance, holding pressure at the minimum level required has a value of its own. Published pressure-management studies show that lower operating pressure reduces leakage, burst frequency and the rate of asset consumption, and lowers pumping energy and supply cost, with the burst benefit best treated as time-dependent (Section 5). Fire-flow requirements have historically limited how much of that benefit utilities can capture, because a fixed pressure setting must be high enough for the worst-case fire draw. Because the MPR™ pump follows the pressure at the critical point, it lowers pressure through normal demand and raises it only when a fire flow is drawn. It therefore addresses the compliance problem and the whole-of-life cost of surplus pressure with the same unit, subject to confirmation of the MPR™-specific benefit through hydraulic modelling and pilot measurement.

## 8. References and Citations

Note: SNZ PAS 4509:2008 is currently under review. A draft revision (DZ PAS 4509) was released for public consultation by Standards New Zealand in late 2024, following the mandate in the Fire and Emergency New Zealand Act 2017 for a new code aligned to Fire and Emergency New Zealand's operational requirements. Until the revised PAS 4509 is gazetted, SNZ PAS 4509:2008 continues to apply under section 33 of the Fire and Emergency New Zealand Act 2017. Reference [1] below is the current operative standard; reference [3] notes the revision in progress.

### 1. Regulatory Standards and Codes of Practice

- [1] Standards New Zealand / New Zealand Fire Service. (2008). SNZ PAS 4509:2008 — New Zealand Fire Service Firefighting Water Supplies Code of Practice. Wellington: Standards New Zealand. [Current operative code. Sets the  $\geq 100$  kPa residual pressure and 12.5–25 L/s flow requirements cited in Section 1 of the use case.] Available (free download, FENZ): <https://www.fireandemergency.nz/assets/Documents/Files/N5a-SNZPAS-4509-2008-NZFS-Firefighting-water-supplies-Code-of-practice.pdf>
- [2] Fire and Emergency New Zealand Act 2017 (No. 17), section 33 — Previously approved code of practice for firefighting water supplies saved. [Confirms SNZ PAS 4509:2008 continues to apply until a new code is approved under section 72.] New Zealand Legislation. Available: <https://www.legislation.govt.nz/act/public/2017/0017/latest/DLM7073062.html>
- [3] Standards New Zealand. (2024, September). Updated Firefighting Water Supplies Code of Practice to be Developed. [News release announcing the review of SNZ PAS 4509:2008 and development of a replacement code under the Fire and Emergency New Zealand Act 2017 mandate.] Available: <https://www.standards.govt.nz/news-and-updates/updated-firefighting-water-supplies-code-of-practice-to-be-developed>
- [4] Standards New Zealand / Fire and Emergency New Zealand. (2024). DZ PAS 4509 — Firefighting Water Supplies: Code of Practice (Draft for Public Consultation). [Draft revision of SNZ PAS 4509:2008, open for submission. Aligns water supply resources with FENZ operational requirements.] Consultation portal: <https://consultations.standards.govt.nz/draft-standards/pas-nzs4509-public-consultation/>
- [5] Standards New Zealand. (2022). NZS 4510:2022 — Fire Hydrant Systems. Wellington: Standards New Zealand. [Sets minimum technical and performance requirements for fire hydrant systems in buildings; references SNZ PAS 4509:2008 for external water supply compliance. Supersedes NZS 4510:2008.] Available: <https://www.standards.govt.nz/shop/nzs-45102022>
- [6] Local Government Act 2002, section 130 — Water supply. [Establishes the legal basis under which water supply authorities are required to provide water supply infrastructure, including firefighting supply in urban fire districts, as referenced in SNZ PAS 4509:2008.] New Zealand Legislation: <https://www.legislation.govt.nz/act/public/2002/0084/latest/whole.html>

## 2. Centrifugal Pump Engineering — H-Q Curves, BEP, NPSH, and Cavitation

- [7] Gülich, J. F. (2020). Centrifugal Pumps (4th ed.). Berlin: Springer. [The authoritative academic reference for centrifugal pump design, H-Q characteristics, NPSH theory, and cavitation behaviour. Section 6 covers NPSH and cavitation in detail, including the steep rise in NPSHr with increasing flow beyond BEP as described in Section 3 of the use case.]
- [8] Hydraulic Institute. (2000). ANSI/HI 1.3 — Rotodynamic (Centrifugal) Pumps for Design and Application. Parsippany, NJ: Hydraulic Institute. [Defines Best Efficiency Point (BEP), Preferred Operating Region (POR 70–120% of BEP flow), and Allowable Operating Region (AOR). The constraint that efficient and reliable centrifugal pump operation is confined to a narrow region around BEP is the basis of the sizing conflict described in Section 3 of the use case.]
- [9] Hydraulic Institute. (2012). ANSI/HI 9.6.3 — Rotodynamic (Centrifugal and Vertical) Pumps — Guideline for Preferred and Allowable Operating Region. Parsippany, NJ: Hydraulic Institute. [Specifies the POR and AOR within which centrifugal pumps should be operated to avoid vibration, recirculation, and premature wear — the engineering basis for the 'narrow efficient operating region' described in the use case.]
- [10] Karassik, I. J., Messina, J. P., Cooper, P., & Heald, C. C. (Eds.). (2008). Pump Handbook (4th ed.). New York: McGraw-Hill. [Standard industry reference. Section 2.1 covers centrifugal pump H-Q characteristics and the fixed-curve constraint. Section 2.3 covers NPSH definitions and cavitation. Directly supports the engineering analysis in Sections 3 and 4 of the use case.]
- [11] Schiavello, B., & Visser, F. C. (2009). Pump cavitation — Various NPSHR criteria, NPSHA margins, and damage mechanics. In Proceedings of the 25th International Pump Users Symposium. Texas A&M Turbomachinery Laboratory. [Technical paper documenting the steep rise in NPSHr beyond BEP and the distinction between incipient and full-performance cavitation onset. Available: <https://oaktrust.library.tamu.edu/bitstreams/fad7b0cc-62b1-40df-a26a-a584a6003e0b/download>]
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## 3. Variable Speed Drives, Pressure Reducing Valves, and Booster Station Control

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#### 4. CST MPR™ Technology and Intellectual Property

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Standards New Zealand's Building CodeHub provides access to SNZ PAS 4509:2008 and NZS 4510:2022 at <https://codehub.building.govt.nz> — sponsored by the MBIE Building System Performance branch. These are the primary regulatory documents referenced in this use case.