WASTEWATER INFLOW AND INFILTRATION REDUCTION – WHERE DOES NZ SIT ON THE WORLD SCENE ?

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ABSTRACT

The New Zealand Infiltration and Inflow Control Manual[10] was published by Water New Zealand (then known as the New Zealand Water and Wastes Association) back in 1996. Over the past 15 years, there has been a significant amount of work done throughout New Zealand in I/I management. Little else has evolved over this time in terms of the documentation of the learnings from this work and guidelines that incorporate these learnings.

The Water Services Association of Australasia (WSAA) is an industry membership organization that represents the 25 largest water companies/authorities in Australia. They recently undertook an I/I Benchmarking and Best Practice Guideline Document project aimed at determining the range of current I/I management practices in use across Australia. These practices and the resulting I/I reduction outcomes were compared and benchmarked with practices in New Zealand, Canada, USA and South East Asia.

Using the identified examples of successful project outcomes, a Best Practice I/I Management Guideline Document for Australian water utilities was developed. This document is set to become the guideline document for I/I management programmes across Australia.

This paper outlines the result of this exercise and in doing so gives a clear picture of where I/I management practices and outcomes being achieved here in New Zealand are at in relation to those in the researched countries. It also discusses the Best Practice Guideline Document and its applicability for use New Zealand water industry going forward.

This paper will be of interest to the wide range of delegates challenged by the issue of infiltration and inflow in the effective management of their wastewater systems.

1. INTRODUCTION

With the general easing of the drought conditions in most parts of Australia over the last 12 months, management of public health issues and environmental damage caused by rainfall dependent inflow and infiltration (RDI/I) will be seen as more of a relevant issue than it has been previously. To respond to this envisaged market need amongst its membership, the Water Services Association of Australia has recently carried out and completed an investigation into current inflow and infiltration (I/) management practices throughout Australia.

To the author's knowledge and understanding, this project effectively represented the definitive research work into I/I management practices and had as its objectives the following:

- To deliver a comparative review and report on the infiltration and inflow management practices within participating Australian Water Utilities with a view to achieving the following:
- Establishment of a common understanding of current I/I performance and management processes across the participating WSAA organisations;

- Benchmarking these practices with those in use in New Zealand, the USA and any other jurisdictions;
- Resulting from the above, development of Best Practice Guidelines / Methodology document for I/I Management.
- Determination of how I/I can be realistically reduced using various rehab techniques and associated costs.
- A definition of how other wastewater system improvements can be integrated with I/I Management Solutions.

2. METHODOLOGY

2.1. UNDERSTANDING CURRENT STATUS IN AUSTRALIA

To better understand the extent and nature of current I/I practices in Australia, as part of this exercise, a survey questionnaire was sent out to all WSAA participant organisations to develop an understanding of current and intended approaches and practices related to I/I management.

Anecdotally, it is acknowledged that with (until late 2010) lower-than-average levels of rainfall across most of Australia over the past 10 years, much of the profile of and many of the normal drivers for I/I management programmes in place elsewhere in the world do not exist in Australia. With normal rainfall patterns occurring this situation is likely to reverse.

Fourteen WSAA participant organisations responded to the questionnaire. Key results of the survey are as follows:

1. Drivers for undertaking an I/I Management Program were identified as follows:

- To achieve regulatory and/or licensing compliance;
- To better manage or mitigate business risk associated with operation of the wastewater system;
- To be more environmentally sustainable;
- To assist with the development of capital works programmes;
- To better manage and address operational problems, including overflows, at the wastewater treatment plant;
- To reduce the location and frequency of overflows within the wastewater collection system; and
- To address problems with treatment plant operation or effluent reuse potential created either by seawater or saline groundwater intrusion.
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3. Only 3 of the 14 respondents confirmed they currently had an I/I Management programme in place.

4. I/I Reduction programmes are seen by respondents as less reliable a solution to wastewater system capacity deficiencies and overflows than system conveyance and detention storage solutions.

5. System target wastewater overflow containment standards are set mainly by regulators but in some cases by the regulators in conjunction with the water company/authority.

6. Storm water interactions and saline intrusion are seen as significant issues for a number of the survey respondents when dealing with I/I.

7. Governance arrangements and wholesaler-retailer interactions are not seen as important considerations in I/I management.

8. There is a good understanding of the role that private house laterals play in being a potential source of I/I into a system.

9. No survey respondent has developed a process for addressing sources of I/I coming from private house laterals.

10. There is significant appetite amongst survey respondents for a Good Practice Guideline Document such as this one.

11. There is some appetite for common I/I KPI calculations tools that could be provided by WSAA to its member organisations.

2.2. CURRENT STATUS ELSEWHERE

Research carried out by the project team indicated that I/I reduction was currently commonly being used as an effective wastewater system management tool in New Zealand, the USA and in Singapore. The predominant nature of combined stormwater/wastewater pipe systems in Europe and the United Kingdom means that I/I reduction is not as relevant to wastewater system managers there as it is in Australia.

Guideline documents for I/I management have been produced in New Zealand[10] (referred herein as "The Manual") in 1996 and in the USA [3,4] in 2003.

To the extent of the authors' knowledge significant I/I reduction work work has been carried out across a wide range of New Councils and water agencies with specific and detailed I/I reduction work having been carried out by the following entities –

- North Shore City Council
- Metrowater
- Palmerston North City Council
- Invercargill City Council.
- Hutt City Council.

2.3. I/I REDUCTION AND A TOOL IN THE TOOL BOX OF WASTEWATER SYSTEM MANAGEMENT

There are a number of different approaches and potential solutions that can be used to improve the performance of sewerage systems in response to issues resulting from shortfalls in system capacity that may be due to excessive Inflow/Infiltration. These include the following:

- Conveyance system augmentation;
- Operational optimisation;
- Peak flow attenuation through detention storage;

- Flow reduction through I/I management; and
- Use of controlled overflow structures.

They each have a place and role in the development of an appropriate wastewater system upgrade strategy. Rather than sole implementation of any one of these tools, often it is some form of combination of these techniques that will comprise the optimised upgrade strategy.

A summary of these methods and the system issues that they are considered most suited for likely to solve is shown in Table 1.

Table 1 Suitability of Application of System Performance Improvement Options

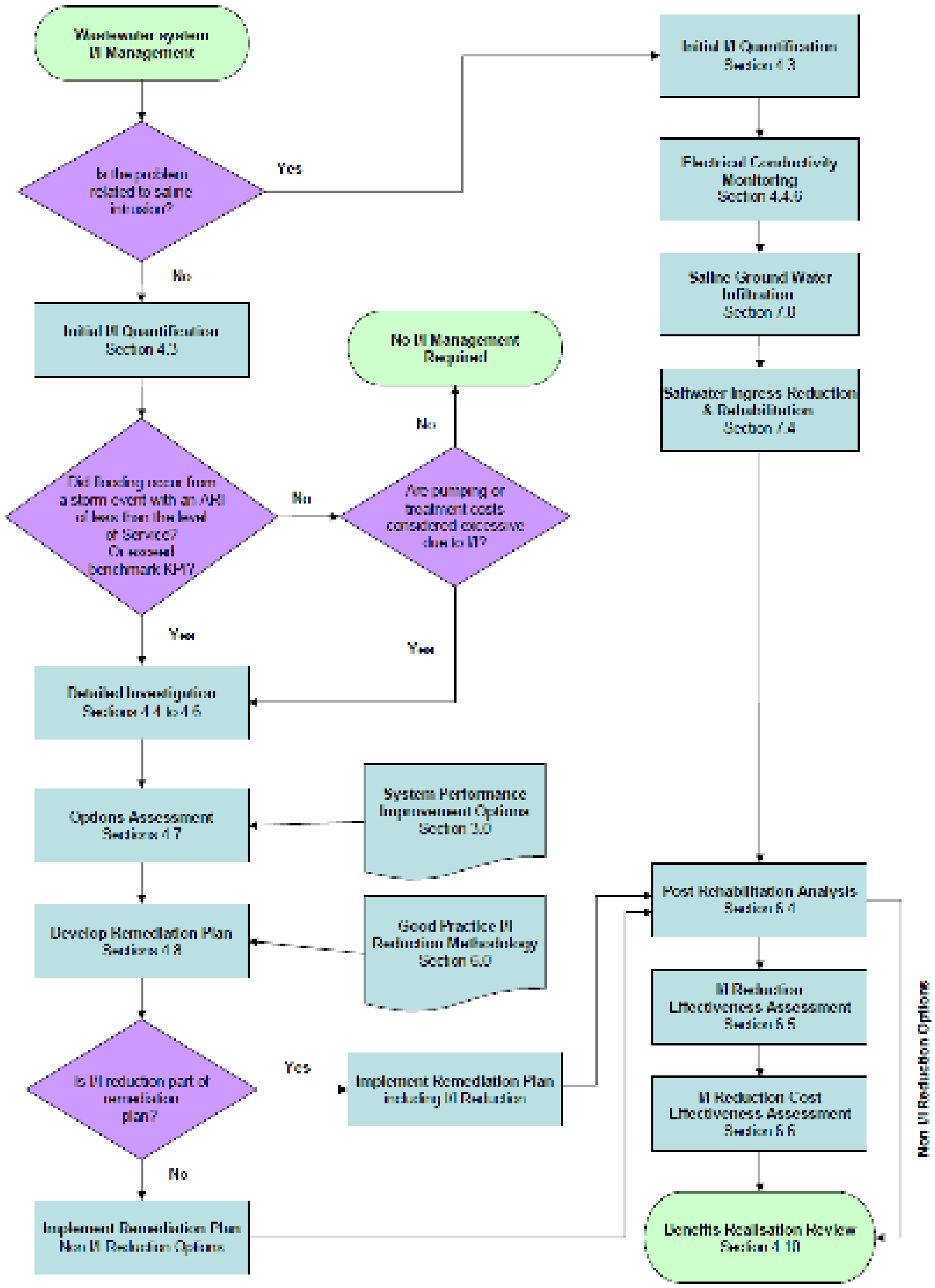
	Operational Performance Issue to be Addressed			
System Performance Improvement Tool	Growth-driven capacity deficiency	Local reticulation overflows exceed target	Treatment plant volume overload exceed licence	Saline groundwater or seawater intrusion
Conveyance Augmentation	✓✓✓	✓	×	×
Operational Optimisation	✓	✓✓	✓	×
Peak Flow Attenuation Using Local Detention Storage	✓✓	✓✓✓	✓	×
I/I Reduction	✓✓	✓✓✓	✓✓✓	✓✓✓
Provision of Adequate Stormwater System	×	✓	✓✓	✓
Controlled Overflows	×	✓	✓	×
Localised Treatment	×	✓✓	✓	✓
Alternative Wet Weather Treatment Technologies	×	✓	✓	×
Pressure Sewers	✓✓	✓	✓	✓✓

×	**not suitable**
✓	**some suitability**
✓✓	**medium suitability**

3. GOOD PRACTICE WASTEWATER SYSTEM PLANNING & ANALYSIS

Figure 1 summarises the Good Practice Wastewater System Planning and Analysis Process derived during the WSAA Study. It is considered equally applicable in New Zealand.

Figure 1 Flow Chart of Good Practice Wastewater System Management



4. INFLOW & INFILTRATION KEY PERFORMANCE INDICATORS (KPIS)

Historically, I/I analysis projects [53,4,5,6,7,8,9,14,22] carried out in Australia, New Zealand and the USA have been done using a range of parameters that quantify the various sources of I/I.

These sources are commonly understood as follows:

Groundwater Infiltration (GWI) or base flow; *and* Rainfall dependent inflow and infiltration (RDI/I).

RDII has historically been analysed using two parameters that are based on the need to target its sources so as to reduce it– one that is an indication of the total volume of RDII and one that is indicative of relatively easily removable direct stormwater inflow.

Taking the learnings of previous projects completed, moving forward, it was recommended in the WSAA Project that I/I be analysed using four simple parameters, each calculated on a flow monitor or pump station catchment basis.

For Dry Weather (Groundwater) Infiltration

A population-based flow factor, which is the ratio of the measured average dry weather flow to the estimated population.

$\boldsymbol{GWI_1 = ADWF_{measured}/Population_{theoretical}}$ where the unit is l/person/day

As guideline values, when the ratio's value is below 140l/p/d, it is indicative of exfiltration. When the value is greater than 220 l/p/d, then significant groundwater infiltration is likely to be occurring.

As a potential cross-check if desired or if available, a water consumption-based flow factor, being the ratio of the measured average dry weather flow to the metered water consumption (where available).

$\boldsymbol{GWI_2 = ADWF_{measured}/Water\ Consumption_{measured}}$

The normal expected range is 0.7 to 0.9.

When the value is below 0.5, it is indicative of exfiltration. When the value is greater than 1.2, then significant groundwater infiltration is likely to be occurring. The relationship between water consumption and wastewater generation was investigated in detail in a study by Melbourne Water[1].

For RDII Volume

A percentage of total ingress parameter, measured on an individual flow monitor or pump station catchment basis, which is the measure of the percentage of actual rainfall falling on a catchment that ends up in the wastewater system.

$\boldsymbol{RDII_1 = Volume\ of\ RDII_{measured}/Rainfall\ Volume_{measured}}$

= (Recorded Wet Weather Volume - Average dry weather volume)/(Measured rainfall depth x catchment area)

Typical values for an older system in good condition are in the range 2-5%. Values of greater than 20% have been encountered in some Australian and overseas projects, indicating very high levels of wet weather response.

For Peak Wet Weather Flows

A wet weather flow peaking factor, which represents the extent of Storm Water Inflow (SWI) is the ratio of the peak flow recorded during a specific rainfall event to the measured average dry weather flow preceding that event.

$\boldsymbol{SWI_1 = Measured\ PWWF/Average\ Dry\ Weather\ Flow.}$

This parameter can be measured at any flow monitoring point.

Historical design practice was to set this number at 5.0. Studies have encountered values as high as 30, indicating a significant number of direct inflow sources in the associated catchments.

4.1. THRESHOLD TRIGGER VALUES

Whether pursuing an I/I reduction programme is justified will depend on the performance and operational problems that are being addressed in the system. In addition, a full multi-criteria analysis on the viability of an I/I management programme in relation to other options as outlined in Section 4 may be warranted.

It is useful however to have some idea of threshold or trigger values of the various I/I KPIs so as to know whether pursuing an I/I reduction program through system rehabilitation is likely to be prudent.

Research [7,8,14,22] carried out as part of this project has identified that when measurable $RDII_1$ parameter is less than 8-10%, the success of rehabilitation programmes aimed at reducing it is much harder to quantify and therefore the associated works are much harder to justify.

A threshold value of the $RDII_1$ parameter of 8% was therefore recommended in the WSAA Study.

Unless there are other on-off reasons such as a localised overflow that would benefit from such a programme, where the $RDII_1$ parameter is less than 8%, consideration of system-wide rehabilitation as an improvement measure to reduce system wet weather volumes is not recommended.

Similar threshold values were included in the Guideline document for the GWI and SWI parameters as follows: Groundwater Infiltration - GWI – 250 l/p/day or as an alternate, where GWI is estimated as 20% of ADWF; and Stormwater Inflow (SWI) – 8.

5. GOOD PRACTICE I/I REDUCTION METHODOLOGY

The research carried out during this projects [5,6,7,8,9,10,22,23] has identified that the most successful results have been achieved where a common five-step methodology has been adopted. On the basis of replicating these outcomes, the common methodology is defined as the Good Practice I/I Reduction Methodology. These 5 stages are summarised in Figure 2 and generally reflect the approach outlined in the Manual.

In relation to Stage 5, it is felt that the methodologies and technques had evolved significantly since the publication of the Manual.

One example is how the levels of I/I reduction achieved have been calculated. Three methods are outlined in the WSAA Report as follows –

- Linear Regression (R% vs Rainfall Volume) Technique
- Linear Regression – Control/Target Technique
- Calibrated Model Technique

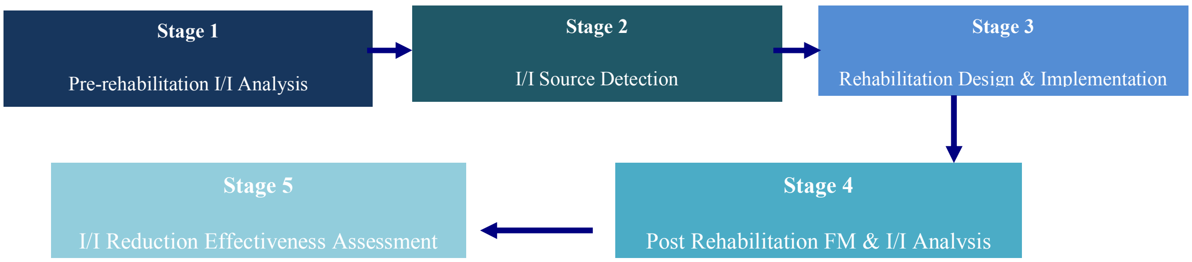
The selection of the most appropriate method is a function of the following all of which require consideration in the method selection process:

- Degree of desired rigour and accuracy;
- Cost;

- Required timeframes for production of results;
- Technical capability that is available to complete the analysis, either in-house or outsourced; and
- The existence or otherwise of a fully calibrated hydrologic and hydraulic models.

There are no known studies where the calculation methods have been compared.

Figure 2 – Summary Flow Chart of Good Practice I/I Reduction



5.1. I/I REDUCTION COST EFFECTIVENESS ASSESSMENT

Calculating the cost-benefit ration of the I/I reduction, either at planning stage or post-implementation is a key process that should be followed on each I/I management project.

The costs of the actual rehabilitation works can be fairly readily defined. At the planning stage, this requires assuming certain levels of rehabilitation works and developing cost estimates for these works.

The benefits of carrying out these works are somewhat more complex to define. The cost benefits of doing the rehabilitation works comprise the following:

- The reduced volumes that would otherwise be transported through the system. There are a range of operations and maintenance costs associated with these, the majority being pump station power costs. With knowledge of current pumping costs, the savings in these costs can be readily estimated.
- The reduced volumes that are treated at the WWTP. With knowledge of treatment costs per ML of wastewater, these savings in costs can be fairly readily estimated.
- The reduced extent of infrastructure upgrades (e.g. pump station or pipe capacity upgrades or storage volumes) that would have otherwise had to have completed and invested in to meet a specific target level of service. It is possible that with an I/I reduction programme in place, these costs are no longer required and hence this is a cost saving.
- The capital reserved for inevitable asset renewal that would no longer have to be invested because of the rehabilitation works.
- Where appropriate, the reduction in fines or other financial penalties for excessive overflows imposed by the Regulator
- Other non-tangibles such as the reduction in water company/authority reputational damage image etc could be valued and included in the assessment.

All of these savings, be they “one-offs” or on-going, need to be estimated on a net-present value basis over the life of the rehabilitation works. It is suggested that the design life of 30 years is adopted for this approach. The various sources of savings then need to be summed and compared against the net present value of the costs of the rehabilitation works to determine the cost-benefit ratio. i.e. is the investment in the rehabilitation programme justified on economic grounds.

5.2. HOUSE LATERAL I/I

The research carried out in this project identified no examples where a comprehensive legal and financial arrangement had been developed an implemented to address the difficulties related to a system-wide lateral repair program.

Assuming traditional ownership structures for house laterals remain in place, there are a number of techniques worthy of consideration as "enablers" for progress to be made on the issue. These will depend on functional and legislative environments within the State and Local government regimes across the various Australian jurisdictions.

5.3. I/I REDUCTION PREDICTIVE CAPABILITY

A significant number of projects in these jurisdictions have now been analysed to the point that there is a robust knowledge base upon which to now make more reliable predictive estimates of I/I reduction levels achieved from different levels of system rehabilitation. This is considered to represent a significant advancement in the planning of wastewater system improvement and management programmes. Of the I/I reduction results obtained through the research exercise undertaken in this project that have been deemed as reliable, the levels of I/I reduction achieved have been evaluated to assess what levels of I/I volume reduction can be achieved from what extents of rehabilitation.

Rehabilitation works have been categorised into one of three classes as follows:

- Level 1 – Removal of all inflow defects identified through a program of house-to-house inspections, smoke testing and manhole inspections;
- Level 2 – Level 1 works in addition to complete sealing of all the public sewers within a catchment and
- Level 3 – Level 2 works in addition to sealing all the private property laterals up to the house.

Clearly and as expected there is significant variation in the results achieved. The conclusions that can be drawn from the research [2, 3, 4, 23] is that with a well advised, managed and controlled program of I/I reduction works the rates of I/I volume reduction as shown in Table 3 can be obtained.

Table 3 – Levels of I/I Reduction Achievable for Different levels of Rehabilitation

Rehabilitation Level	Reduction in RDII (%)	Reduction in Peak Flows
1	0-15	0-25
2	15-50	30-40
3	40-80	N/A

The most advanced research that could be located in the WSAA Study identified that North Shore City Council (now part of Watercare Services Limited) have rehabilitated 32 catchments over the last 10 years. Results have been analysed for more than 14 of these catchments.

The effectiveness of the rehabilitation in I/I has been described by two models, one predicting the percentage reduction in the RDII% (essentially, the reduction in the rainfall volume in the sewer); and the other predicting the percentage reduction in the Peak Wet Weather Flow (PWWF). Between

60 and 75% of the variability in the effectiveness of sewer rehabilitation can be described by the two models via RDII% and PWWF as measures of the rehabilitation effectiveness.

The models use the *initial RDII%* and the *percentage of the catchment that was rehabilitated* as input factors. Other variables with strong correlations to the rehabilitation effectiveness were identified, but were not included in the models developed during this study. Additional I/I reduction effectiveness measurements for additional mini-catchments will become available over time. Watercare will refine the model when the data becomes available. It is expected that the confidence intervals in the models will improve with the additional data.

6. CONCLUSIONS

The project has used the outcomes of research and a range of case studies to define what is now regarded as good practice for the Australian water industry and this is now documented in WSAA's Good Practice Guideline document. Features of this document include:

- Definition and adoption of a consistent set of I/I key performance indicators.
- A five-step process, which if followed rigorously, will result in reduction outcomes consistent with the most successful programmes completed in these jurisdictions.
- Discussion of the contentious issues associated with the responsibilities for removal of I/I entering the system through privately-owned house laterals.
- Advice regarding potential risks and failure points in implementing a successful I/I reduction programme.

In relation to applicability to New Zealand, the project identified that –

- The most advanced techniques already being used in New Zealand are considered to represent the basis for much of what has been documented now in WSAA's Good Practice Guideline document.
- Most of what is relevant for the Australian industry is directly transferrable and relevant for the NZ industry.
- The NZ Manual[10], published in 1996, is in part still reliable information, but requires revision to bring it in line with what is considered to be current good practice in this technology.

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8. REFERENCES

1.	MWH | Inflow Reduction at Eastern Treatment Plant | Report prepared for Melbourne Water Corporation | 2004
2.	MWH | Inflow/Infiltration Review | Project Report prepared for Melbourne Water Corporation | 2008
3.	WERF | Reducing Peak Wet Weather Flows through I/I Reduction | 2003
4.	WEF | Existing Sewer Evaluation & Rehabilitation| MOP FD-6 | 3rd Edition | 2009
5.	Gutteridge Haskins and Davey Pty Limited | Sunshine East Stony Creek I/I Study | Project Report prepared for City West Water | 1999
6.	Gutteridge Haskins and Davey Pty Limited | Moe, Yallourn North and Rawson Sewerage | Project Report on I/I Investigations | 1995
7.	GHD Limited | Devonport I/I Analysis | Project Report for North Shore City Council | Project Report prepared for North Shore City Council | 2003
8.	GHD Limited | Hillsborough I/I Pilot Study | Project Report prepared for Metrowater | June 2007
9.	GHD Limited | Invercargill I/I Pilot Study | Project Report prepared for Invercargill City Council | NZ | 2009
10.	New Zealand Water and Wastes Association | Inflow and Infiltration Control Manual | 1996
11.	Urban Water Solutions | Williamstown Sewerage Catchment Study | Final Report | Project Report prepared for City West Water Limited | August 2008
12.	Carroll, D | Case Studies from Municipalities | WERF/USEPA Grant Project Report Control of Infiltration/Inflow In Private Sewer Service Connections | May 1998.
13.	Eyles,W, Kerr R and Hackett, A | "The Planning and Effectiveness of Sydney Water's Sewer Fix Small Pipes Programme" ASTT Conference | August 2002 | Sydney
14.	GHD Limited | Expert I/I Review prepared for North Shore City Council | Draft Report | June 2003
18.	Larsen, J, Garcia, Marquez,C | Broward County Florida Successful I/I Rehabilitation Programmes | WEFTEC Paper | October 2000
21.	Selvananthan, B | Results of Sydney Water I/I Reduction Programs | Project Results Conveyed to North Shore City Council | June 2003
22.	Shaw, N | Developing a Predictive Model for I/I Reduction | Water New Zealand Annual Conference Paper | September 2009
23.	Carne, S C | I/I Reduction – What can you Really Get and How Much Will it Cost? | New Zealand Water and Wastes Association Annual Conference | Rotorua, NZ | September 2005
25.	Sydney Water Corporation | The Effectiveness of Rehabilitation in Reducing Rainfall Derived Inflow/Infiltration, Volumes 1 and 2 | August 2004
26.	Melbourne Water Corporation | Hobsons Bay Main Infiltration Investigation Report | June 2011
27.	Sydney Water Corporation | Saltwater Ingress Standard Operating Procedures | February 2010

28.	Sydney Water Corporation | Millers Point – Tidal Ingress Investigation and Rehabilitation Works | Final Report | March 2010