LONG DISTANCE PUMPING OF WASTEWATER ALONG UNDULATING RISING MAINS

Tom Scott (Black & Veatch) and Langford Sue (Beca)

ABSTRACT

A range of factors are driving water utilities to centralise their wastewater treatment, including stricter consent and licencing conditions for treatment plants, discharges, and re-use, enhancement of resource recovery, and adaptation to a changing climate. This forces many cities around the globe to pump wastewater considerable distances. This is further exacerbated as urban boundaries extend to accommodate growing populations.

Constraints of urban environments, geotechnical conditions, and environmental, heritage, and statutory planning considerations restricts route options, often resulting in complex hydraulic profiles that incorporate pumped sections, pressure gravity sections and part-full gravity sections.

Schemes are often designed on a 50-year population horizon with assets appropriate for 100 years of service. A key driver for these schemes is to provide the backbone wastewater service to growth areas. Schemes linked to growth projects are challenged by high upfront capital cost and a risk that development may not occur quickly enough to generate the required start-up flows to manage flushing and septicity. Equally, the start-up flow can be a fraction of the design population meaning hydraulic design and pump selection must consider a broad operating range. The commercial terms imposed on developers by asset owners relating to developer contributions, land sale and house construction timeframes are a key consideration in mitigating slow build-out and high capital cost.

Understanding how an asset owner's maintenance regime, particularly pump replacement timeframes, aligns with population growth offers a means of identifying natural points in the asset lifecycle where pumps can be upsized as part of a standard maintenance replacement programme to suit the catchment development. Identifying how to 'sweat' an asset is essential in identifying the tipping point where provision for greater population requires a full scheme upgrade or pipeline duplication. Pressure main velocity range is a good place to focus for this assessment.

The potential for generation and release of nuisance odour increases with long distance pumping. Longer rising mains are more susceptible to generating odours due to longer residence times and the increased potential for septicity. Air expelled during filling of free-draining sections are another source of release of potentially odorous air. Air valve locations need to consider the functional requirement to facilitate emptying, filling and limit transient pressures, alongside the potential to generate odour complaints from customers and ensure that air valves have sufficient pressure to maintain a seal under a variety of flow scenarios.

It may take an extended period of pumping to generate self-cleansing velocities along the whole pipeline to ensure that sediment does not accumulate, and wall slimes are maintained within the system's hydraulic limitations. Sufficient volume must be allowed for in the pump sump or parallel storage provided as catchments develop. Optimising the

flushing regime to flush the longest section of sagged pipeline, as opposed to the full line, may help to reduce the flushing volume required.

This paper describes the delivery of some major long-distance conveyance schemes in Australia and the United Kingdom, and discusses the design and operational challenges faced and the solutions to overcome them.

KEYWORDS

Wastewater, pumping, pumping station, rising main

PRESENTER PROFILE

Tom Scott is an Engineering Manager with a track record of delivering designs for innovative and successful projects across the three waters. Tom has worked collaboratively with suppliers and constructors to extract the maximum benefit to projects, from collection to conveyance, transmission, treatment and storage.

Langford Sue is a Technical Director at Beca and leads their Water Conveyance technical practice. Langford's expertise is in the hydraulic analysis and design of municipal, commercial, and industrial conveyance systems and treatment plants. He specialises in complex systems and the application of numerical and physical modelling.

1 INTRODUCTION

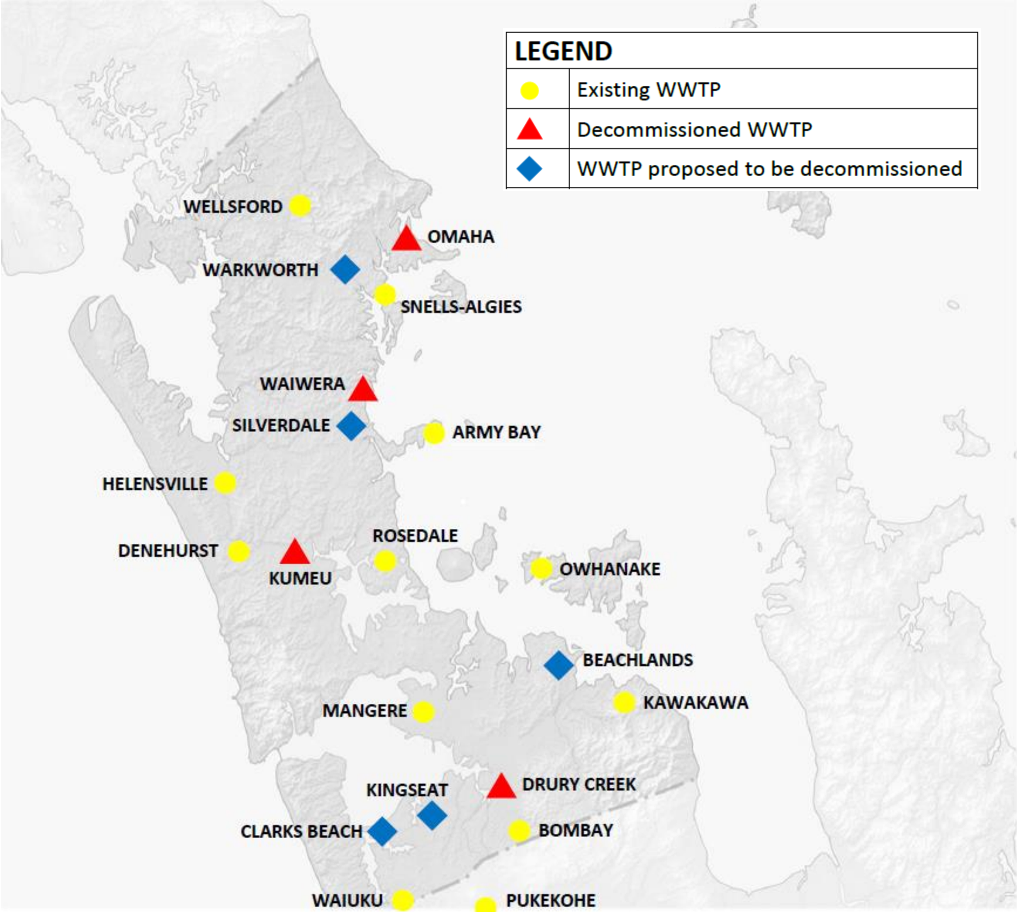
A range of factors are driving water utilities to centralise their wastewater treatment, including stricter consent and licencing conditions for treatment plants, discharges, and re-use, enhancement of resource recovery, and adaptation to a changing climate. This forces many cities around the globe to pump wastewater considerable distances. This is further exacerbated as urban boundaries extend to accommodate growing populations. Figure 1 below shows wastewater treatment plants around Auckland, New Zealand, that have been decommissioned in recent years and showing plants proposed to be decommissioned by 2036, which is likely to drive a need to convey wastewater longer distances.

Constraints of urban environments, geotechnical conditions, and environmental, heritage, and statutory planning considerations restricts route options, often resulting in complex hydraulic profiles that incorporate pumped sections, pressure gravity sections and part full gravity sections. As sewage is pumped over greater distances, more varied terrain is likely to be encountered resulting undulating profiles.

The sewage infrastructure needs to be in place to facilitate urban development and so until developments are largely full, flow into the system is a fraction of the design flow and well below the capacity of the system. This has the consequence of exacerbating issues related to low velocity, sedimentation, odour and septicity.

This paper focusses on issues related to the hydraulic design and operation of longer pipelines conveying sewage, the main issues that need to be resolved through design, and the potential consequences of failing to do so.

Figure 1. WWTPs in Auckland recently decommissioned or proposed for decommissioning



2 AIR MANAGEMENT

Air within a rising main can come from drop shafts, hydraulic jumps, drops into pumping stations, swirl and vortices associated with pumps, dissolved air, and undulating pipelines with a discharge lower than the high point where parts of the pipeline may run part full periodically or permanently.

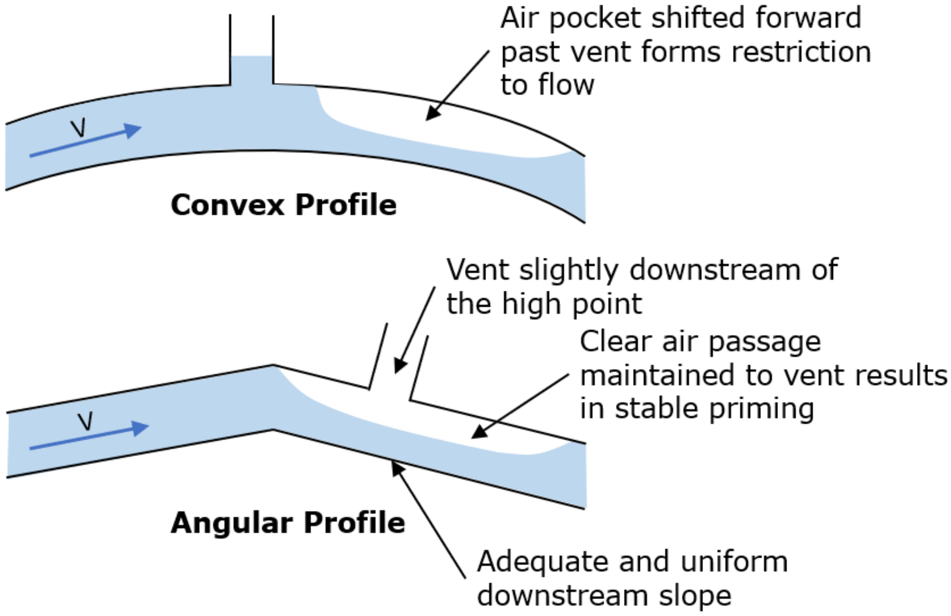
This invariably leads to loss of carrying capacity due to air pockets reducing the effective cross-section of the pipe, can reduce the efficiency of pumps and result in loss of priming, cause flow instability (especially during priming), and small accumulations of air can amplify hydraulic transients and increase surge pressure (HR Wallingford, 2005). As it exits the system air can create odours or cause foaming at the discharge point.

2.1 AIR-VALVES

While crucial to the management of air for the efficient and safe operation of a pipeline system, incorrectly placed or sized air valves can create operational problems. Maintenance of air valves is also often neglected to the point that they are sometime not functional.

To provide stable priming of a pipeline, air valves should be sited slightly downstream of the highpoint. On a convex profile the air pocket can be shifted passed the high point and the air pocket isolated from the air valve, rendering it ineffective. Locating the air valve downstream of the high point, with an adequate and uniform downstream slope that encourages part full flow conditions, maintains a clear passage to the air valve and helps with stable priming.

Figure 2, Air-valve positioning for stable priming



In addition to locating the air valve in the correct place, it is important to provide a tee connection for the air valve of sufficient size for the capture of air at the air valve. A larger tee provides a buffer for air being expelled by the air valve, while a smaller tee may result in air travelling passed the air valve and remaining in the system. Recommendations vary as to the exact size of the tee required. Examples given range from 0.35 times the diameter for up to 350mm pipes or being an equal tee up to 800mm diameter. Larger tees also provide the potential for access for maintenance.

Consideration of the pressure acting on the air valve under steady operation at the design flow, at the priming flow, and at rest should also be considered. While improvements to air valves have been made to air valve design that allow correct seating the air valve at lower pressures, and manufactures will generally indicate air valve seals will operate down to around two metres of pressure above atmospheric pressure, regular maintenance is required to prevent leakage from air valves regularly subjected to low pressure. An alternative horizontal alignment that increases the head on the air valve is the preferred solution, however in urban environments very often there is little room to deviate from an allowed corridor.

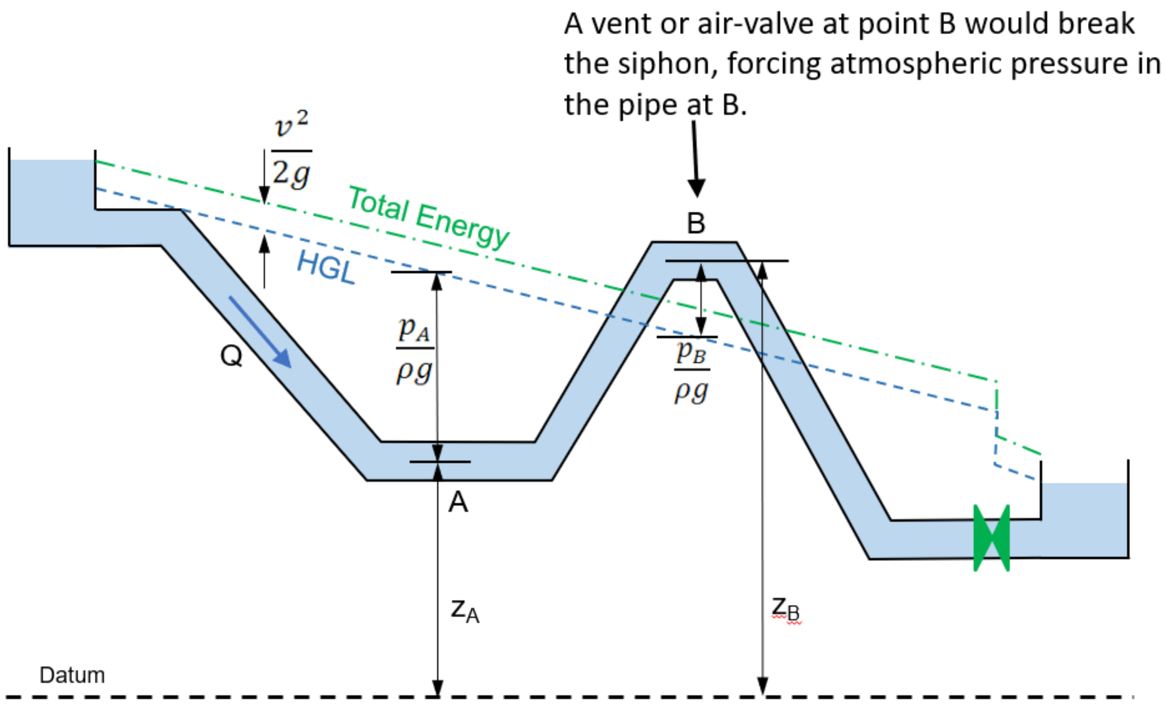
3 SUB-ATMOSPHERIC AND VACUUM CONDITIONS

If the pipeline profile lies above the hydraulic grade line at any point, then there will be a negative gauge pressure at that point, or an absolute pressure less than atmospheric pressure. This is known as a siphon, and if this is a design condition, then pipe structural design must take this into account.

The maximum siphon that can be sustained is under 10m head of water, because if the local pressure falls to the vapour pressure of the liquid, the liquid at the high point will be rapidly replaced with water vapour, creating an air lock.

Generally, in a combined pumped and gravity system, this is unlikely to occur during normal operation on the pumped section and air valves are usually installed at local high points to admit air during transient events, which should be considered during surge analysis. However, the gravity sections should also be checked for the potential to generate sub-atmospheric conditions.

Figure 3. Sub-atmospheric pressure in a pipeline.



In the context of wastewater pipelines, sub-atmospheric pressures can result from inadequate venting during draining, pressure transients, and to a lesser extent cavitation at mechanical devices.

4 HIGH VELOCITY

Rising mains are generally sized on the basis that pipes are full and a velocity range of 0.75 to 2.5 m/s is typically targeted. Therefore, excessively high velocities within these typical pipes is not expected to be an issue. On pipelines having sections of full-bore and part-full gravity flow, the velocity should be checked to confirm that very high velocities do not develop and potentially cause damage to the pipe.

High velocity part-full pipe flow tends to entrain air through shear at the free surface. This entrained air will need to be managed, particularly if the flow transitions back to full-pipe flow downstream, where a hydraulic jump at the transition will further exacerbate air entrainment.

In practice, high velocities give uncertainty about the actual head loss within the pipeline as uncertainty in head loss predictions increases with increasing velocity. High velocity can have also mean that standard head losses across fittings become inaccurate and more detailed assessment is required.

Special care should be taken at the discharge point of the pipeline especially where the final section of the pipeline may be gravity flow and appropriate measures are taken to prevent damage to structures that receive the discharge.

5 LOW VELOCITY AND SEDIMENT

Schemes linked to growth projects are challenged by high upfront capital cost and a risk that development may not occur quickly enough to generate the required start-up flows to manage flushing and septicity. Equally, the initial flow may be a fraction of the ultimate design flow and so the hydraulic design and pump selection must consider a wide range of flows.

In any combination pumped and gravity system there is a delay between the pump reaching its design flow and that same flow being discharged at the outlet point of the system as air is purged from the system. Consequently, where the design flow is required to achieve a self-cleansing or slime-stripping velocity there can be a delay in this velocity being achieved through the whole system. It is necessary to size the sump and arrange the pump start and stop levels, not only to achieve the required starts and stops per hour and avoid long periods between operations, but to ensure that there is sufficient volume and therefore a sufficient pumping duration to develop self-cleansing and slime-stripping velocity throughout the pipeline length.

6 UNSTABLE FLOW CONDITIONS

Pipelines with undulating profiles and partially filled sections require the same careful consideration of transient pressures as fully primed pipelines. In terms of surge analyses, the effect on the pipeline is often only considered to the permanent discharge point of the pumped section where there is a delineation between pumped and downstream gravity sections as it is the characteristics of the pumped section that will largely determine the size of any surge vessel required.

Consideration should also be given to the potential for gravity flow sections following transient events to determine whether re-priming of sections of the pipeline is required. If not managed correctly, this can lead to unstable flow conditions where the air is evacuated rapidly and eventually causing the fast-moving pumped flow to collide with the filling section and creating further pressure surges.

7 PRIMING

Special attention must be paid to air management so that the main can prime in a stable way. Historically, guidelines on pipe filling have suggested limiting flows so that the pipe filling velocity to no more than 0.3m/s to allow air to escape from the pipeline. For sewage rising mains this is generally impractical, especially for long rising mains where the time required to fill the pipeline at this rate a would sometimes be measured in hours.

However, if a partially full rising main is filled quickly such that air is not able to reach the air valves or be expelled quickly enough, unstable conditions may develop that may generate transient pressures or restrict the flow of water.

Difficulties can arise when sections of the pipeline have drained in periods between pump starts. Other sections, between local high points, will retain standing columns of water. When the pumps start, the moving column of water propelled by the pumps will collide with the standing columns of water, causing a transient pressure spike.

To allow the pipeline to prime in a stable manner one recommendation is to provide for open channel flow on descending sections of pipework so that there is enough area above the water surface to allow air to ascend back to the air-valve at the high point. A flow depth of 2/3 the diameter of the pipe is recommended (Hunt, 2004). In practice setting the flow depth at 2/3 of the pipe diameter for the design flow determines the minimum pipeline gradient for installation. Where impractically steep minimum slopes result, it may be effective to increase the pipe diameter in these sections, as long as self-cleansing velocities are maintained.

8 ODOUR AND SEPTICITY

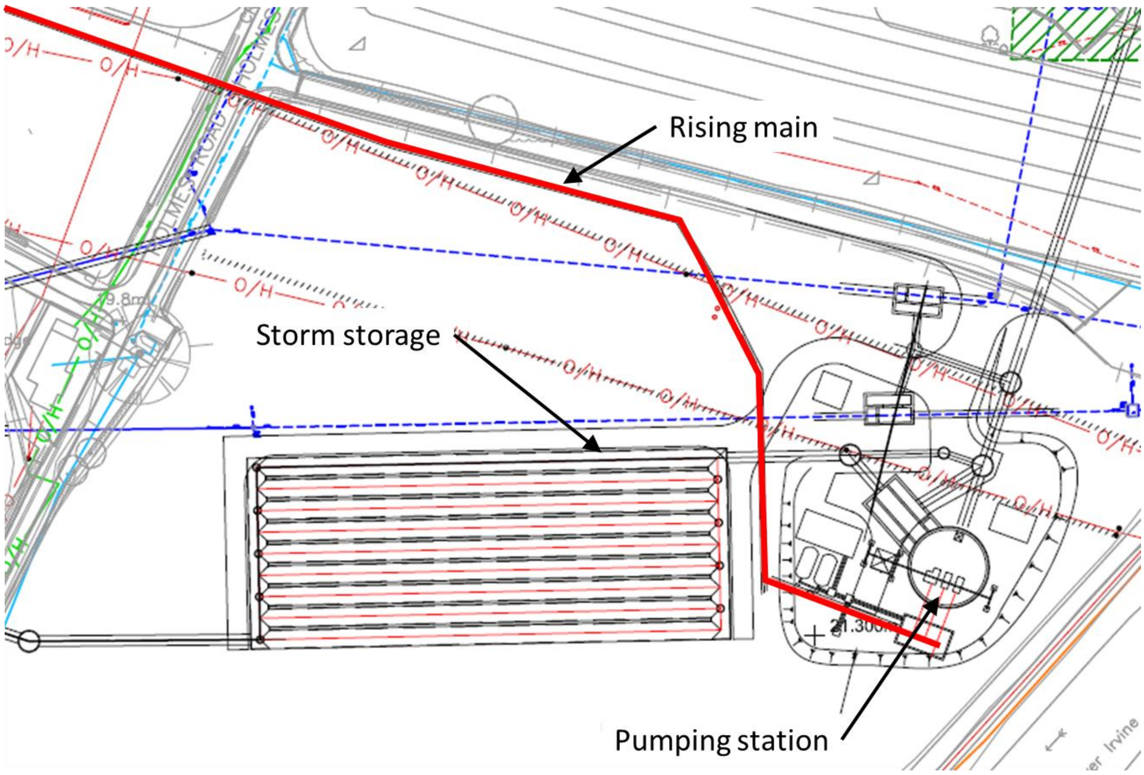
The potential for generation and release of nuisance odour increases with long distance pumping. Longer rising mains are more susceptible to generating odours due to longer residence times and the increased potential for septicity. Odour and septicity control for long pumped systems need to be robust, flexible, and reliable to accommodate the wide variety of flows and loads from the initial dry weather low flows when development has only just started to the fully-developed catchment wet weather peak flows.

In rising mains that fill and partially drain, air is drawn in and expelled on every cycle. Therefore, consideration of the potential for odour nuisance from air valves is an important consideration, especially in more urban areas. As the volume of air expelled can be significant and more than the intermittent release of air accumulating at high points there is the potential that odour treatment units may need more frequent media changes or a larger unit normal is required.

9 CASE STUDY 1: KILMARNOCK NORTH LODGE PUMPING STATION

The Kilmarnock North Lodge Pumping Station was part of a larger scheme that involved reducing combined sewer overflows from the sewage network in Kilmarnock and Irvine, in Scotland, and transferring these storm flows to a screening facility at the Meadowhead Wastewater Treatment Plant. The design & build contract was undertaken by a joint venture between Morrison Construction and Black & Veatch, with design elements variously undertaken by MWH (now Stantec), Halcrow (now Jacobs) and Black & Veatch.

Figure 4. Kilmarnock North Lodge Pumping Station

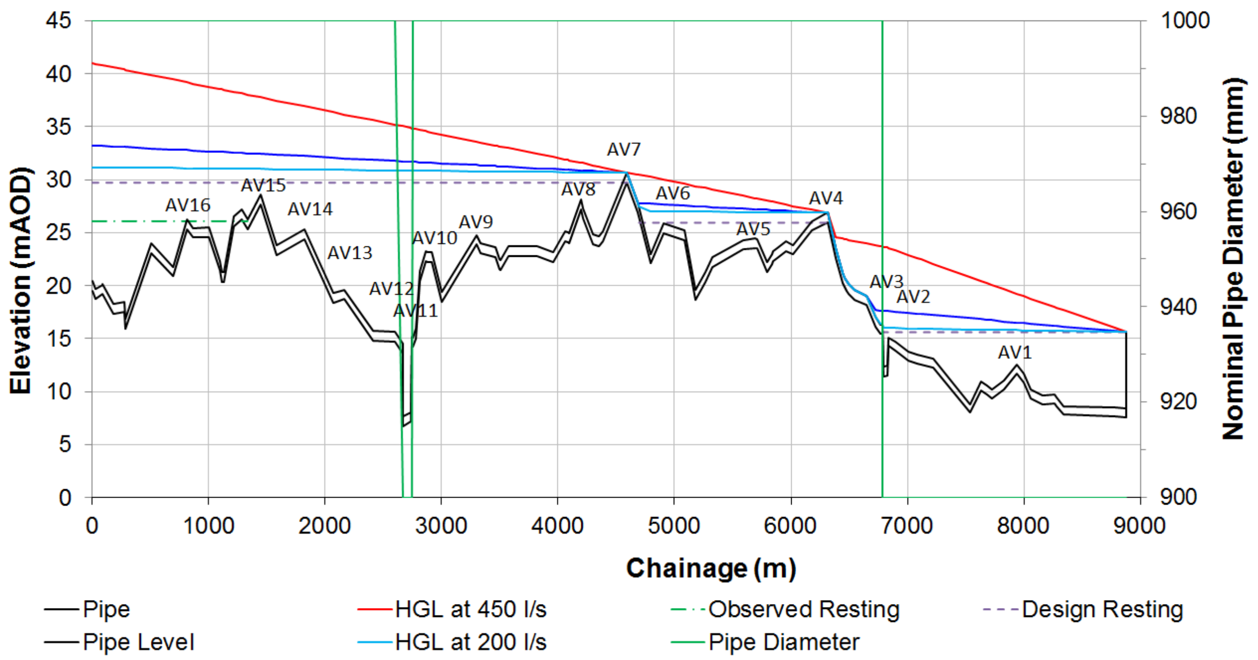


The Kilmarnock North Lodge Pumping Station has a 900 l/s discharge capacity provided by three pumps in a duty, assist and standby arrangement and 10,000 m^3 of storage in the pumping station and adjacent pipe nest storage arrangement. The rising main that the pumping station discharges to is nine kilometres long with a discharge level of

15.6mAOD and intermediate high points of 29.7mAOD and 25.9mAOD that have hydraulic significance. Initially and at lower pumped flows the static lift is determined by the first high point and at higher flows it is determined by the second high point. Scottish Water specify that the velocity should be a minimum of 0.75m/s for self-cleansing and less than 1.8m/s to minimise energy loss. With polyethylene the preferred pipe material, a pipe diameter of DN1000 was chosen with an SDR of 26 giving a pipe full velocity of 1.35m/s at the design flow. Even at the maximum pump design flow the last section of the rising main never achieves pipe full flow.

Figure 5 shows the pumping main long section, with flow direction from right to left. Three hydraulic grade lines are shown: full flow from two pumps (900 l/s); full flow from one pump only (450 l/s); and at a flow velocity of 0.3m/s (200 l/s), a standard safe priming velocity. Locations of air valves are also indicated.

Figure 5. North Lodge rising main profile



9.1 AIR MANAGEMENT

Between pump operations, the system drains by gravity from the high point at AV7 toward the discharge point at Meadowhead WWTP. Local high points will hold water upstream, most notably at AV4 and AV7.

The pipeline profile was developed considering the slope of the pipe required to manage air effectively. Minimum pipe slopes were checked so that part full sections had sufficient gradients to provide a maximum flow depth of two thirds of the pipe diameter so that air could migrate back to upstream air valves. Generally, the minimum pipe slopes were flatter than slopes practical for laying other than at the full design flow.

Table 1: North Lodge pipe hydraulic parameters

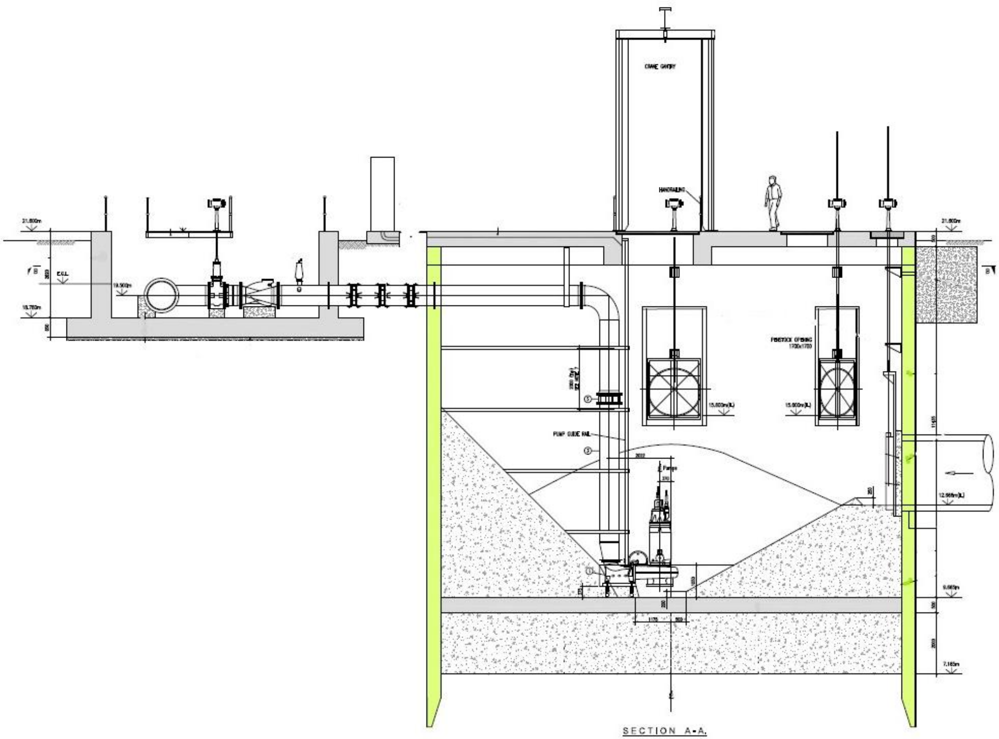
OD (mm)	ID (mm)	Flow (l/s)	Velocity (pipe full) (m/s)	Slope (pipe full) (1:X)	Max slope (1:X) at v=0.75 m/s	2/3 depth (mm)	Slope (2/3 depth) (1:X)	Velocity (2/3 depth) (m/s)
900	830.8	450	0.83	1022	1022	554	618	1.17
1000	923.1		0.67	1773	1806	615	1070	0.95
900	830.8	900	1.66	257	257	554	156	2.34
1000	923.1		1.35	447	447	615	271	1.90

To provide sealing pressure to air valves AV1 and AV2 to the discharge point, a raised bellmouth was provided to elevate the discharge point. This also provided the opportunity to reduce the diameter of this section of pipework to 900mm and increase the velocity in this section without affecting the pumping head. The 900mm diameter pipe was only used in the submerged section and so part full parameters are given in Table 1 only as an indication to show the effect on pipe slope had they also been used in the part full sections. On other sections such as at AV5, AV8 and AV14 low sealing pressure air valves were recommended as some draw down was predicted to occur during pump failure events.

9.2 SUB-ATMOSPHERIC CONDITIONS

A single surge vessel of around 50m³ was provided to limit the adverse effects of sub-atmospheric pressure in the pipeline. All but the lowest air valves between AV7 and AV16 would open during a surge event generated by pump stoppage from full flow and admit air to lessen the impact of the surge event. Normally, larger air valves may have been considered to allow some minimisation of the surge vessel size, by using the air admitted by the air valves to provide a cushioning effect. In this case, the more air admitted by the air valves would require longer time following any surge event to re-prime the line up to AV7 and so the surge vessel was sized allowing only for a standard air valve size.

Figure 6. Pumping station cross section



Another source of air into the system came from the pump riser. The pump riser was slightly greater than 10m in height an air valve was located upstream of the non-return valve. Without this air valve, there was the potential for vapour pressures to be created upstream of the non-return valve on the pump stopping, along with the potential for transient pressures in the riser. By providing the air valve the vacuum would be broken, but the riser needed to be primed during each pump start. By utilising the slow start required to prime the line generally and appropriately sizing the air valve, most of the air could be purged from the system before the pump reached full speed. The air valve tee was smaller than recommended and so was not as efficient at removing all the air that it should have, which led to some air passing forward through the pipeline and it found its way to the surge vessel. The initial automatic vent to the surge vessel was not designed to accommodate this and, during commissioning of the pipeline, had to be enlarged to accommodate this.

The falling column of water also causes the pump to turbine in reverse and that this needed to be considered when specifying the pumps to ensure that this was safe to do so without damage to the pump or motor. The reverse-flow condition was beneficial in flushing out debris from the pump body and suction pipework.

9.3 UNSTABLE FLOW CONDITIONS

Transient modelling demonstrated that there was no significant risk at AV2 during priming, even at full flow. However, the initial profile had AV6 sitting slightly higher than AV4 and it was determined that there was a strong likelihood of high pressures developing at AV6 when the stationary water column contained by AV4 collided with the pumped flow.

The initial recommendation was to reduce this risk by pumping at a minimum rate of 450 l/s for a period of two hours at the beginning of each storm event. The main implication of this would have been that for the first two hours of any storm event the maximum allowable flow rate would be at least halved. Not only would this have meant the full treatment capacity of the treatment plant would not be used, but it would have meant that the storage at the pumping station would be filled more quickly resulting in more frequent spills at Kilmarnock.

Ultimately, the recommendation was relaxed by adjusting the pipe profile such that the level of AV6 was reduced to approximately one metre lower than AV4 that an air pocket would not form at AV6 at resting hydraulic levels. For the final profile shown in Figure 5, the recommendation was still to pump at a rate of 300 l/s until the rising main was fully primed. As can be seen by the profile pumping at this reduced rate or even 450 l/s (one pump at full speed), this would not result in the pipeline becoming fully primed between these points. However, a slow pump start-up and initial minimum speed operation of the pumps was retained within the control philosophy so that air was able to be purged from the system before reaching full flow. The step between 450 l/s and 900 l/s as the pumps changed from single pump to two pump operation was managed over a period that allowed for a more stable transition.

9.4 LOW VELOCITY AND SEDIMENTATION

As can be seen in Table 1 the pipeline generally achieves self-cleansing velocity of 0.75m/s for the operation of a single pump providing 450 l/s. This not quite achieved for the 1000mm diameter sections that operate as a traditional rising main in that they are generally full where the velocity at 450 l/s is 0.67m/s. This section could have been reduced to 900mm diameter to improve the self-cleansing of the pipeline for single pump operation. This would have resulted in an increase in operating head of only 1.9m for a single pump at 450 l/s and so would have been feasible in this respect. However, the proposed change came at a late stage in the design and the head increase of 7.5m on the pumps at 900 l/s was considered likely to cause a pump reselection with the potential for further changes being required to the MCC, power supply and surge vessel selections, with the cost of any delay outweighing the benefits. Consequently, only the last section of rising main immediately upstream of the discharge was reduced in diameter as this had no hydraulic effect on the pumps.

9.5 ODOUR AND SEPTICITY

Odour and septicity were not considered to be a likely problem in this system as it was primarily capturing overflows generated by storm events and the pipeline passed through a primarily rural area. However, key air-valve locations were provided with chambers suitable for the retrofitting of odour control units and space was assigned for the future fitting of a chemical dosing plant for septicity if it was found to be a problem once the pipeline was in operation.

10 CASE STUDY 2: MORNINGTON PENINSULA BACKLOG SEWERAGE SCHEME

The Southern Mornington Peninsula Backlog Sewerage Scheme transfers sewage from several coastal residential and holiday towns to Boneo Sewage Treatment Plant (STP) and will ultimately connect over 15,000 properties to the system. The trunk transfer system broadly consists of:

- 15.4km pressurised transfer main comprising 12.5km of pumped main, a steep 0.2km long partially-full falling section, and 2.7km of pressurised gravity main
- 97 l/s capacity first-stage pump station and 233 l/s capacity re-lift pump station
- 25 pressure sewer reticulation direct injection points
- Liquid chemical dosing, biological treatment, ventilation, and activated carbon filters for odour control
- Works at the terminal high point to control air entrainment and to manage odorous discharges.

The transfer system was delivered by a design and construct voint venture with Beca undertaking the design and Fulton Hogan and Delplant completing the construction.

10.1 PIPE MATERIAL

The pipeline was constructed of DN355 to DN560 PN16 polyethylene to suit the mostly trenchless installation (horizontal directional drilling), cater for the long-term operation at operating pressures of up to 10 bar, and to help mitigate the risk of leakage from joints into surrounding ecologically-sensitive areas.

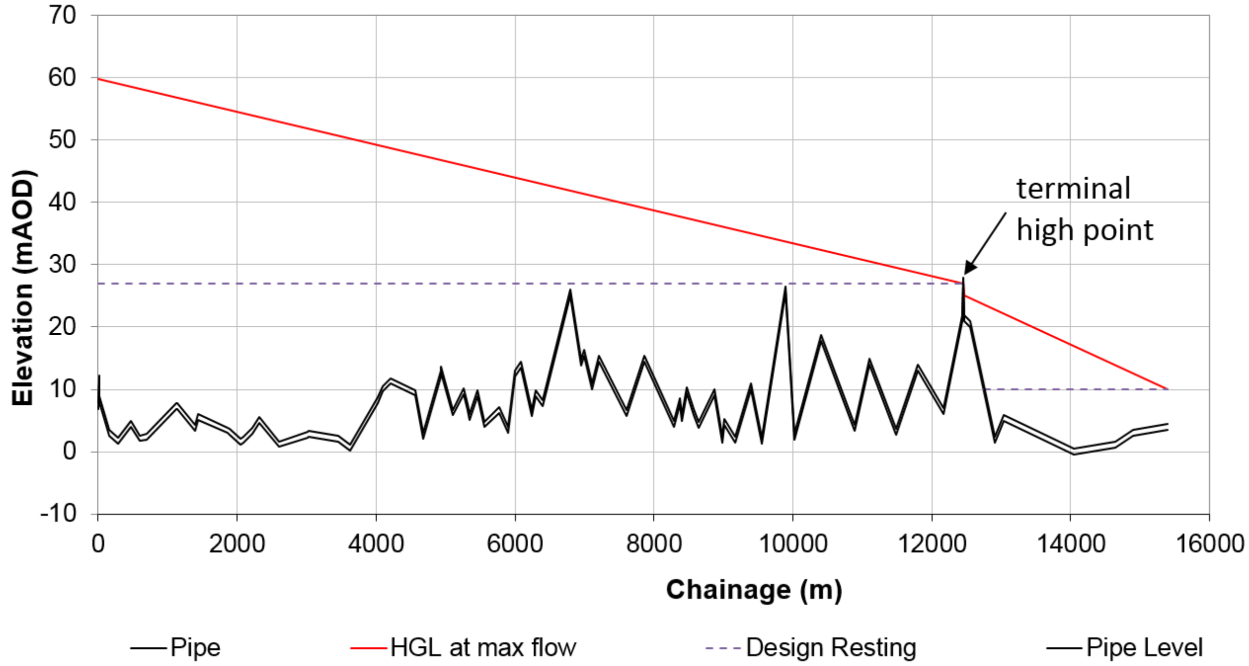
10.2 PIPELINE ALIGNMENT

The vertical profile of the pipeline was significantly dictated by the required pipeline location, which needed to cater for the location of reticulation injection points and be generally located within public road reserves and existing pipe easements to avoid impacts to the community and ecologically and culturally-sensitive areas. The resultant vertical alignment presented several challenges related to hydraulics, operating pressures, air management, and surge.

The alignment resulted in the formation of a terminal high point approximately 2.9km from the discharge to the treatment plant. This required careful consideration to manage air and odour.

The pipe loop incorporated at the terminal high point helped to maintain sufficient static pressure for air valve sealing, and to provide a hydraulic break between the pumped section and the falling/gravity section at all flows up to the maximum design flow.

Figure 7. Pipeline longitudinal profile and hydraulic grade line



10.3 PUMPING STATIONS

Both the first-stage and re-lift pump stations were wet well types with duty/standby pumps on VSD control. The pumps operated in three modes; traditional start/stop at a fixed low speed during periods of low inflows, variable speed to maintain a constant level in the wet well during moderate to high flows, and full speed during the highest flows and during periodic flushing of the main.

10.4 HYDRAULICS

The hydraulic requirements of the system under a range of flows was assessed within an Infoworks model. Since the transfer main is hydraulically connected to the pressure sewer reticulation network via 25 direct injection points, the hydraulic assessment had to evaluate both the transfer main and the reticulation network.

In the early years of scheme operation with a low number of houses connected, the transfer main would need to operate at flow rates considerably lower than predicted ultimate rates. A number of potential issues associated with low flows and long rising mains that required consideration included:

- Lack of adequate solids transport
- Not achieving slime shearing velocity
- Excessive retention times
- Air entrainment and discharge of odorous air

10.5 AIR MANAGEMENT

Raw sewage air valves were provided at high points in the transfer main and drain down valves at the low points. To minimise ingress of air into the pipeline, air valves were single acting to allow air out of the main, but not into the main. Low pressure sealing types were used where the operating pressures were low. Manual bleed valves were provided for air admittance during pipe draining.

Generally, DN50 air valves were considered sufficient for the small quantities of foul air expected to be discharged. The inclusion of a 200-litre activated carbon canister at each air valve was adopted for odour control. Access suitable for a light vehicle was provided at each valve to permit maintenance and allow changing of the canisters.

The air valves were fitted with an isolating valve to permit maintenance without having to drain the main line. Quarter-turn ball valves were used for DN50 air valves, with resilient-seat gate valves adopted for larger air valves.

More demanding air and odour management requirements applied at the terminal high point before the falling section, which under most flow conditions operated as a part-full gravity pipeline for some of its length. Substantial volumes of air could be introduced to, and expelled from, the falling main. This was due to air being expelled when the pumps started, and also entrainment of air at the hydraulic jump which would occur where the flow transitions from a fast, shallow part-full flow regime to full pipe flow. To avoid entrained air quantities substantially overloading the air valves downstream, several concepts were investigated, as described below.

10.5.1 ADOPTED SOLUTION

The methodology adopted was to manage the air entrainment and re-release to ensure the amount of entrained air was minimised in the first instance, that any air that was entrained was removed quickly, and that excess air was adequately treated before discharge.

- Minimising the quantity of air entrained was achieved by increasing the diameter of the transfer main from DN560 to DN800, DN710 & DN630 for a 200m section downstream of the high point. The reduced flow velocity in the enlarged section allowed bubbles of entrained air to rise to the pipe obvert and then flow back upstream to the air gap in the section of part-full pipe flow. While this was expected to capture the majority of the air, some air may become entrained in the flow and carried downstream.

- Releasing the entrained air was undertaken in two stages, primarily through capturing it at the base of the hill by provision of a full-diameter (DN560) tee and air valve and then piping it back up to the high point through a DN100 return vent. This effectively 'recycled' the air back into the falling main, which minimised the amount of air that had to be discharged from the pipeline and treated. This air valve was installed several metres below ground to maintain sufficient sealing head. Given this air release point would deal with potentially large volumes of air and would need to operate with a high degree of reliability, twin DN100 air valves were installed (a single DN150 air valve would have been too heavy to easily lifting from the pit). Even though the pipe loop provided a hydraulic break at flows greater than the maximum design flow, an air valve was utilised as protection against uncontrolled discharge in the event the pipeline become blocked downstream.

- The next air valve downstream was expected to capture relatively small amounts of remaining air, but significantly more than the 'average' air valve. Therefore, it was fitted with twin activated carbon canisters for effective odour treatment.

- An odour control facility was incorporated at the top of the terminal high point to treat air that would be discharged as the empty falling main filled and residual air recycled through the return vent. This foul air would be highly odorous, and an activated carbon filter sized for the expected maximum air flows (up to 305 l/s) was initially installed. Provision for addition of a biotrickling filter was made in case the odours became too severe for the carbon filters.

10.5.2 ALTERNATIVE STRATEGIES CONSIDERED

Two alternative air management strategies were considered during the design stage, as described below, but were ultimately ruled out.

The first alternative air management option that was considered was to keep the line full with a pinch valve at the bottom of the hill, effectively avoiding any sections of part-full pipe flow. The valve would be automatically controlled to partially close so that the line would remain full at low flows and when the pumps stopped. This would avoid the need for a major odour management unit at the high point, though an air valve and carbon canister would still be required to release any captured air.

Whilst this option was theoretically possible, it had a number of practical issues, the most significant of which was operation under some failure conditions. If there was a local power failure at the valve and not at the pumping stations, control would be lost. Under these conditions there would be a risk of ingress of air (and subsequent odour release) if the valve was opened too much, and a risk of sewage spill if the valve was too closed.

A second alternative option considered was to operate the falling section as a part-full gravity pipeline under all conditions and installing another pumping station at the base of the falling section with an odour treatment facility. Air that the gravity pipeline entrained would be released at the wet well. A simple air inlet vent would have been required at the high point to admit air. Odour management at the pump station would need capacity to positively ventilate the falling section of the pipeline under all conditions.

This option had operational advantages and disadvantages. The advantage was that it would be more effective at removing entrained air and so there would be less air released from the downstream air release valves. The disadvantage was that it required another pumping station that came with its associated capital, operating, and maintenance costs. Additional approvals and land acquisition would also be required.

10.6 SUB-ATMOSPHERIC CONDITIONS

The critical transient condition for the pump and rising main system is uncontrolled stop of the pump, particularly at high flows. This event would create a negative pressure that would propagate away from the pump station and along the rising main. While the polyethylene pipe is capable of withstanding vapour pressure conditions in conjunction with the external loads, the water authority required measures to mitigate column separation and cavitation to be implemented.

While air valves are a common method for relieving vacuum conditions, the one-way air valves used at the high points on the pipeline (to help manage odour associated with air ingress and expulsion) would be ineffective. Therefore, the mitigation measure adopted comprised of an air vessel to rapidly force a large volume of liquid into the pipeline following pump shutdown. The air vessel was a dipping-tube type, suitable for use with wastewater. This type of air vessel helped reduce the required maintenance as it had no internal bladder or need for permanent pressure regulation. In the event that the air vessel was not functional, the pipe would rely on its inherent capacity to withstand the resultant pressures.

10.7 UNSTABLE FLOW CONDITIONS

Rising mains often have problems with rapidly changing hydraulic grade lines when sections transition from part-full gravity flow to pressurised falling main. The resultant pressure surges can lead to premature pump failure.

This was avoided on the transfer main with the above-ground pipe loop at the terminal high point providing a hydraulic discontinuity between the upstream pressure main and the downstream falling main section. The downstream HGL at the maximum design flow of 305 l/s was several metres below the top of the pipe loop.

A vent from the top of the pipe loop allowed air to flow into and out of the main as the falling section filled and emptied under varying flow conditions.

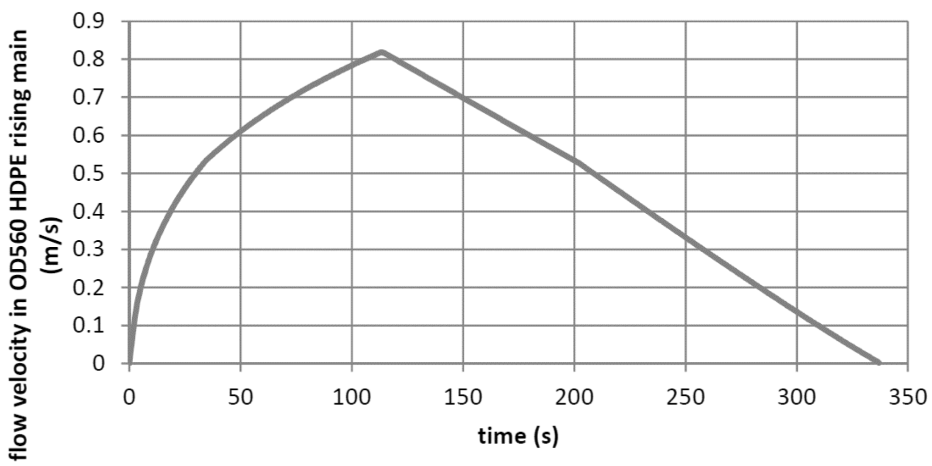
10.8 LOW VELOCITY AND SEDIMENTATION

Options to stage the delivery of the pipeline to help maintain sufficiently high flow velocities and reduce residence times in the main during the early years, when only a small number of properties were connected, were evaluated. This included installing a smaller main for the initial flows and a second larger pipe to help convey the higher flows. However, the limited construction width within road reserves and pipe easements precluded installation of two side-by-side pipes, particularly given that the pipes would need to be installed by trenchless construction methods. The adoption of a single full-size pipe required regular high flow flushes to be implemented, along with chemical dosing to address septicity issues associated with long residence times.

The pipeline to the terminal high point was always full and acted as a conventional sewage rising main. Regular flushing of the pressure main was achieved through pumping at sufficiently high flows for self-cleansing and slime stripping. Flow detention in the wet well above normal cut-in level and undertaking the flush during the diurnal peak flow provided a greater flushing volume.

Downstream of the terminal high point the pipe could partially empty and, beyond that, the pipeline effectively acted as a pressurised gravity main. The ability to generate flushing flows in the gravity section was hampered somewhat by the volume available in a pump cycle and the need to fill the initial falling section in order to develop the driving head to generate the flows. The re-lift pump station had sufficient wet well volume to provide 233 l/s for around two minutes. Surge pressures did not unduly prevent the pumps from ramping rapidly to full speed. This generated around 3.4m of driving head in the gravity section to produce a flow in excess of the 0.7m/s self-cleansing velocity for over a minute. Slime shearing velocities could not be achieved and so the system hydraulics accounted for a higher wall roughness through that section.

Figure 8. Velocities achieved in the gravity section during a flushing cycle



10.9 ODOUR AND SEPTICITY

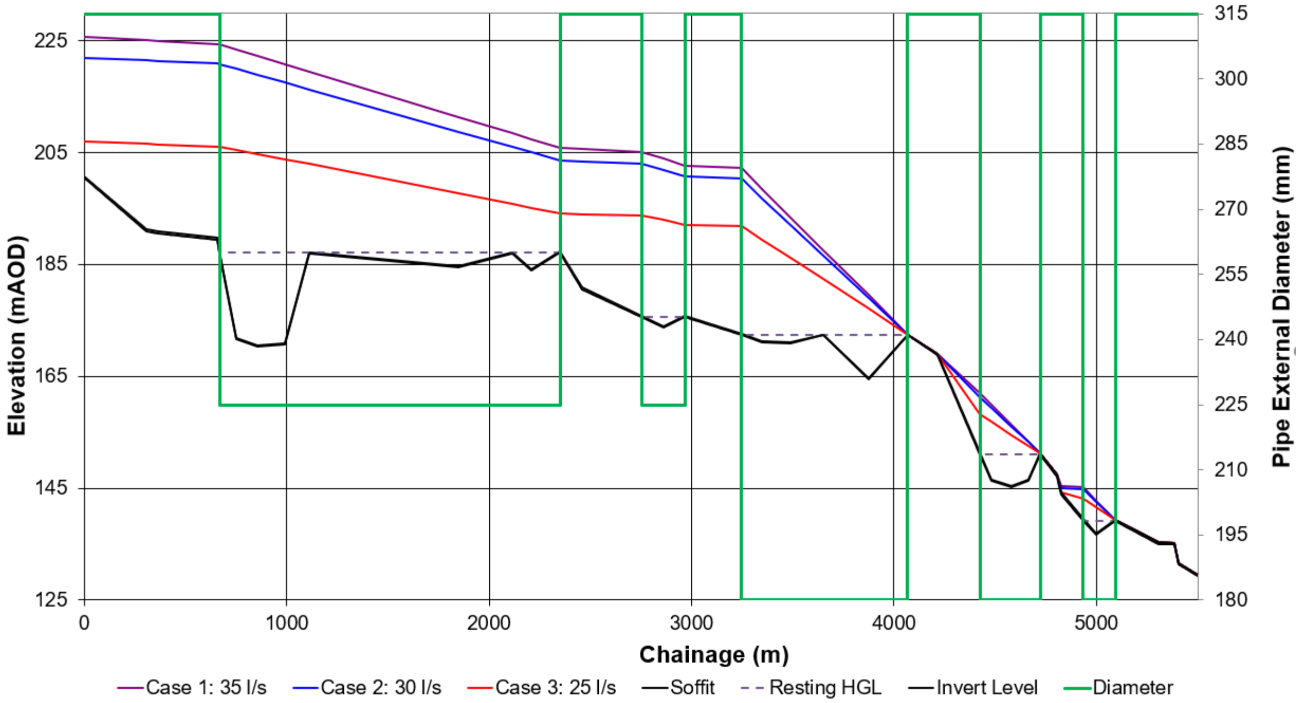
The odour and septicity control for the transfer system had to be robust, flexible, and reliable to accommodate the wide variety of flows and loads from the initial low flows to the peak flow, intermittent nature of flows in a holiday home area, and sludge age following a 24-hour power outage. Fugitive emissions from the transfer system could not exceed 500 ODU (odour units) at the vent stack. Sulphide concentration in the liquid phase discharge to the treatment plant had to be 5-10 mg/l. The odour and septicity management system adopted comprised of:

- Gas phase treatment consisting of mechanical ventilation through a biotrickling filter and activated carbon polishing at both pump stations
- Liquid phase treatment comprising dosing of iron salts at the re-lift pump station
- Activated carbon filters on all air valve discharges

11 CASE STUDY 3: GLENCORSE WTW SLUDGE MAIN

The sludge main for the Glencorse Water Treatment Works conveyed process sludge and sewage from facilities at the treatment works to a local sewer some 5.5km away. While not a dedicated sewage pumping station, the development of the design required several key considerations that the main initial lift was provided by a pumping station, however the majority of the pipeline was generally falling towards the discharge point and so large sections of the main emptied when the pumps stoped.

Figure 9. Glencorse WTW Sludge Main Pipeline Profile



11.1 PIPE MATERIAL

The pipeline was constructed of a mixture of DN180, DN225 and DN315 polyethylene to suit the velocity in sections that were permanently primed and free draining. The pipe rating was SDR 21 largely to withstand earth pressure and for constructability rather than for pressure requirements.

11.2 AIR MANAGEMENT

Between pump operations, the system drains by gravity almost completely except for a few sections. The local high points that hold water upstream in several locations is shown by the resting HGL in Figure 9.

The pipeline profile was developed considering the slope of the pipe required to manage air effectively. Minimum pipe slopes were checked so that part full sections had sufficient gradients to provide a maximum flow depth of two thirds of the pipe diameter so that air could migrate back to upstream air valves. Generally, the minimum pipe slopes were flatter than slopes practical for laying other than at the full design flow. Table 2 shows the consideration of the slopes for the relevant sections of pipeline and the effect of choosing different flowrates for the pump.

Table 2: Glencorse WTW Sludge Main Hydraulic Parameters

OD (mm)	ID (mm)	Flow (l/s)	2/3 depth (mm)	Vel (full) (m/s)	s (full) (1:X)	max s, v= 0.75	s (2/3 dia) (1:X)	V (2/3 dia) (m/s)
315	285.0	25	190	0.392	844	237	516	0.553
180	162.9		109	1.200	43	236	26	0.436
225	203.6		136	0.768	141	141	86	1.085
315	285.0	30	190	0.470	588	265	360	0.664
180	162.9		109	1.440	30	268	677	0.523
225	203.6		136	0.922	98	98	60	1.301
315	285.0	35	190	0.549	433	287	265	0.775
180	162.9		109	1.680	22	296	499	0.610
225	203.6		136	1.075	72	72	44	1.518

11.3 SUB-ATMOSPHERIC PRESSURE

The primary concern with regard to the generation of sub-atmospheric pressure was the ability to draw in sufficient air through air valves once pumping ceased. This was achieved through standard DN100 air-valves because of the small diameter of the rising main.

11.4 PRIMING

The major consideration for the pipeline was ensuring that self-cleansing velocity was developed along the full length of the pipeline. This was a particular concern as the sludge had a high sediment load compared to sewage and needed to be kept moving through the system. A priming model was built to determine the volume required to mobilise self-cleansing velocity through the whole pipeline. In this case the volume required between the pumping start and the pumping stop was 46m^3.

11.5 ODOUR AND SEPTICITY

Odour and septicity were not considered to be a likely problem in this system as it was in regularly used and flushed and the pipeline passed through a primarily rural area.

12 CONCLUSIONS

A range of factors are driving water utilities to centralise their wastewater treatment, including stricter consent and licencing conditions for treatment plants, discharges, and re-use, enhancement of resource recovery, and adaptation to a changing climate. This forces many cities around the world to pump wastewater considerable distances.

Undulating vertical pipeline alignments in particular present several challenges related to air and odour management, hydraulics, and surge.

Air within a rising main can come from various sources and undulating pipelines with a discharge lower than the high point in particular, where parts of the pipeline may run part-full periodically or permanently, need to consider the management of air within the pipeline to ensure that carrying capacity is not reduced.

While crucial to the management of air for the efficient and safe operation of a pipeline system, incorrectly placed or sized air valves can create operational problems. Maintenance of air valves is also often neglected to the point that they are sometime not functional.

The potential for generation and release of nuisance odour increases with long distance pumping. Longer rising mains are more susceptible to generating odours due to longer residence times and the increased potential for septicity. Pipe mains that fill and partially drain on every cycle air draw in and expel air on every cycle and so the potential for release of nuisance odour is increased. Odour and septicity control for long pumped systems need to be robust, flexible, and reliable to accommodate the wide variety of flows and loads from the initial dry weather low flows when development has only just started to the fully-developed catchment wet weather peak flows.

Rising mains often have problems with rapidly changing hydraulic grade lines when sections transition from part-full gravity flow to pressurised falling main. The resultant pressure surges can lead to premature pump failure.

In a combined pumped and gravity system, there is a delay between the pump reaching its design flow and that same flow being discharged at the outlet point of the system as air is purged from the system. The pump run time must be managed to ensure that self-cleansing and slime-stripping velocities can develop along the whole length of the pipeline.

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