CONSIDERATIONS FOR SELECTION OF ENERGY DISSIPATION VALVES

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ABSTRACT

Water and wastewater conveyance systems often require the use of mechanical flow control devices to dissipate energy. Examples of these situations include pressure reducing and sustaining valves for in-line pressure reduction, preventing free-draining of pipes, free discharges from pressurised mains, and bypasses around hydro-electric power plants.

The characteristics of each situation are unique and require a high degree of consideration to identify suitable options and to, ultimately, reach a well-considered solution. Valve manufacturers play a major role in determining feasible solutions that meet the specific needs of each situation, particularly in provision of quality test data.

The consequences of inappropriate valve selection include higher capital, operation and maintenance costs, the need for additional monitoring, pre-treatment or actuation, nuisance noise and vibration, poor flow or pressure control, or cavitation and excessive wear leading to premature failure of the component or pipeline.

Outlined are some common applications that require energy dissipation valves, types of control devices available, and their characteristics and suitability to those applications. The considerations when selecting valves are discussed within the context of actual project examples from New Zealand and Australia. The options considered, design, construction and operational challenges faced, the solutions to overcome them, and the lessons learned are presented.

KEYWORDS

Valves, energy dissipation, conveyance, water, wastewater

PRESENTER PROFILE

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1 INTRODUCTION

The water industry regularly encounters situations where energy within a pressurised pipe system needs to be dissipated. Some typical examples of these include:

1. In-line pressure reduction (e.g. pressure reducing valve).
2. End of a falling main (e.g. pressure sustaining valve).
3. Atmospheric discharge from a pressured main or a dam.
4. Hydro-electric power plant bypass.

Dissipating energy in these situations needs to be done safely, reliably, and efficiently under the full range of operating conditions, with due consideration of the surrounding environment and sensitivity of nearby receivers.

This paper outlines many of the considerations that are required when selecting energy dissipating valves. Valve selection must be undertaken on a case-by-case basis and will typically involve liaising with sales and technical representatives from valve suppliers. Outlined below are some of the issues that need considering in those discussions to increase the chances of a successful outcome that meets the required performance.

It should be noted that the characteristics and operation of some conveyance systems are suited to energy harvesting schemes such as mini- or micro-hydro, that rather than dissipate the energy, harness it to generate electricity. These require moderately high pressures and relatively regular and consistent flows to be economical. They also require significant mechanical and electrical supporting infrastructure. This paper focuses on energy dissipation through mechanical valves only, but opportunities for energy harvesting schemes should also be considered.

1.1 ENERGY LOSS

Energy dissipation is typically undertaken through mechanical means, relying on the process of converting pressure (or strain) energy into kinetic energy and ultimately into heat via turbulence and friction. The energy of a pressurised system is described by the Bernoulli equation, as shown in Equation 1.

$$\frac{\rho V^2}{2} + \rho g h + P = constant \quad (1)$$

As there is typically no elevation change across a valve (i.e. the valve is at a fixed elevation), the ρgh term is constant and the pressure energy loss (ΔP) becomes simply a function of the velocity head of the flow ($\rho V^2/2$), as shown in Equation 2. This can be rewritten as a head loss (ΔH) in the form of Equation 3.

$$\Delta P = K \frac{\rho V^2}{2} \quad (2)$$

$$\Delta H = K \frac{V^2}{2g} \quad (3)$$

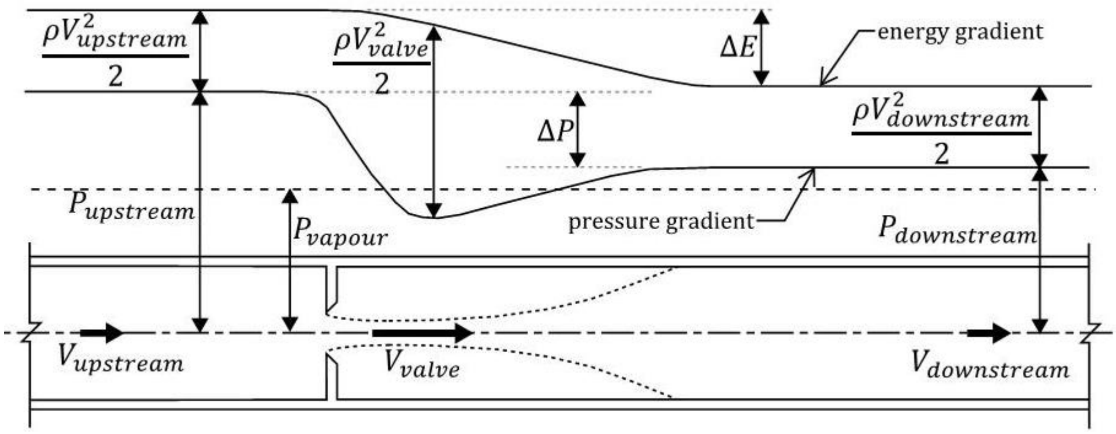
Fundamentally, the greater the velocity through the constriction of a valve, the greater the turbulence and the greater the energy dissipation.

1.2 CAVITATION

For flow through a local contraction such as a valve, the sudden increase in the velocity through the throat of the contraction results in a corresponding rapid decrease in pressure (refer Figure 1). Should the decrease be so great that the pressure locally falls below the fluid’s vapour pressure, then some of the liquid will vaporise into bubbles. As the velocity reduces downstream of the valve and the local pressure increases again above the vapour pressure, the gas cavities will collapse and release significant energy into its surroundings. This is typically known as cavitation and generates loud noise, and should it occur close to a solid surface, such as part of the valve or the pipe wall, it can lead to significant vibration and damage to the structure and cause premature failure.

Increasing the downstream pressure can help keep pressures through the valve above vapour pressure and reduce the risk of cavitation.

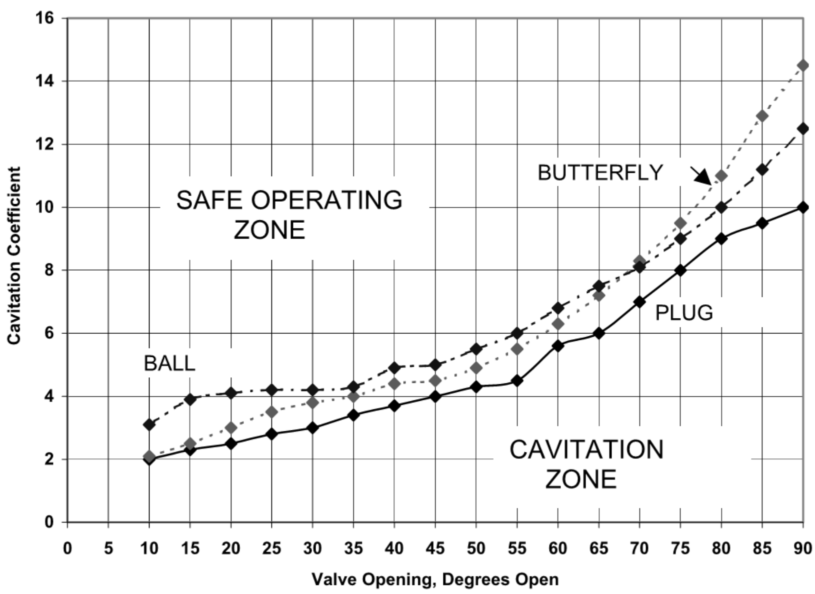
Figure 1. Energy and hydraulic grade lines illustrating energy loss (ΔE) and pressure loss (ΔP) through a local contraction



The potential for cavitation to occur in a valve is often characterised by a cavitation index (σ), as defined in Equation 4. It is the ratio of the pressure differential between the pressure upstream of the valve and the fluid's vapour pressure to the pressure differential across the valve. Cavitation indices are specific to the valve type, manufacturer, and model, and should be sought directly from the manufacturer. Example cavitation index curves are shown in Figure 2.

$$\sigma = \frac{(P_{upstream} - P_{vapour})}{(P_{upstream} - P_{downstream})} \quad (4)$$

Figure 2. Example of cavitation indices (courtesy of Valmatic)



Valve are often designed to manage cavitation through:

1. making the flow path more tortuous
2. providing the pressure drop through multiple smaller stages
3. controlling cavitation by directing it to occur away from solid surfaces
4. manufacturing the valve material to withstand cavitation (e.g. hardened trim)

2 VALVE TYPES

A range of valves exist, with some of the more common ones listed below with their broad characteristics. The types of valves that suit each individual situation will need to be carefully assessed depending on the characteristics of the application. These considerations are discussed further below.

Table 1: Characteristics of valves

Valve Type	Pressure Capability	General Characteristics
Orifice plate	Low	• Compact with no moving parts • No controllability • Poor solids handling • Low maintenance
Butterfly	Low	• Compact and in-line • Limited controllability • Quick-acting • Poor solids handling
Pinch	Low	• Moderate controllability • Quick-acting • Moving parts isolated from flow • Copes with solids – full-bore and non-clogging • Low maintenance
Ball	Low-moderate	• Limited controllability • Quick-acting • Low maintenance
Plug	Low-moderate	• Limited controllability • Quick-acting • Copes with some solids • Low maintenance
Globe	Low-moderate	• Quick-acting • Good controllability • High torque required
Segmented-ball	Moderate	• Good controllability (especially with v-port) • Copes with solids • Low torque
Multi-orifice	Moderate	• Compact, small actuation movement • Lower controllability • Rapid flow stabilisation • Specialised
Multi-port sleeve	High	• Good controllability over a wide range in flow • End-of-line free discharge • Requires control of spray and erosion • Specialised

Valve Type	Pressure Capability	General Characteristics
Needle/plunger	High-very high	• Good controllability over a wide range in flow • For in-line applications • Large and heavy • Poor solids handling • Expensive and specialised
Fixed cone/hollow jet	High-very high	• Good controllability over a wide range in flow • End-of-line free discharge • Large and heavy • Poor solids handling • Expensive and specialised

3 CONSIDERATIONS FOR SELECTING VALVES

In order to identify suitable valve types and to appropriately size them, a range of issues need to be considered and managed, as presented below.

Table 2: Considerations for selecting energy dissipation valves

Characteristic	Considerations
System and Fluid Properties	• Range of flows and pressures – multiple valves in parallel or series may better suit large variations in flow or pressure • Frequency and duration of flow – the valve should be selected to suit the typical flow/pressure but also withstand the minimum and maximum flow/pressure • Criticality of energy dissipation – consider incorporating redundancy through multi-stage pressure drop or a standby valve • Solids and grit – free-passage should pass the maximum expected particle size. Valve type and material selection should also consider whether the flow characteristics (e.g. grit) may cause high wear on valve seats and bearings • Controllability – the valve type should suit the degree of flow/pressure control required in the application. Special trim and v-ports can be added to some valves to increase responsiveness and controllability • Seating/unseating – the type of actuation (manual with or without gearbox, electric, hydraulic, pneumatic) and required torque should be considered, particularly in higher pressure applications • Transient pressures – the potential to generate adverse transient pressures will need to be managed when determining the required responsiveness of the valve

Characteristic	Considerations
Cavitation	• Avoid cavitation through careful selection and sizing • Control unavoidable cavitation through appropriate designs and materials, or direct cavitation away from sensitive surfaces • Provision of sufficient back-pressure or submergence on the valve can keep pressures through the valve from falling below vapour pressure • Consider whether a multi-stage pressure drop (e.g. valves in series) will be beneficial in controlling cavitation • Valve selection and sizing should be based on actual test data at the required valve size and operating conditions, and not on extrapolated data
Suppliers	• Assess whether off-the-shelf valves are suitable or if they will need to be bespoke • The valve manufacturer/supplier’s reputation and support during design and operation will be beneficial • Understand what testing has been carried out in the design and characterisation of the valve (physical testing, CFD) • Feedback on previous installations provides valuable information on possible performance and likely issues • Some valves, and bespoke valves in particular, tend to have longer lead times • Assess availability and lead times for critical spares
Construction	• Valve cost will depend on a range of factors, including size, pressure class, and materials. • Consider the need for, and cost of, supporting structures – size and depth of valve chambers and foundation slabs/plinths to suit the valve size and mass, geotechnical conditions, and required noise attenuation • Type of valve actuators and power/hydraulic/pneumatic supply • Instrumentation and communications/telemetry to support the valve

Operations and Maintenance	• Some valves may require position indication or mechanical limiters to assist with safe operation
	• Availability of maintainable components and access for maintenance
	• Frequency of inspection and maintenance will dictate the access requirements, particularly for enclosed valves, including:
	  – Vehicle, crane and personnel access
	  – Access hatches or fully removable lid
	  – Security, safety, and restricted/confined space access
	  – Ergonomics, ventilation, lighting and ladders
	• Drainage from valve chambers may be needed
	• Erosion potential will need to be managed on free discharges. Submergence of the discharge or a spray hood could be utilised in some circumstances
	• Protection and security will be needed where valves may be accessible to the public

4 CASE STUDY 1 – RAW WATER RIVER DISCHARGE

4.1 BACKGROUND

The ecological health of a river near Melbourne, Australia, was unable to be maintained as a result of the limited release capacity at the upstream dam to supplement seasonally high flows. To overcome this, two existing DN225 scour offtakes from nearby raw water pipelines were identified as potential release points to the river. They required upgrading to be able to each deliver a fixed 1.2m^3/s of raw water into the river in a controlled manner over a two- to four-week period twice a year. The pressure within the two raw water pipelines that the environmental flows would be sourced operated at up to 132m head (1,300kPa), which needed to be dissipated prior to discharge to the river.

The proposed river discharges were approximately 15km apart and each comprised a DN1000 piped outlet with a check valve to minimise the risk of backflow and vermin entry, a trash rack and barrier fencing to prevent public access, and rockwork for scour protection of the river bed.

The range of issues that the discharge solution needed to address included:

1. Cost-effectiveness, particularly given the discharges occurred for a short period at set times of the year.
2. Moderate-high levels of energy dissipation required.
3. Managing flow cavitation and minimising noise production and its impact on the nearby communities.
4. Construction, operations and maintenance, and public safety considerations
5. Minimising the planning and environmental approvals required for the works that were adjacent to the river and where environmental, heritage and recreational values are high.
6. Preventing damage to the river environment from the discharge flows.
7. Reliability and minimising maintenance given the sites are remote and would not be regularly inspected.
8. Electromagnetic flow meters with local flow rate monitoring (instantaneous and totalised) and datalogging via battery power due to remoteness from reticulated electricity and telecommunications and poor radio and cellular coverage.
9. Manual valve operation due to lack of power and communications.

4.2 OPTIONS AND CONSIDERATIONS

A high-level assessment of energy dissipation options was undertaken and the shortlisted options and their comparison is summarised in the table below.

Table 3: Raw water river discharge valve options and comparison

Option	Benefits	Risks
Submerged multi-port sleeve valve in a discharge chamber	• valve type proven in high pressure loss applications • valve type is known to the water authority • low risk of vibration and cavitation-induced damage to the valve	• valve is large and heavy, necessitating a large and deep concrete structure adjacent to the river, in difficult ground conditions and subject to water inundation • valves and supporting civil/structural works are expensive • risk of generation of significant noise due to cavitation occurring • safety hazards associated with large below-ground structures that need to be accessed by operations personnel • limited number of suppliers with potentially long lead times for spares or replacements • more susceptible to damage if flow contains significant heavy debris
Anti-cavitation ball valves with flow restrictor valve in series	• proven in local industrial applications and overseas district heating applications for high pressure losses • can be direct-buried, removing the need for large and complex below-ground discharge structures • low risk of cavitation and vibration resulting in low noise production and good reliability • is available ‘off-the-shelf’ • lower cost compared to other bespoke high-energy dissipation valves (such as multi-port sleeve, needle, or fixed cone valves)	• valve type not known to water authority • limited previous use in Australian municipal water transfer systems • more susceptible to damage if flow contains significant heavy debris

Option	Benefits	Risks
Inline needle valve	• valve type proven in high pressure loss applications • valve type is known to the water authority as they were used on the discharges to some of their reservoirs • low risk of vibration and cavitation-induced damage to the valve resulting in low noise production and good reliability	• valve requires housing in a below ground pit, adding additional costs for civil/structural works. • safety hazards associated with large below-ground structures that need to be accessed by operations personnel. • limited number of suppliers with potentially long lead times for spares or replacements • more susceptible to damage if flow contains significant heavy debris • valve is approximately 50% more expensive than an equivalent ball valve, though the valve cost is a small proportion of the overall capital cost
End-of-line discharge via fixed cone or hollow jet valve	• valve type proven in high pressure loss applications • valve type is used by the water authority on dam outlets • low risk of vibration and cavitation-induced damage to the valve	• free discharge from the valve will create a 'rooster tail' that poses public safety and river bank erosion risks • valve is large and heavy, necessitating a substantial headwall structure adjacent to the river in difficult ground conditions • valves and supporting civil/structural works are expensive • risk of generation of significant noise due to cavitation occurring in the free discharge • limited number of suppliers with potentially long lead times for spares or replacements

The option utilising two anti-cavitation ball valves in series with a downstream flow restrictor valve was preferred for both sites on the balance of simplicity, proven effectiveness, low noise, ability to avoid cavitation, lower capital valve cost, and ability to meet the water authority's requirements for infrequent and short duration local operation.

Environmental flows of up to 1.2m^3/s from each outlet would be controlled through a multi-stage flow control and pressure reduction valve arrangement incorporating two segmented ball valves in series followed by a variable orifice automatic flow restrictor valve. The flow restrictor valve is a stiff rubber nozzle similar to a duckbill valve and maintains moderate back-pressure on the second ball valve to further reduce the likelihood of cavitation occurring. The purpose of a multi-stage pressure reduction arrangement was to dissipate the high pressure in a controlled manner and reduce the risk of cavitation and noise impact across each valve to acceptable levels.

Figure 3. Example of a segmented ball valve (courtesy of Ramén Valves AB)

The multi-port sleeve, needle, and fixed cone/hollow jet valve solutions were not preferred due to their higher risk profile, as tabulated above, and their need for large/deep structures proximal to the river requiring additional cost, approvals, and safety management.

4.3 KEY LEARNINGS

The following key learnings were identified through this project:

1. Energy dissipation can be very noisy and so needs careful management to meet regulatory noise limits, particularly in rural areas
2. Valve selection needs to be fit for the intended purpose
3. The asset owner needs to be comfortable with the valve type
4. Valve supplier's technical representatives are valuable in providing relevant engineering data and information on effective performance on previous similar installations
5. In a system that utilises two direct-buried manual valves in series, it is important to know the position of each valve so that the energy dissipation duty is evenly shared across the valves

5 CASE STUDY 2 – FALLING SEWER MAIN

5.1 BACKGROUND

A degrading DN300 gravity sewer required urgent replacement with a sewage pumping station and transfer main to deliver raw wastewater to the treatment plant. The replacement system had to cater for significant population growth in the area and so the design pumped flow range of 270L/s to 650L/s was substantial. The pumping station and DN650 GRP pressure main was preferred over rehabilitation of the gravity sewer due to time and cost constraints and the need to provide additional flow capacity.

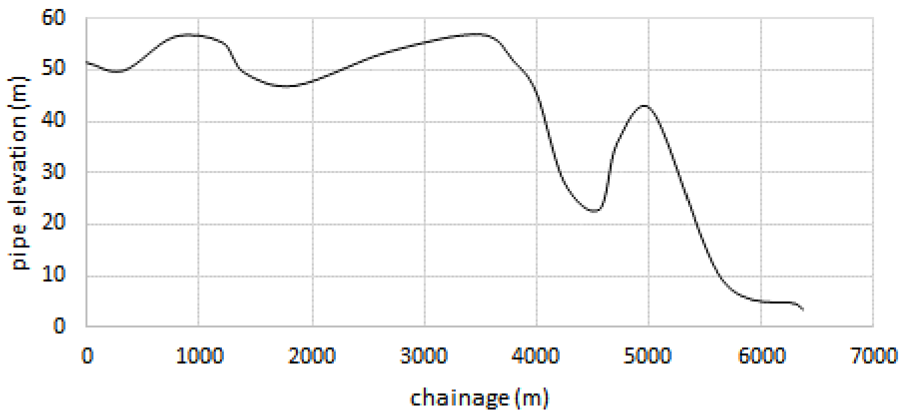
The pipeline route resulted in the last two kilometres to be steeply falling (refer to Figure 4). To avoid a long section of the main filling and emptying during each pump cycle and the need to subsequently manage air and odour release, the main would be operated as a fully pressurised main for the entire 6.5km length. This required the discharge at the treatment plant to be controlled to maintain positive pressure throughout the main.

The discharge at the treatment plant needed to maintain around 10m of residual head in order to deliver flow up to new inlet works. Even so, a significant residual energy of up to 50m (490kPa) needed to be dissipated under a wide range of flow rates.

The range of issues that the discharge solution needed to address included:

1. Moderate levels of energy dissipation required over a wide range of flow rates.
2. Ability to cope with solid and fibrous material without clogging.
3. Managing flow cavitation to improve valve reliability and reduce maintenance.
4. Cost-effectiveness.

Figure 4. Sewer pressure main longitudinal profile



5.2 OPTIONS AND CONSIDERATIONS

The likely presence of solid, fatty, and fibrous material in the flow limited the available options to those with openings large enough to pass the 80mm maximum free passage size of the pumps, and therefore would provide only low levels of energy dissipation. The flow control and energy dissipation valve options that were identified, and their comparison, is summarised in the table below.

Table 4: Falling sewer main control valve options and comparison

Option	Benefits	Risks
Orifice plates	• orifice plates are cheap and simple • replacement plates are readily available	• low pressure loss capability, requiring multiple orifices in series to dissipate energy in multiple stages to manage cavitation • no controllability - unable to cope with variable flow, requiring a range of orifice sizes with valves and controls to divert flow to the appropriate orifice as the flow changes • pressure drop required orifices smaller than the 80mm maximum free passage size of the pumps and therefore prone to blockage • susceptible to cavitation if poorly controlled
Throttled isolation valves (ball, globe, or plug)	• valves are reasonably cheap and simple • provides some controllability • can be opened fully to help clear any blockages • common valve type provides simple sourcing of parts and replacements	• low pressure loss capability, requiring valves in series to dissipate energy in multiple stages to manage cavitation • limited controllability - requires multiple parallel valve trains, and associated diversion valves and controls, to cater for the range of flows • at risk of blockage due to snagging of fibrous and fatty material when valve is throttled • susceptible to cavitation if poorly controlled
Throttled pinch valves	• while the valve sleeve would need to be pinched smaller than the 80mm maximum free passage size of the pumps, it can be opened fully to help clear any blockages • no sharp edges in the flow and so not likely to snag fibrous material • provides some controllability • isolates moving valve parts from the wastewater	• low pressure loss capability, requiring valves in series to dissipate energy in multiple stages to manage cavitation • limited controllability - requires multiple parallel valve trains, and associated diversion valves and controls, to cater for the range of flows • susceptible to cavitation if poorly controlled • internal sleeve is a maintainable item

The option utilising pinch valves was selected due to its greater ability to deal with solid, fatty, and fibrous materials. The outstanding risks associated with the use of pinch valves were addressed by:

1. Low pressure loss capability and risk of cavitation - three DN450 pinch valves in series followed by three DN150 local contractions in series (larger than the 80mm free passage size of the pumps) was used to dissipate the energy progressively. The sleeve aperture was varied between 83mm and 40mm to suit the flow rate and maintain acceptable velocities through the valve. The 10m of residual head required at the inlet to the treatment plant proved useful in providing back-pressure to the last pinch valve to help further control cavitation.
2. Limited controllability – three parallel trains (each with three pinch valves in series), with one, two, and then three trains operating simultaneously as the flows increased, catered for the wide operating range. A DN200 pinch valve at the head of each train was opened to allow flow through. The multiple parallel trains assisted with providing system redundancy, particularly when maintenance and sleeve replacement was required.

5.3 KEY LESSONS

The following key learnings were identified through this project.

1. Importance of confirming that the selected valve has been used before in the same application and operating conditions.
2. Seek verified test data at the size and pressure required. Confirm that quoted performance is not simply extrapolated from that of smaller or lower-duty valves. Some valve supplier offers indicated greater pressure loss capabilities but were found to have little supporting proof. Reliance on the optimistic data would have resulted in a system that would not have achieved the required outcome.
3. Work with and gain the interest of the valve manufacturer, particularly where additional research and product testing may be beneficial. This will help avoid surprises and delays during commissioning.

6 CONCLUSIONS

As a natural resource, the value of energy continues to increase and so the loss of energy from conveyance systems should be minimised in the first instance. Different flow management strategies, means of conveyance, or system operation and control may assist with this. In some instances, it may even be possible to harness the excess pressure to generate useable energy, such as through micro- or mini-hydro generators.

Where the need for flow control and dissipation of excess energy in water and wastewater conveyance systems cannot be avoided, the challenges of doing so should not be underestimated. Falling mains associated with a shift to long distance centralised sewage transfer systems are becoming more common and present their own sets of challenges.

Each situation requiring valves for energy dissipation has a unique combination of drivers and constraints. These characteristics require definition and consideration so that the solutions developed are fit for their intended purpose and address the key requirements.

Energy dissipation needs to be done safely, reliably, and efficiently under the full range of operating conditions, with due consideration of its surroundings.

Quality valve test data and evidence from similar installations should be sought and critically scrutinised to mitigate unnecessary cost and delay associated with poor valve performance.