STORMDRAIN & CULVERT REHABILITATION OPTIONS USING TRENCHLESS TECHNOLOGY

Jim Raz
Interflow Pty Limited

ABSTRACT

Stormdrain and Culvert rehabilitation is fast becoming the next major market segment for companies offering No-Dig and environmentally sensitive solutions for pipeline repair. This paper will discuss the diversity and size of this emerging market and will also consider the range of issues confronting both Clients and Solution providers. Issues include service life; pipeline inspection and duty of care; details on the extent of the problem; the variety of options available; structural design philosophies; hydraulic performance and environmental considerations.

---

1. INTRODUCTION

The International Pipeline Rehabilitation industry is mature, with many technologies in commercial use for more than twenty years to repair aging sewer infrastructure. Recent times have highlighted that sanitary sewers are by no means the only type of pipe system in dire need of preventative maintenance and rehabilitation solutions.

Stormwater pipe systems represent a major investment in infrastructure. They are however only in the public eye when they fail. As with all buried pipe systems, repairs can be a costly and disruptive process. In order to mitigate the high capital cost of repairing or replacing these assets, it has been common practice to schedule works so as to coincide with road resurfacing and highway widening. The consequence of this practice is that delays waiting for the major works program may allow the pipe or culvert to deteriorate to a point where they become dangerously close to catastrophic failure. As trenchless technologies are becoming more economic and versatile, this need no longer be the case.

The market for stormwater and culvert rehabilitation is not new – rather the opportunities that it presents for trenchless technology providers are now becoming more obvious as demand is increasing for authorities to maintain this vital infrastructure. This paper discusses the increasing awareness of the deterioration of stormdrain and culvert systems, the various types of problems and the means by which trenchless technology can be employed to address these problems.

Particular reference is made to the market within the United States of America, where the government authorities have been quick to recognise the problems that they face with aging storm drain and culvert infrastructure. These problems are by no means isolated to the USA. Many Australian Road and Rail authorities have a specific interest in this issue. They are putting in place protocols to assess the condition of their assets and putting capital works plans in place to restore or extend the service life of these structures.

2. THE INCREASING AWARENESS OF STORMWATER AND CULVERT FAILURE

2.1. Stormwater Pipe Failure

An awareness of the problems surrounding stormwater pipe infrastructure is becoming greater as detailed investigation becomes common place. Due to the emergence of a greater range of closed circuit television (CCTV) inspection tools, which can inspect the smallest pipe networks, more authorities are using the technology to inspect old pipes and insisting on post construction inspections before the hand over of a project. This practice alone has unearthed problems which would have been sleepers without such scrutiny.

2.2. Culvert Failure

Culvert failure is a much better documented phenomenon than storm drain failure. This is generally because culverts are larger diameter and more exposed than stormwater pipes and hence easier to inspect. Culverts are generally below main transportation routes, creating an additional incentive to ensure that they are not in danger of catastrophic failure. "By far the largest single source of flood loss, on both a monetary basis and in terms of directly affecting the greatest number of people, is damage to transportation infrastructure and utility services. Infrastructure damage also represents the greatest public safety hazard. All of the three flood related fatalities since 1995 were associated with washed out culverts on town highways; although a number of near fatalities have been experienced with residential flooding. Public health and safety is also compromised when access to homes and businesses is unavailable or essential services such as power, telecommunications, fire and rescue, water supply and wastewater collection and treatment are interrupted." - Options for State Flood Control Policies and a Flood Control Program; Vermont Agency of Natural Resources Department of Environmental Conservation Water Quality Division, Waterbury, Vermont January, 1999.

Figure 1: Road damage due to culvert failure

3. OWNERS OF THE ASSET

Owners of the assets have a duty of care to inspect and maintain infrastructure. When a problem trend is identified in pipe networks, authorities have a responsibility to monitor the problem to ensure that it is not worsening or endangering life or property. A regular inspection program also allows the authority to make informed decisions in their maintenance program – identifying both priorities and schedules for rehabilitation. This applies not only to government related authorities but also to members of the private sector, such as mining companies and irrigation authorities who, in Australia, own and are responsible for many thousands of kilometres of piping infrastructure.

"The Minnesota DOT is engaged in a statewide program of inventorying and evaluating culverts in the seven Rural Districts, and culverts and storm pipe in the single Metropolitan District" – John Boynton, Hydraulic Engineer, Minnesota DOT.

The trend of culvert and pipe deterioration is clear. Whilst previous USA EPA estimates put a figure of US$140 billion spending required on USA Water Infrastructure more recent estimates have revised the figure in it's "Needs Gap" analysis to nearly US$200 billion largely to address anticipated sanitary sewer overflow needs, without the addition of 20 year replacement costs. Independent studies conclude that adding this figure would bring the total to approximately US$300 billion. The American Metropolitan and Sewerage Authority and the Water Environment Federation published the "Cost of Clean" Report, estimating that more than US$330 billion is required over the next 20 years to repair and improve the United States wastewater infrastructure. These figures include money for treatment; pipe infiltration and inflow correction; sewer replacement and rehabilitation; new collector/interceptor sewers; **combined sewer overflows; stormwater and non-point source control.**

The problem is clearly more widespread than first thought and whilst the figure for stormwater pipes is a relatively small percentage of these figures it is contended that when more thorough and widespread inspections are made then the full scope of the problem will be better known and that the US$8 billion figure, in the USA alone, will escalate. **The fact of the matter is that a large percentage of the stormwater and culvert pipe infrastructure that was installed in the past 30 to 50 years is reaching the end if its service life.** There is a problem – ignoring it will not make it go away and only places lives and infrastructure at risk.

Whilst typically, in the USA national governments construct major highways, the state and local governments have the responsibility for maintenance. Previously state government authorities would attempt to schedule any culvert works until such time as they could perform other work at the same time, such as patching, resurfacing or widening the road itself. This was predominantly due to the requirement for traffic control whilst performing work on the infrastructure. Now that trenchless methods of culvert rehabilitation are becoming better known and more economical, there is no reason to delay these works and risk either failure or loss of life or property.

4. MODES OF FAILURE

4.1. Introduction

In order to make informed judgements and select priorities in stormwater and culvert maintenance and rehabilitation it is of benefit to know the possible signs of failure and probable causes.

4.2. Load bearing failure

Both flexible and rigid pipe require proper backfill material and placement technique, although the pipe/backfill interaction differs. When a flexible pipe deflects against the backfill, the load is transferred to and carried by the backfill. When loads are applied to a rigid pipe, on the other hand, the load is transferred through the pipe wall into the bedding. For both types of materials, proper backfilling is very important in allowing this load transfer to occur.

This behaviour under load is shown overleaf.

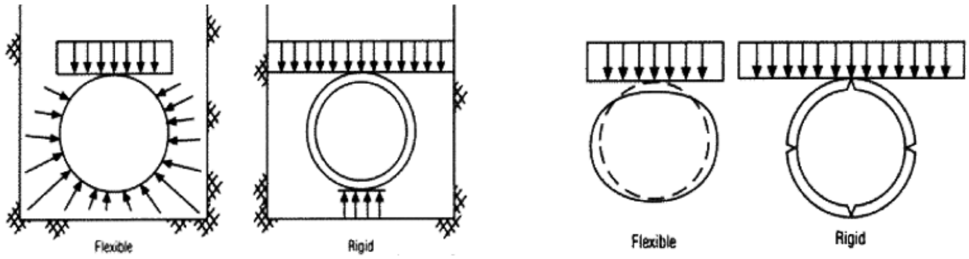

Figure 2: Pipe Behaviour Comparison

If not properly designed and installed either pipe type can fail. Flexible pipes most frequently fail in buckling (generally a result of inadequate backfill compaction and support). Rigid pipes generally crack and, whilst this may not lead to immediate structural failure, it can accelerate the effects of corrosion to be discussed below.

Generally load bearing failure occurs in the construction phase. If a pipe has been successfully installed, having been subjected to the loads applied by heavy construction equipment, load bearing failure is not likely without the influence of other aspects of failure in the pipe system as discussed below.

Post construction surveying is being more commonly used now, showing alarming results in many cases. Audits by Brisbane City Council in 1994, 1995 and 1997 over 1.8 kilometres of pipe showed that just under 30% of the pipe surveyed exhibited cracks. The conclusion reached was that the cracking was most likely due to construction loads imposed by the heavier installation and compaction equipment used in recent times. **In short, it does not matter what the pipe material is – if it is not designed <u>and</u> installed properly, taking into account loading, soil types, external environmental conditions and the like, then chances are that the design life expectancy of the pipe will be reduced dramatically.**

4.3. Structural Failure

Structural failure of the pipe system can arise from a number of sources, generally related to loss of structural integrity either from corrosion or loss of support from the pipe backfill.

<u>Abrasion:</u>

Abrasion of the pipe wall occurs through the action of materials carried in flow (bedload) impacting on the pipe wall. It is affected by the frequency of heavy loads in the flow and velocity of the flow. Obviously, the amount, type and size of material carried in the flow have a significant impact on the life expectancy of the pipe, as does the material composition of the pipe itself.

Debris carried in high flow storm events, such as tree branches, boulders, ice or any other substantial debris can impact on the pipe walls causing serious damage.

Pipe material is obviously of great importance in pipe design.

- Steel pipes are generally accepted as being the most susceptible to the actions of abrasion in conjunction with corrosion – this has led to a wide range of protective coatings being offered.
- Aluminium, whilst useful as a coating to prevent corrosion, displays worse abrasion characteristics than steel.
- Plastics offer good abrasion resistance and are not subject to corrosion effects.
- Concrete exhibits good corrosion resistance, though variable depending on the aggregates used in the material composition. Concrete pipes can be manufactured with greater wall thickness over the steel reinforcement to make them more abrasion resistant. In cases of high velocity, such as induced by steep grades, the use of concrete pipe will generally be avoided due to the risk of reduced service life due to excessive abrasion.

Figure 3: Examples of Invert failure

Joint Dislocation:
Joint dislocation can occur as a result of errors in the installation process, including improper alignment, bedding or improperly installed backfill. Settlement or other forms of pipe movement (earthquakes or landslides) can produce differential movement of pipes, leading to openings in the joints of the pipe. These openings allow erosion of the backfill material, leading to inadequate support for the pipe. Such a situation lends itself to pipe failure. Erosion effects are generally accelerated when the pipe is below the water table.

Erosion at Culvert Ends:
This can be a problem at both upstream and downstream ends of a culvert. At the upstream end erosion of bedding material and headcutting can progress to such a point as to reduce support to the pipe, leading to problems such as described above in the Excessive Deformation section. At the downstream end, water leaving the pipe with inadequate energy dissipation can erode soil. If left unchecked this can lead to the same problem.

Brick Mortar Loss:
Older stormwater and sewage conduits made from brick frequently have problems with mortar loss and, subsequently, brick and backfill material loss. The results of this action can be likened to the effects of corrosion in corrugated metal pipes.

Interflow®

Corrosion:
There are several main types of corrosion leading to failure in pipes – atmospheric, microbiological and galvanic corrosion. Any of these methods of corrosion are influenced by the structure of the soil, with particular regard to pH levels, the soil resistivity, levels of chlorides and sulphates. Other factors that can influence the corrosion rates are the effects of industrial effluents from either commercial or residential sources or stray electrical currents in close proximity to the pipe. Stray current sources include electricity transmission lines, electrified rail lines and the like.

Importantly, corrosion is not always evident prior to substantial investigation, hence an ongoing monitoring schedule is recommended.

5. REHABILITATION AND RENEWAL: ISSUES TO BE CONSIDERED

5.1. Impacting Factors

Depending on the state of the host pipe, several means of rehabilitation are possible. Factors most frequently having an impact on the decision on how best to address problems associated with a deteriorated pipe are as follows:

5.1.1. The condition of the pipe

Rehabilitating early has the potential to save big money.
When the owner of the asset has the ability to program remediation works well ahead of significant deterioration, large sums of capital works and maintenance dollars can be saved. A structurally sound pipe that is showing early signs of scour or abrasion will typically only require a liner material which offers abrasion resistance. Costs will increase where the invert is lost, joints separated, voids present, lost surround material, major deflections, erosion of the inlet or outlet or where a pipe creates a disruption to the hydraulic conditions. Where one or more of these conditions described is present, significant preparation and/or structural liner design will be required. To ensure that the most cost-effective method of maintenance or rehabilitation technique is specified a clear understanding of individual site and pipe condition is vital.

This is when the Client needs to make a value judgement on maintenance vs. rehabilitation.

Figure 4: Culvert with advanced signs of deterioration

5.1.2. Hydraulic requirements of the pipe

Maximising the cross sectional area of the pipe is important! It's not just about superior flow characteristics!

The hydraulic characteristic of most modern pipe and rehabilitation systems is better than the original host pipe by a large degree. When comparing the water dynamics of say a 1170mm PVC or HDPE slip-liner inside a 1525mm corrugated metal host pipe using the Manning's n value for flow capacity it can be argued that the 1170mm liner will have a superior performance compared to the larger structure. In the case of a culvert however, the roughness co-efficient is not the only consideration because the culvert is typically not an integral part of a larger pipe system. Of greater importance in this circumstance are the water entry, exit and flushing characteristics of the pipe. **For this reason alone the Client should be looking to maximise the cross section of the system when renovated regardless of the traditional hydraulic factor.**

5.1.3. Economics of replace vs. rehabilitation and future asset management factors

Cost the solution according to its design life. Most rehabilitation products are designed for a life typically in excess of 50 years. They should therefore be regarded as asset-replaced and depreciated accordingly.

When the depth of culvert is shallow enough to economically dig up and replace, the designer may elect to do so in preference to rehabilitating the asset. This circumstance will generally occur in a rural or secondary road system with few services laid between the road surface and pipe. When considering the option to dig up and replace, thought must be given to the realised life of the old pipe and the cause of its ultimate demise. The cheapest material for replacement may be the same as the original. The new asset should therefore be depreciated over the same period.

Most renovation materials are superior to the original pipe with respect to chemical resistance and abrasion characteristics. Assuming hydraulic performance can be maintained or enhanced, it is reasonable to conclude that often a longer life can be expected using a rehabilitation method in preference to replacement with a like product to the original.

5.1.4. Site conditions, logistics

Reduce costs by choosing a rehabilitation/renewal system that can deal with the conditions.
Conditions such as water flow, soil characteristics and accessibility, amongst others, have a major impact on the decision making process. Amount of water flow may eliminate some choices in rehabilitation, short of major bypass / diversion of water. Other rehabilitation techniques may not require water diversion. Soil contaminants may also eliminate some lining materials from consideration. Accessibility to the line is also often a critical issue. **Pipes under steep embankments and/or with high cover may require significant site works to enable rehabilitation with some methods.** The extent of site works will often require EPA or governing authority approvals and permitting before construction works can take place. **This process alone can impact on the overall cost and timing of the project.**

5.1.5. Environmental considerations

There must be minimal impact on the environment, a legal requirement.
EPA regulations are very strict with respect to site impact on endangered flora and fauna. This poses restrictions on both the size and type of operations which, can be employed on site. Land clearing, sediment control and re-vegetation are key issues scrutinised. Contaminated water resulting from some rehabilitation techniques must be **fully** contained and transported off site. Permits to engage in construction activity are often difficult to obtain, particularly in regions where the environment, flora or fauna is fragile due to endangered or threatened species and plant life are being covered under EPA regulations. This subject is one which both the Client and contractor must consider in more detail now than ever before.

The EPA USA has proposed, under the Clean Water Act, a stricter National Pollutant Discharge Elimination System permit. Permit requirements would include submitting a **Notice of Intent** including information on general construction activities and certification that the activity will not impact on threatened or endangered species. It would also require the development and implementation of a **Storm Water Pollution Prevention Plan** with Best Management Practices suitable for minimising the discharge of pollutants from the site. Finally, a **Notice of Termination** is required to indicate completion of works, or handover of the site.

Such measures will likely have most impact on operations that require significant amounts of equipment and apparatus, methods such as sliplining that require water diversions or storage and some land clearing or excavation, or that require chemical action to install – whereby water may become contaminated by resins within the impregnated liners and needs to be contained and removed from site to conform with EPA guidelines.

5.1.6. Effluent constituents

The flow in the culvert or storm drain may contain elements that restrict the choice of material. Generally, this would only occur in a dual sewer/storm drain system but can be due to upstream above ground infrastructure.

5.1.7. Safety considerations

Occupational health and safety regulations and the safety of those on and around the site are of major importance to both the contractor and the Client. Whereas operations such as pipe jacking show an obvious need for due care, all works are subject to varying regulations. For example, confined space requirements in large diameter pipes.

5.1.8. Availability of funding

In comparison to funding sources, costs of rehabilitation can seem great. However, the consequences of avoiding repair increases both the cost of subsequent rehabilitation and the risk to the community in general.

5.1.9. Duty of care

When a problem trend is identified, authorities have a responsibility to monitor the problem to ensure that it is not worsening or endangering life.

5.2. Rehabilitation Methods

5.2.1. Short Term Rehabilitation

Short term rehabilitation methods include measures such as:

Grouting
Grouting typically involves filling voids in the soil side of the invert and the scope of materials used can include urethane or other chemical based specialty grouts to reinstate joints.


Figure 5: Internal Chemical Grouted Joint

Invert paving and plating
A common measure with corrugated metal pipe where bedload has eroded away the invert leaving the residual pipe structurally sound. This may be described best as a medium term measure as the bed load may continue to erode the areas where the concrete meets the pipe.


Figure 6: Metal culvert with paved concrete invert

Joint Sealing
Joint sealing is suitable for situations where leaking is confined to joints whilst the remainder of the pipe is structurally sound. This is achieved through the use of an expansion ring gasket and band for longer term use.

For short term use other methods may also be suitable, such as silicone joint sealants or other expansive chemical materials over backer rods pressed into the joints. This latter method is generally not suitable in situations of external pressure.

5.2.2. Long Term Rehabilitation

Longer term rehabilitation measures generally involve placing a pipe liner within the existing pipe by one of a number of methods. These can be structural or non-structural, depending on the condition of the host pipe:

Sliplining
As an alternative to dig up and replace methods of pipe rehabilitation, sliplining involves sliding a pipe of smaller diameter within the deteriorated host pipe. Commonly these pipes are made of HDPE or PVC. Care must be taken to ensure the hydraulic difficulties created by excessive diameter reduction such as turbulences and entry losses are overcome.

Sliplining can require a great deal of site and pipe preparatory work before being carried out. The host pipe needs to be prepared to ensure that the slipliner diameter will suit the entire line. Voids in the host backfill should be filled prior to sliplining to control the amount of grout required. Embankment and entry points will often need to be cleared to create a large staging area in order to allow access for long sliplining runs. Sliding rails are also used, although different companies utilise different methods.

Figure 7: Inserting a PVC slipliner

Cement Mortar Lining

The application of cement mortar applied to the inside of the pipe. Steel reinforcing mesh or bars can generally be placed prior to cement mortar application if required.

Epoxy Lining

As per the cement mortar lining method, however for additional strength thickness is increased or reinforcing fibres are added during the application process.

Spiral Wound Structural Liners

Spiral Wound liners are typically made at the entrance, or inside the pipe to be rehabilitated. This process has benefits in traffic control, size of foot print or staging area, flow management of incoming water, speed of installation and environmental benefits associated with eliminating the need for jacking trenches or other excavation. Another chief advantage of these methods is that the finished liner diameter results in minimal cross sectional area reduction.

Figure 8: Spiral Wound Full bore lining systems.

Pipe Bursting

Generally used where upsizing of the original pipe is a requirement. The host pipe is destroyed by the machine as it pushes it outwards. This method is generally used in conjunction with fusion-welded HDPE pipe drawn behind the machine or jacked behind it (though this requires more infrastructures). This method is not suitable for ductile pipes or heavily steel reinforced concrete pipes.

5.2.3. Replacement Methods

If the decision is made to replace the pipes rather than rehabilitate there are still choices to be made. Aside from the obvious choices in pipe materials there are still both open cut methods and trenchless methods for culvert construction.

Open cut trench construction can be an option where traffic diversion is convenient, in situations of low volume or short closure periods. It can also be economical in instances of low cover height and low water flows. If any of these are not the case it is generally more prudent to investigate trenchless methods. Trenchless methods include pipe jacking and utility tunnelling; directional drilling; auger and micro-tunnelling methods.

Pipe jacking is used for reinforced concrete or steel pipe in diameters from as low as 450mm to 3,350mm – although generally sizes are limited to those that accommodate man entry for conventional pipe jacking methods.

Whilst pipe jacking offers an alternative for trench and replace methods, its nature makes it imperative to properly investigate the soil structure and surrounding infrastructure to evaluate its suitability. Soil must be uniform in composition, free of large boulders or rock structures and certain soil types may cause complications in certain situations. The presence of a water table adds further complications as the soil structure can not be guaranteed to be stable and uniform.

Safety during the jacking process is paramount, as in all construction works. The pipe jacking procedure requires great forces in order to push the pipes through the soil in opposition to friction forces imposed by the soil. Personnel safety requires special consideration.

6. REHABILITATION DESIGN PHILOSOPHIES

6.1. Flexible Design Standards

For Australian pipe rehabilitation projects, authorities generally specified one of several world standards. For example, Australian Water Authority pipeline rehabilitation specifications generally specify that the design must be based on Australian Standards AS2566.1 “Buried Flexible Pipelines, Part 1: Structural Design”. Internationally, Standards such as ASTM base their design methods on those for pipelines installed by conventional buried means.

Most Australian projects benefit from utilising performance based specifications for each project at hand, rather than specifying that a pipe should have a minimum stiffness regardless of the intended application.

An example of this was made clear in a project in Box Hill, Melbourne, Australia. This brick 1200mm diameter stormwater line built in 1909 was suffering severe mortar loss. The fact that it passed underneath houses restricted the options for excavation and replacement. Melbourne Water recognised the brick line retained some of its structural integrity, provided re-pointing of the brick work and re-establishing surrounding soil support could be achieved. It recognised that re-pointing alone was still a temporary measure. Instead, the decision was made to rehabilitate the line with a liner designed in accordance with the method given in AS2566.1.

6.2. Annular Space Grouting

Regardless of the stiffness of the liner system, the complete and proper grouting of the liner is necessary for the success of the integral solution. The requirement for an experienced installation contractor is paramount. Whilst high stiffness liners can be employed as a safety factor against liner damage in the grouting process, it in no way mitigates the responsibility of the infrastructure owner or contractor to ensure that the grouting process is carried out properly with due care. There have been many instances of very high stiffness liners being damaged through the grouting process. Such occurrences are not confined to low stiffness liners.

The grouting contractor must develop a plan to ensure that the grout is placed in a way that does not damage the liner or impede its performance for the required project. This plan should include the following elements:

The proposed grouting mix	The proposed grout densities and viscosity
Initial set time of the grout	The proposed grouting method and procedures
The grout working time before a 15 percent change in density or viscosity occurs	The 24-hour and 28-day minimum grout compressive strengths
The maximum injection pressures	Flow control
Bulkhead designs and locations	Buoyant force calculations during grouting to prevent pipe floatation.
Proposed grout stage volumes (eg Stage 1, to springline; Stage 2, fully grouted)	Provisions for re-establishment of service connections
Pressure gauge, recorder and filed equipment certifications (eg calibration by an approved certified lab)	Written confirmation that the Contractor has coordinated grouting procedures with the grout installer and the liner pipe manufacturer
Vent location plans	

If an experienced contractor is employed to ensure that the grouting is carried out properly, there is no reason not to consider the full variety of liner options that the project requires.

7. CONCLUSION

It is well documented that significant growth in road construction occurred during the 1950's and 60's. This alone tells us that there are many thousands of kilometres of piping infrastructure which is now at the end of its design life. It is not often practical or desirable to dig up and replace these conduits. Furthermore, in most cases it should not be necessary to burden constituents with the tremendous social cost of open cut pipe replacement.

There are elegant solutions available to solve even the most difficult logistic and design challenges. New technologies are emerging, which accommodate modern design criteria, but still have regard for environmental, logistic and economical requirements of a project. Client can now choose a technology which offers the "total solution" to all rehabilitation challenges.

- Customised products with the ability to meet stiffness requirements according to a variety of specifications
- Maximum diameter liner, which reduce entry and exit turbulence, whilst maintaining greater hydraulic capacity than the host pipe.
- Minimal site preparation, excavation of embankments and approach areas
- Liner can be produced in a wet environment
- Small site footprint, minimum disruption to road traffic
- Elimination of conventional jointed pipes
- Materials that are resistant to abrasion and corrosion
- No pollutants to be contained
- Fast installation

The onus is clearly on infrastructure owners to fully understand the extent of the work required on a given project. Once all contributing external factors are considered a determination is made of what technologies are available to match the project needs can be made. The design should maximise the technical benefits of the system whilst considering the total economics of the asset renewal process.

ACKNOWLEDGEMENTS
Shaun Melville, co-author, Rib Loc Australia Pty Ltd
Rich Jakovac, communications on EPA regulations and funding guidelines, Rib Loc
David Gellings, communications on grouting rehabilitation projects, Trenchless Resources, Inc.
Barry Phelan, communications regarding Channar mine project, formerly of Minenco Consulting Engineers
John De Grazia, communications regarding Box Hill Project, Melbourne Water
John Boynton, communications on Minnesota inspection program, Minnesota DOT
Mal Bilaniwskyj communications on RTA NSW projects and asset assessment initiatives.

REFERENCES

1. Chris Demartini - Brisbane City Council, "The Cracking of Stormwater Pipes and the Significance of Construction Loads", paper presented at Pipes Wagga Wagga, 1999
2. David J. Gellings, "Standards Needed for Annular Space Grouting", Trenchless Technology
3. DOT California, "Design Information Bulleting Number 76 – Culvert Rehabilitation Using Plastic Pipe Liners"
4. DOT Florida, "Section 431 Pipe Liner" and "Section 934 Non-shrink Grout" Specifications
5. DOT Indiana, "Sliplining of Existing Pipe with Thermoplastic Liner" Design Guidelines
6. EPA Survey, "Clean Water Needs" 1996
7. EPA Analysis, "Needs Gap" March 1999, not yet finalised
8. Greenbook Standard Specifications for Public Works Construction, "500-3.1.10 Submittals and Required Calculations", pg 452, 2000
9. Interflow Pty Ltd, Australian Case Studies, www.interflow.com.au
10. Preussag Pipeline Rehabilitation, USA Case Studies, www.preussagpipe.com
11. Rib Loc Australia Pty Ltd, Various Case Studies, www.ribloc.com.au
12. Streeter & Wylie, "Fluid Mechanics", pg 229, 244, McGraw Hill, 1987
13. Vermont General Assembly Pursuant to Act 137 Section 2 (1998), "Options for State Flood Control Policies and a Flood Control Program", prepared by the Vermont Agency of Natural Resources Department of Environmental Conservation Water Quality Division, Waterbury, Vermont January, 1999