SOLVING OPERATIONAL PROBLEMS WITH INVERTED SIPHONS

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ABSTRACT

Inverted siphons on sewer networks typically suffer three main types of operational problems: siltation, air locking and odour. This paper describes the successful implementation of solutions for all 3 of these problems at inverted siphons on North Shore City Council's (NSCC) trunk sewer network.

Siltation and blockage is often thought of as the main operational problem likely to afflict an inverted siphon. NSCC has one trunk sewer with 4 single barrel inverted siphons in series, which has had a history of overflow problems. These inadequacies have now been mitigated by the construction of a storage tank upstream and the addition of access and drainage facilities.

Air Locking is another cause of reduced siphon capacity, and is usually the result of poor hydraulic conditions at the inlet and insufficient consideration of air passage out of the descending leg. NSCC has a twin barrelled siphon that has suffered particular air locking problems until recently. These problems were solved using a low-cost venting arrangement on the descending leg, avoiding the need to replace sections of siphon barrels with larger diameter pipes.

Odorous air discharge has been the most frequent and challenging problem encountered by NSCC. Biofilters have been one of NSCC's favoured solutions for odour treatment, and 2 have been constructed at siphon locations, with good, although varying, levels of success. However, a combination of odour treatment together with chemical dosing is currently being trialled, and is showing considerable promise.

KEYWORDS

Inverted siphon, silt, air locking, odour, biofilter

1 INTRODUCTION

North Shore City Council (NSCC) operates a wastewater network which includes 1,344 kilometres of sewers with sizes ranging from 100mm diameter to 1335mm diameter. These drain to the Rosedale Wastewater Treatment Plant, which discharges highly treated effluent into the Hauraki Gulf.

The majority of NSCC's sewer network comprises gravity pipes, but the network also contains 11 trunk sewer siphons (of size 300mm diameter and above) and 11 local siphons (smaller than 300mm diameter). Although NSCC commonly refers to them as just siphons, they are actually inverted siphons (or depressed sewers) and they typically traverse valleys, watercourses or pass under the sea. Some of the trunk sewer siphons have been identified as posing a high operational risk. Four of them are twin siphons (i.e. they have two parallel barrels).

The operational problems associated with these inverted siphons have included high levels of odour at the upstream end, and also the inability to determine their condition due to the fact that they are always full of water and are therefore very difficult to inspect.

2 SILTATION

2.1 OVERVIEW

Siltation is often thought of as the main operational problem likely to afflict an inverted siphon, causing increased head loss, a reduction in carrying capacity and being a source of odour. Hard debris can also damage the interior of the pipe.

NSCC has a trunk sewer (TS11) with 4 inverted siphons in series, which have a history of odour and overflow problems. The siphons are all 635 mm ID single barrelled concrete lined steel pipes varying in length from 88m to 227m. They traverse steep sided bush clad valleys, and each has a horizontal pipe bridge section crossing the stream on the valley floor. The majority of flow in the sewer comes from a major multi-pump pumping station upstream, with a minor portion from local catchments. Flows approaching the siphons are either less than 10 l/s or approximately 140 l/s, 245 l/s, or 320 l/s, depending on the number of pumps operating. The siphons were built in the 1960s without provision for drainage or access. As a result, they have been very difficult to clean and pose a significant operational risk to NSCC.

The recent provision presence of a large storage tank at the pumping station made it possible to develop and implement a solution involving the addition of access hatches and drainage facilities. These allowed the 45 year old siphons to be drained, cleaned and internally inspected for the first time, and removed the need for a much more expensive duplication/replacement project.

This section outlines the challenges of the project, how they were overcome, observations about the condition of the siphons and a comparison of the original siphon design against current design practice.

2.2 PHYSICAL WORKS

While addition of access and drainage facilities appeared to be a straight-forward project, many issues needed to be addressed to ensure it was completed safely and with the minimum of environmental effects. Steep terrain, dense vegetation and slippery surfaces were some of the issues that had to be accommodated (see Photo 1). The first task was to create safe access to the horizontal sections, for installation of the drainage points and for future maintenance works. This was achieved by clearing vegetation and constructing paths, steps and working platforms.

Photograph 1: Typical Terrain around the Horizontal Sections of the Inverted Siphons

Hatch box assemblies and drainage valve stubs were then welded onto convenient locations on the horizontal pipe bridge sections. The tapping rig was manually handled into place down the newly built steps and live tap-ins were carried out on the same day as the hatch boxes and stubs were fitted.

When welding the access hatch assemblies on, the MIG welding process caused some small leaks from the pipe. These were repaired, but as a matter of precaution a Non Destructive Testing Technician was asked to inspect the pipelines using ultrasound equipment. The tests found that there were some spots of surface corrosion and pitting, particularly at the spiral welds. However, it was all treatable and any exposed corroded areas were cleaned back to the metal surface, then properly primed and painted.

One of the siphons could be drained to a local sewer which is at a lower elevation than the drainage point. However, to drain the others, flows had to be lifted 15 to 20 m, either to the downstream end of the siphon or to a more convenient location on the local network. Flow rates to local sewers also had to be controlled to prevent overflows occurring lower down the catchment. Due to the criticality of the drainage operation, a trial run of the draining equipment was undertaken at the contractor's yard prior to taking the equipment to site. A trial was then carried out on site. The drainage apparatus comprised a short length of flexible hose from the drainage valve to a light weight 0.4kW electric pump with a 100mm shut off valve, 100 m length of 100mm lay-flat hose laid out uphill to a weir box flow measurement device set up to drain into the local sewer manhole (see Photo 2 below).

Photograph 2: The weir box flow measurement device discharging to a local manhole

Photograph 3: Completed installation

After a successful trial on site, arrangements were made to shut down the upstream pumping station. A clear window of about 6 hours was available until the storage tank would be close to its capacity. Drain down of the siphons was generally completed in 1 to 2 hours with no spills occurring.

Once emptied, the siphons were CCTV'd, jetted clean and CCTV'd again. 600 x 400mm holes were also cut in the pipe wall through the welded on hatch box assemblies. These openings allowed stones and other debris to be removed from the horizontal sections of the siphons using shovels and sewer spades. Photograph 3 shows an example of a completed installation.

2.3 CCTV OBSERVATIONS

Below the normal water level the internal concrete lining was in a good condition, showing few signs of deterioration. However, above the normal water level there was evidence of acid corrosion, most significantly in the upstream sewers and where there is an initial shallow slope to the descending leg (see Photo 4).

Stones and silt were present in the horizontal sections of all the siphons, and had tended to accumulate at the transition from horizontal to ascending leg, with depths up to 1/2 pipe diameter (see Photo 5). Silt had also collected along the invert of the shallower (7° and 12°) sloping sections of the ascending legs. But no material was observed in any steeply sloping (25° and 34°) ascending legs. Some larger objects were also found, such as a mallet and a barrow wheel.

Photograph 4: Corrosion on the descending leg of one of the siphons

Photograph 5: Silt build up at the transition from horizontal to ascending leg

2.4 COMPARISON WITH CURRENT DESIGN GUIDANCE

Common design practice for inverted siphons has been to ensure that some assumed minimum velocity, often 0.9 m/s (Metcalf & Eddy, 1981), is exceeded at least once a day (BS EN 752, 1998) to avoid a build up of silt. More recent design guidance by May, 2000 attempts to take into account sediment load and inclination of the acsending leg of the siphon when determining a minimum velocity. Applying May's method to the TS11 siphons for a typical separate system sediment load, suggests that velocities would need to be in the region of 1.1 m/s to 1.3 m/s at least once a day to achieve self-cleansing.

Analysis of the TS11 system suggests that velocities through the siphons don't even reach 0.5 m/s on a daily basis and peak at only 1 m/s when the upstream pumping station is running at capacity, which only occurs during severe wet weather. Design guidance suggests that these conditions are not sufficient to keep the siphons free from silt build up; and this has been borne out by the observations made during the CCTV survey discussed above, and the reported occurances of blockages and overflows over the years.

2.5 CONCLUSIONS

It would have been best to locate the access hatches close to the transition from horizontal to ascending leg, as this is where most of the heavier sediment collects. These also happen to be the lowest points on the siphons, as the horizontal sections were constructed with a slight slope in the downstream direction. However, locating the drainage points where most of the silt collects would have lead to blockages. In the end, feasible access routes, terrain, vegetation and consent issues determined where the hatch boxes and drainage valves could go.

In summary, the TS11 siphons do not incorporate two fundamentals of inverted siphon design. Firstly, it is common practice for inverted siphons to have at least two parallel barrels. Multiple barrels give more scope to maintain adequate self-cleansing velocities during dry weather, and allow one barrel to be taken out of service for maintenance. Secondly, no consideration was given, during either design or construction, to draining and cleaning the siphons in the future. Even if theoretical self-cleansing velocities are achieved, stones and larger objects are almost certain to collect in the invert, and the provision to remove them is essential.

In the case of the TS11 siphons, these inadequacies have been mitigated through the construction of storage upstream (although this is not the primary purpose of the storage, that being overflow reduction) and the addition of access hatches and drainage facilities.

3 AIR LOCKING

3.1 OVERVIEW

Air Locking is another cause of reduced siphon capacity, and is usually the result of poor hydraulic conditions at the inlet and insufficient consideration of air passage out of the descending leg.

At Spoonbill Place, NSCC has a twin barrelled siphon that has suffered air locking problems until recently. These problems were solved using a low-cost venting arrangement on the descending leg, avoiding the need to replace sections of the siphon barrels with larger diameter pipes.

3.2 SIPHON INLET GEOMETRY

Figure 1 below, shows (schematically) the geometry of the Spoonbill Place siphon. Photograph 6 is an overhead view of the inlet chamber. The siphon barrels are nominally 250mm and 310mm diameter, and the inlet manhole approximately 3m depth to invert. The siphon receives the discharge from a multi-pump pumping station only, with no local catchment connections. Flows approaching the siphon are therefore either zero or approximately 70 l/s, 100 l/s, or 110 l/s, depending on the number of pumps operating. Basic hydraulic grade-line capacity analysis did not identify a capacity problem. However, simple observation revealed that at 70 l/s surcharge was significant, at 100 l/s surcharge reached to within 300 mm of ground level, and at 110 l/s the inlet manhole overflowed. Once the pumps stopped, and as the surcharge abated, bubbles of air would “burp” out of the siphon barrels.

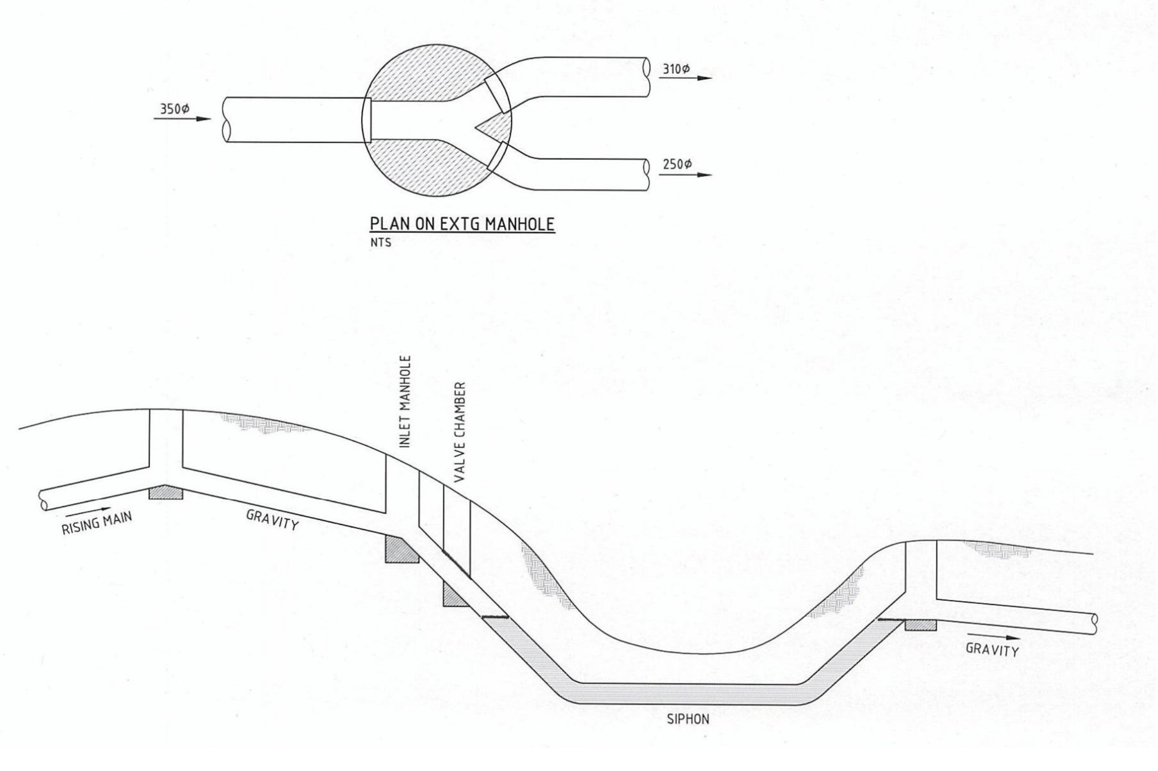

Figure 1: Spoonbill Siphon Geometry (Schematic)

The siphon outlet is some metres lower than the inlet, meaning a significant air space exists in the descending leg when flow begins. To compound problems, the approach sewer is very steep and approach velocities high, circa 4 m/s at 70 l/s.

Consideration of the possible causes of the observed behaviour led to the hypothesis that a large portion of the air bubble was remaining trapped in the siphon immediately downstream of the inlets, effectively reducing the diameter of the siphon barrels by a substantial degree.

Photograph 6: Siphon Inlet Layout - Flow from left to right

3.3 AIR RELEASE VENTS

A few metres after the inlet manhole the siphon barrels are fitted with isolation gate valves in a dry manhole chamber. This chamber therefore offered a convenient way to fit a pair of simple 50 mm diameter air release vents into the region where the air bubble was believed to be trapped. Photograph 7 shows the new vents. The vents exhaust back into the inlet manhole.

The change in siphon behaviour with the vents operational has been significant Flows at 70 l/s remain within the benching of the inlet manhole and higher flows remain well within the manhole depth although some nominal surcharge is still observed. Photograph 8 shows the present behaviour at 70 l/s. Note that while flow remains within the benching channels, the flow pattern is still extremely turbulent reflecting the very poor layout of the inlets with the high velocity inflow jet directly striking a splitter structure.

Photograph 7: Air release vents

Photograph 8: Behaviour at 70 l/s after installation of air release

3.4 CONCLUSIONS

Flows exiting a manhole may behave like an inlet–controlled culvert, effectively submerging the outlet opening and giving the outward appearance that the downstream pipe is under sized. In a siphon situation of the layout sketched in Figure 1, this phenomenon can also permanently trap a large bubble of air within the siphon, substantially reducing the useable pipe cross-sectional area and severely reducing its carrying capacity. Provision to allow this bubble to escape back into the inlet manhole is sound practice.

At sufficiently high velocities, the air bubble will be purged onwards through a descending pipeline, but this may take a considerable time even when velocities are theoretically adequate. Escarameia, 2005 provides guidance on the necessary velocities for purging air; the critical velocity being dependent on the downward slope and the size of the air pocket. However a more pragmatic design approach is to avoid this problem altogether, or at least include some venting provisions on the descending legs of the siphon.

Siphon inlet chamber design requires careful consideration to avoid air locking problems. The layout shown in Figure 1, is not recommended. A deeper manhole as sketched in Figure 2, where the driving head can develop in a large diameter vertical shaft is preferred. Where this not possible, air release provisions must be included to allow air bubbles to escape.

The inlet structure, like all manholes, must also be arranged to minimise turbulence and hydraulic losses. Figure 3 shows one improved layout to that seen in Figure 1. Normal flows directly enter one barrel and at higher discharges the additional flow spills over a low weir into the second barrel.

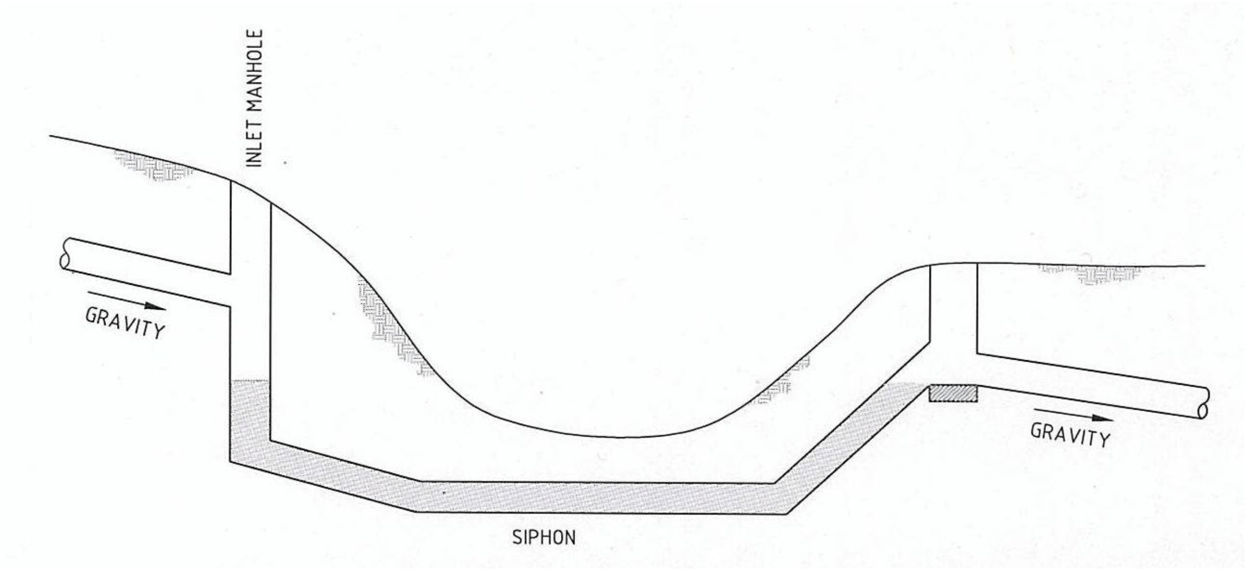

Figure 2: Deep Inlet Manhole

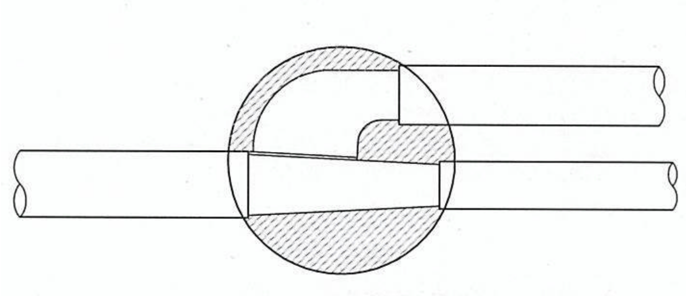

Figure 3: Suggested improved design for the manhole in Figure 1

4 ODOUR

4.1 OVERVIEW

Odorous air discharge has been the most frequent and challenging problem encountered by NSCC. Past designs have often ignored the obstruction to sewer air flows caused by an inverted siphon, resulting in odorous air escaping in an uncontrolled manner from the upstream sewer. A number of options are available for dealing with this problem. Biofilters have been one of NSCC's favoured solutions for odour treatment, and 2 have been constructed at siphon locations, with good, although varying, levels of success. However, a combination of odour treatment together with chemical dosing is showing considerable promise.

4.2 SIPHON BEHAVIOUR

Another poorly understood requirement for siphons that receive rapidly varying flows (such as intermittent discharge from a fixed-speed pumping station), is the need to *accelerate* the water body in the siphon itself from a low (or stationary) velocity condition to working velocity over a brief time interval. The inertia in a large or long siphon can be significant and considerable surcharge may be necessary at the inlet manhole in order to mobilise the siphon water body. This surcharge will displace a significant volume of air from the sewer headspace and if the air is odorous a significant nuisance can arise. In addition, flows in gravity pipelines approaching the siphon tend to drag significant quantities of air toward the siphon, exacerbating the odour nuisance potential at the siphon inlet.

If provision is not made to handle this air flow and treat the potential odour nuisance the odorous air will discharge from local manholes, and domestic drainage vents near the siphon. This positive air pressure within the sewer headspace and the resulting odour leakage can manifest a surprising distance from the siphon inlet chamber.

The same siphon that suffered the air-locking problem discussed above (Spoonbill siphon), was also the council's worst odour "hot spot". Until recently the siphon inlet was in "green fields" and the odour issue was not recognised. However, when recent development surrounded the vent, odour complaints immediately arose. Photograph 9 shows the proximity of the neighbouring houses to the siphon inlet manhole vent stack.

Photograph 9: Proximity of houses to odour source

4.3 HYDROGEN SULPHIDE AS A SURROGATE MEASURE FOR "ODOUR"

The rising main discharging to the siphon is long and generates high levels of dissolved sulphide during periods of dry weather. The extreme turbulence at the siphon inlet is then very efficient at stripping out the dissolved sulphide, leading to extremely high levels of air-borne H_2S and other odorous compounds.

NSCC has recently begun a city-wide Odour Management Strategy and has made a decision to monitor air-borne Hydrogen Sulphide as a convenient surrogate for odour, using small portable Odaloggers. Levels of air-borne H_2S within the siphon chamber regularly exceeded 200 parts per million and even now, with the measures described below, levels can still exceed 100 ppm. Unfortunately, at the time of writing, what concentration might represent “unacceptably odourous” remains to be determined. This will be determined as part of the Council’s Odour Management Strategy, but for the purposes of comparison levels elsewhere in the network are typically a few, to a few tens of parts per million. Figure 4 illustrates a typical diurnal H_2S concentration pattern experienced at Spoonbill siphon. The plot extends over 13 hours from around 10 am to around noon the following day and shows steadily increasing H_2S peaks through the night that coincide with each pump run from the contributing pump station. The highest levels (160 to 200 ppm) occur between 8 and 9:30 am, when the morning peak flushes the rising main to the siphon inlet.

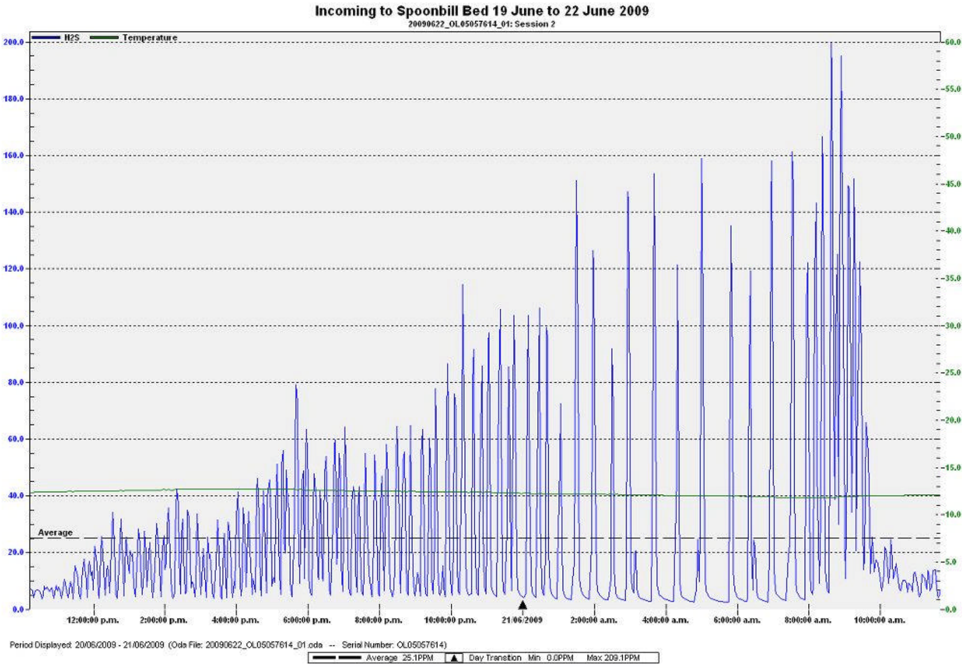

Figure 4: Observed Airborne H_2S concentrations at Spoonbill Siphon

4.4 BIOFILTERS

At Spoonbill a small pine-bark biofilter of approximately 15 m^2 footprint and operational since April 2008 has proved extremely effective at reducing the odour nuisance. Occasional odour is still noticed, particularly during warm, still summer days, but monitoring of the air immediately above the odour bed has demonstrated better than 99% H_2S removal and by inference, similar odour release reduction. Foul air is extracted at approximately 150 litres/second by fan from the siphon inlet chamber. The vent stack visible in Photograph 9 now operates as a supply of dilution fresh air, rather than a foul air exhaust.

While the fan and odour bed have addressed the odour nuisance potential at Spoonbill, the high sulphide levels still represent a significant corrosion hazard to concrete parts of the sewer network. Chemical dosing trials are therefore underway to try and reduce the generation of dissolved sulphide in the rising main. Currently Ferric Chloride is being trialled and is showing promising results, although the effect so far is a significant *reduction* in air-borne sulphide levels rather than *elimination*. The results of these trials may be the subject of another paper in due course.

4.5 CONCLUSIONS

Air discharge and associated odour nuisance potential is an essential operational consideration to include during design of inverted sewer siphons. Biofilter odour treatment offers one effective mitigation measure.

An alternative is to construct an “air jumper” pipe line parallel to the water siphon barrels. This would allow air reaching the siphon inlet to pass forward to the siphon outlet. However, it will introduce some additional design and operational issues of its own, including the drainage of accumulated condensation in the air duct low point.

Evaluation of the odour nuisance at particular locations in a sewer network has typically been assessed on the basis of complaints. This approach is not systematic and does not offer a reliable quantitative measure. By using convenient, portable odalogger instruments, NSCC has found that measuring air-borne H_2S appears to provide a reliable surrogate for measuring both odour nuisance and the effectiveness of various odour mitigation measures.

5 SUMMARY

The design of inverted siphons requires the consideration of a wide range of issues, which if not accommodated can lead to future operational problems. Recommendations that siphons should be avoided are common in sewerage design literature. However, they are often the only economic option for crossing water bodies, valleys or transport corridors. They are a reality for many sewer networks and so their weaknesses need to be understood and mitigated by water engineers if detrimental environmental effects are to be avoided, or at least mitigated to an acceptable level.

This paper outlines potential solutions for some of the most common problems that NSCC has experienced with the inverted siphons on their sewer network. It is hoped that these experiences will prove useful to other wastewater asset owners and engineers in managing existing, and designing future inverted siphons.

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REFERENCES

BS EN 752. (1998). *Drain and Sewer Systems Outside Buildings.* British Standard.

May, R. (2000). *Self-Cleansing Flow Conditions for Inverted Siphons.* HR Wallingford.

Metcalf & Eddy. (1981). *Wastewater Engineering: Collection and Pumping of Wastewater.* McGraw Hill.

Escarameia, M. (2005). *Air Problems in Pipelines - A Design Manual.* HR Wallingford.