water NEW ZEALAND

The New Zealand Water & Wastes Association Waiora Aotearoa

Infiltration & Inflow Control Manual

Volume One
Overview, Background, Theory

2nd Edition March 2015

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Definitions

Abbreviation	
ADWF	Average Dry Weather Flow
ARI	Average Recurrence Interval
Authority/Authorities/ Water Agency	Any council or organisation responsible for the provision of water and wastewater services to customers within its jurisdiction
CIPP	Cured-In-Place Pipe
DWF	Dry Weather Flow
EPA	Environmental Protection Agency
GIS	Geographical Information System
GWI	Groundwater Infiltration
I/I	Infiltration & Inflow
KPI	Key Performance Indicator
NIWA	National Institute of Water and Atmosphere
ORG	Overflow Relief Gully
Private Lateral	The private sewer pipeline extending from the sewer main to serve a property. Also known as a private sewer, private drain, house lateral, house service line, service connection
PPII	Private Property Infiltration & Inflow
PWWF	Peak Wet Weather Flow
RDII	Rainfall Dependent Infiltration & Inflow
SCADA	Supervisory Control And Data Acquisition
SW	Stormwater
SWI	Stormwater Inflow
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WSAA	Water Services Association of Australia
WWTP	Wastewater Treatment Plant

1. Introduction

1.1 Background

Water agencies around the world have increasingly been driven to manage and reduce inflow and infiltration (I/I) into their wastewater systems. Inflow and infiltration is the process of liquids other than wastewater, such as stormwater and groundwater, entering the wastewater system. I/I is a complex issue and the most successful strategies have been multi-disciplinary in nature. Furthermore, it has historically been difficult to accurately predict the amount of I/I reduction corresponding to a certain level of system rehabilitation. I/I management has been an increasingly important issue for the New Zealand water industry.

1.1.1 Previous Guidelines

Several manuals and guidelines have been written to assist the industry in dealing with I/I, with notable documents originating from the USA and Australia.

This document has been developed cognisant of the material in, and knowledge gained from, the following existing I/I guideline documents:

- Water Services Association of Australia (WSAA), *Good Practice Guidelines for Management of Wastewater System Inflow and infiltration*, *Volumes 1 and 2*, 2013
- Water Environment Research Federation (WERF), *Reducing Peak Wet Weather Flows through I/I Reduction*, 2003
- Water Environment Federation (WEF), *Existing Sewer Evaluation and Rehabilitation, MOP FD-6, 3rd Edition*, 2009
- NZ Water and Wastes Association, *Inflow and Infiltration Control Manual,* 1996

The precursor to this I/I management document is the *New Zealand Inflow and infiltration Control Manual*, published in 1996 by the New Zealand Water and Wastes Association.

Given that the WSAA Good Practice Guidelines listed above is a relatively recent publication, particular reference has been made in this I/I Control Manual to the WSAA Good Practice Guidelines.

It should be noted that the WSAA Guidelines were written by the same authorship for a very wide audience that spanned the WSAA membership. This I/I Control Manual has adapted much of the WSAA material to reflect the specifics of New Zealand's systems and circumstances. In doing so, in no way should it be seen to suggest that the WSAA Guidelines are not appropriate for its intended audience or superseded by this Manual.

This manual intends to build on the information presented in the 1996 Water New Zealand manual with new methods and technologies, and present good practice strategies that have proven to be effective at New Zealand jurisdictions as well as agencies overseas.

1.2 Purpose

Volume 1 includes higher-level information on the management of Inflow and infiltration, the corresponding issues and complexities, and good practice strategies to effectively reduce and manage I/I. Volume 1 presents a five-stage good practice methodology for I/I projects.

Volume 2 includes the details on how to manage and reduce I/I, including the detailed information on how to undertake each of the five stages in the good practice methodology.

Volumes 1 and 2 have been developed with a common structure, with chapters and major topics being consistent across both Volumes.

This Manual is intended for wastewater managers, planners, engineers, and operations and maintenance staff. The manual is organised into the categories shown in Figure 1-1, with each category listing the corresponding related sections.

Introduction, Background, Purpose	ÅSection 1 - Introduction
Management & Decision-Making	ÅSection 2 - System Improvement Options ÅSection 3 - I/I Program Management ÅSection 6 - Key Performance Indicators ÅSection 7 - Predicting I/I Reduction Levels ÅSection 8 - Private Property Inflow and Infiltration ÅSection 10 - Preventive I/I Measures
Good Practice I/I Reduction Methodology	ÅSection 11 - I/I Reduction Methodology Overview ÅSection 12 - Pre-Rehab Monitoring and Analysis ÅSection 13 - I/I Source Detection ÅSection 14 - System Rehabilitation ÅSection 15 - Post-Rehab Monitoring and Analysis ÅSection 16 - I/I Reduction Effectiveness Assessment
Community and Stakeholder Engagement	ÅSection 4 - Community and Stakeholder Engagement
Modelling and Analysis	ÅSection 5 - Preliminary Evaluation ÅSection 9 - Seawater Ingress ÅSection 12 - Pre-Rehab Monitoring and Analysis ÅSection 15 - Post-Rehab Monitoring and Analysis
Physical Works	ÅSection 13 - I/I Source Detection ÅSection 14 - System Rehabilitation

Figure 1-1 - Manual Organisation

1.3 Sources of Inflow & Infiltration

For most agencies, I/I typically originates from stormwater, but I/I could also originate from groundwater or seawater. The sources of inflow and infiltration are outlined in the following sections.

Inflow

Inflow enters the wastewater system directly, e.g. via illegally or misconnected storm water drains. With a fast response and very short time of concentration to rainfall, typical inflow sources may consist of:

- roof downpipe connections;
- low gullies that act as low drainage points;
- damaged or improperly constructed gullies;
- surface area-drainage cross-connections;
- catchpit drainage cross-connections;
- at-surface manhole defects such as holes in the lid or rim, particularly where surface ponding occurs;

- shallow defects in private sewers permitting direct stormwater entry; and
- inspection openings with loose or missing caps.

Inflow sources are generally easier and less costly to detect and repair than those of infiltration.

Infiltration

Infiltration typically has a longer response time than that of inflow and also has a longer effect on the network.

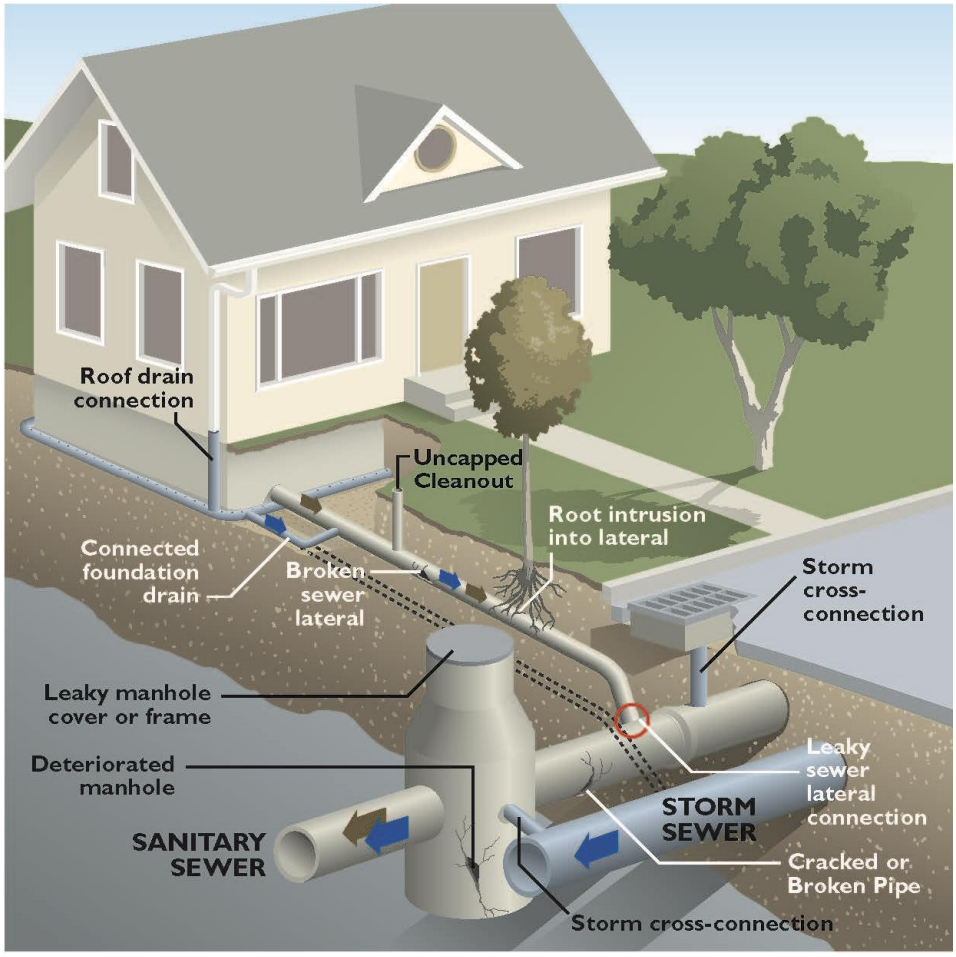
Infiltration sources can be due to either groundwater or rainfall and typically consist of the following:

- cracked public sewer or private sewer pipes;
- open and moved joints in either public or private sewer pipes; and
- cracks in or construction joint leaks in manholes, lampholes, and other wastewater structures.

Infiltration is generally more difficult to detect and locate than inflow. Also, the total volume from infiltration resulting from a particular storm event is typically more than the volume of inflow.

The typical sources of inflow and infiltration are shown on Figure 1-2.

Figure 1-2 Sources of Inflow & Infiltration



(Source: www.crd.bc.ca)

1.4 Key Drivers

There are various reasons, or drivers, for an agency to pursue I/I reduction and they can be categorised into: Regulatory, Engineering/Economic, Community, and Environmental. Several key drivers are described in the following sections.

1.4.1 Regulatory

Regulatory bodies such as regional councils are tasked with the responsibility to protect public health and the environment through the creation and enforcement of regulations. As the regulatory environment becomes increasingly more stringent, councils and water companies need to find new ways to achieve compliance. Many agencies have been pushed by regional councils to reduce wastewater overflows from their systems, and some are even specifically required to implement an I/I Program (eg, Watercare, New Plymouth District Council).

A more detailed discussion on the legal and regulatory environment surrounding New Zealand, in relation to I/I management, can be found in Section 1.5.

1.4.2 Engineering / Economic

Delay or Reduce Infrastructure Upgrades

Many agencies undertake I/I reduction to free up capacity in the network to take on additional wastewater loading and to permit new connections. If a portion of the network is already under-capacity, and I/I reduction is effective, then the upgrade of the pipe, or segment of the network, can be delayed or its size significantly reduced. Further, network upgrades could be delayed at network segments that are not currently under-capacity but would be rendered so with the inclusion of predicted future flows.

Pumping and Treatment Cost Reduction

The introduction of I/I into the wastewater network creates the need to pump and treat the additional water. Excessive I/I can result in peak wet weather flows and large volumes of wastewater entering pump stations and treatment plants. The pumping and treatment of these additional flows creates additional and unnecessary costs. The reduction of these costs can be a factor in undertaking I/I reduction.

I/I can also cause adverse effects on treatment processes. I/I spikes can overwhelm and wash out treatment processes and the dilution effects can also adversely affect reaction rates. Seawater and saline groundwater infiltration can cause treatment plant influent to exceed allowable limits for treatment. In this case, preventing treatment process modifications would be the cost savings.

Other

Other engineering/economic drivers could include:

- to better manage or mitigate business risk associated with operation of the wastewater system;
- to assist with the development of capital works programmes; and
- to address problems with treatment plant operation or effluent reuse potential resulting from seawater or saline groundwater intrusion.

1.4.3 Community

Public Health and Property Damage

Discharges from the wastewater system pose a risk to public health and safety. Examples of where these occur are:

- internal discharges in and around homes creates a health risk as there is a potential for human contact with the high concentration of bacteria and pathogens;

- overflows into water bodies could come into contact with swimmers, affect fishing, and impact other recreational activities.

Overflows also damage property as they flood streets, lawns, and homes. The resulting damage creates a liability issue to water agencies and could create negative public perception towards the agency. It should be noted that overflows caused by stormwater are diluted and have lower wastewater strength than dry weather flows.

Cultural Values

The discharge of human waste (untreated wastewater) into natural water bodies could be considered offensive to Maori cultural values including tangata whenua.

Customer Complaints and Public Perception

Overflows and backups are a cause of customer complaints. To provide a high level of service to its customers, water agencies are looking to reduce the number of complaints by reducing the overflows. Reporting this publicly will be a mandatory requirement starting 1 July 2015.

As overflows flood and damage property, pose risks to public health and increase the number of complaints, the public perception of the agency could turn negative. Some notable forms of negative perception are negative journalism and news stories, and pressure from environmental groups.

1.4.4 Environmental

Water Quality and Ecology

Wastewater overflows can negatively impact the water quality and ecology of receiving water bodies. The pathogen and nutrient-rich wastewater could increase turbidity and decrease dissolved oxygen in receiving waters. Wastewater could also damage ecological functions as well as pose human health issues as described previously. Ecological consequences could include the harm or killing of fish and other marine life, and the harm to plankton and other microflora and microfauna. The release of high levels of ammonia can cause eutrophication which depletes dissolved oxygen and kills aquatic organisms. Furthermore, the receiving water bodies could be deemed protected or environmentally-sensitive by regulatory authorities.

1.5 Legislation and Regulations

1.5.1 Resource Management Act 1991

The Resource Management Act is the national legislation used to protect New Zealandôs natural resources such as land, air, water, plants, ecology, and stream health. Resource consents draw their legal authority from the Resource Management Act 1991.

Resource Consents

Regional councils are responsible for issuing resource consents to water agencies for activities that have significant effect on natural resources and this includes the discharge of wastewater treatment plant effluent into natural water bodies. Some of these consents contain overflow standards which necessitate utilities to reduce their wastewater overflows.

1.5.2 Local Government Act

The Local Government Act (LGA) is the national legislation that lays out the obligations of Councils and Council-Controlled Organisations in regards to public services, and also controls their regulatory and enforcement powers. The LGA:

- states the purpose of local government.

- provides a framework and powers for local authorities to decide which activities they undertake and the manner in which they will undertake them.
- promotes the accountability of local authorities to their communities.
- provides for local authorities to play a broad role in meeting the current and future needs of their communities for good-quality local infrastructure, local public services, and performance of regulatory functions.

Part 26 of the LGA 1974 contains provisions for sewerage and stormwater drainage by territorial authorities. Section 459 states that Council may require owners of land in certain cases to provide private drains.

The LGA 2002 includes the following requirements and provisions that relate to I/I management:

- the requirement to assess sanitary services
- regulatory, enforcement, and coercive powers
- powers of local authorities to make bylaws
- removal of works in breach of bylaws
- construction of works on private land
- powers of entry onto private land
- powers in relation to water services, including discharge of sewage.

The LGA includes provisions that provide water agencies the legal basis to perform certain actions that relate to I/I source detection and rehabilitation. The provisions have notable significance to works relating to private property I/I. Some of the provisions include powers of entry to perform investigation and rehabilitation work, the construction of works on private property to rehabilitate sewers and/or disconnect illegal inflow sources, and the removal of works that are a source of inflow.

Bylaws

Nelson City Council is an example of a local authority that has adopted bylaws to facilitate their I/I works. In their Wastewater Bylaw (No. 224) June 2014, it is stated that the discharge of stormwater into the wastewater system is prohibited. This provides the Council a legal basis for investigating and rehabilitating I/I sources on private property. This could also be used to issue defect notices and require property owners to remediate I/I issues on their property.

1.5.3 Building Act, Building Code and Building Consents

The Building Act is the national legislation that regulates building design and construction. The Building Code sets out performance standards that all building work must meet.

The Building Act requires building consents be issued for new homes, buildings, or renovations, additions, alterations or demolition. Councils hold the authority to issue building consents as well as perform building inspections, which may include plumbing and drainage inspections. The drainage inspection could be considered a key time for the Council to confirm that there are no illegal stormwater connections and also that private sewer laterals are properly constructed.

Clause G13 ï *Foul Water* of the Building Code sets out the objective, functional requirements, and performance requirements of private sewers and sewer laterals. The Building Code also includes *Acceptable Solution G13/AS2 Drainage*, which includes the detailed requirements (or acceptable solutions), for the materials, design, and installation of sanitary drainage. G13 states that it is imperative that the waste pipe connections to the gully remain watertight to prevent the ingress of ground/surface water. G13 requires that gullies used for overflow relief have a grating that will allow for surcharge. 3.3.1 a) of G13 states that the overflow level of the gully dish be no less than 25 mm above paved surfaces, or 100 mm above the unpaved surfaces.

1.5.4 Health Act

The Health Act and the Health (Drinking Water) Amendment Act 2007 place responsibilities on water agencies to protect the quality and safety of drinking water. These responsibilities include the duty to take reasonable steps to contribute to protection of source of drinking water.

Wellington Water uses provisions in the Health Act as legal bases to issue I/I defect notices to property owners. I/I problems lead to sewer overflows which in turn poses a risk to public health.

1.5.5 New Zealand Standards - AS/NZS 3500 Plumbing and Drainage Works

AS/NZS 3500 is a New Zealand standard for plumbing and drainage that is referenced by the Building Code. The standard consists of several sections covering water, sewage and drainage areas.

The standard details the requirements for on-property plumbing and drainage, including a number of requirements of particular relevance to I/I reduction. These include requirements for:

- Overflow Relief Gullies (ORGs) so that they do not become a conduit for local storm water drainage;
- ORGs so that they provide a point of discharge relief to protect against discharges within the house;
- wastewater systems in flood prone areas; and
- lining of sewers constructed of asbestos or clay where demolition of buildings occur.

The following are several notable excerpts taken from AS/NZS 3500.2:2003:

Section 4.6.6.6

A minimum height of 150 mm shall be maintained between the top of the ORG and the lowest fixture connected to the drain.

Section 4.6.6.7

The minimum height between the top of the ORG and the finished surface level shall be 75 mm, except where the gully is located in a path or paved area, where it shall be finished at a level so as to prevent the ponding and ingress of water.

Section 4.6.6.8

The top of the ORG in flood-affected areas shall be ï (a) finished at a level not less than 150 mm above the declared flood level (to be declared by local authorities).

In regard to some of the issues identified there appears to be sufficient requirements within the current standard to address them subject to a willingness to monitor and enforce the requirements. A standard is only effective if it is followed.

In regard to issues such as overflow relief gullies being used to drain local areas, the current requirements may not be applicable particularly where the use of overflow relief gullies are not identified in the Building Code. This may also be complicated by the use of terms in the Standard which are not defined such as declared flood levels which are open to interpretation. In these situations, changes to the standards may need to be pursued. Most agencies do not have declared flood levels and this creates difficulties in enforcing the standard.

1.6 Asset Management Perspective

Modern asset management principles encourage consideration of the risk of various failure modes of a network.

Wastewater system assets can fail by any number of failure modes such as the following:

- structural failure ï the pipe is in a sufficiently deteriorated state (e.g. cracks etc.) that it ultimately collapses;
- hydraulic failure ï the pipe no longer has the capacity for the flow that it is required to convey; and
- operational failure ï the network has deteriorated to an extent that permits ingress of I/I to an extent that is considered excessive and results in pumping stations and treatment facilities to fail level of service targets.

In this context, I/I reduction through system rehabilitation aims to address each of these failure modes ï structural, hydraulic and operational.

Root intrusion, blockages and lack of maintenance can cause hydraulic failure by significantly reducing the hydraulic capacity of pipes.

On-going Asset Management renewal programs (either refurbish or replacement of assets) aim to extend the life of assets where and when it is cost-effective to do so, and in doing so reduce the risk of such failure modes occurring.

Given this, I/I reduction is considered to represent a key tool in the management of wastewater system assets in a responsible manner and can be communicated within a water agency as such.

1.6.1 Using I/I Performance to Target Asset Renewals

Wastewater system asset renewal programs should be developed based on actual I/I performance, in addition to available condition or age profile assessments. This would generate a more informed means of developing such a program because it considers all the potential failure modes of the asset.

Long-term wastewater renewal programs are often developed based on condition assessment information (most commonly CCTV inspections), analysis of historical maintenance data, or in more rudimentary forms, asset age or material profiles.

Whilst a potentially valid indicator of likely system performance, failure on these criteria may not actually be the cause of operational problems that usually take priority in the development of limited-budget renewals programs. This may result in a sub-optimal system renewals program with sewers being renewed that are not actually contributing to operational problems. Conversely, sewers that are causing operational problems may not actually be renewed because they have not been picked up by the condition or age criteria.

1.7 Inclusion in Water Plans/Capital Programmes

Whether specified in Water Plans/Capital Programmes as part of normal on-going asset renewal programmes or specified as separate system upgrade projects, on-going expenditure for I/I management should be specified in such Water Plans and Capital Programmes.

Due to the costs involved and the longer-term system renewal nature, it is usual that budgets reserved to achieve I/I reduction through system rehabilitation need to be specified over longer time frames, eg 5-10+ years, rather than a short timeframe, eg 1-2 year projects.

2. System Improvement Options

2.1 Introduction

There are a number of different approaches and potential solutions that can be used to improve the performance of wastewater 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 unique role in the development of an appropriate wastewater system management strategy. I/I management is commonly just one part of a strategy. Rather than sole implementation of any one of these approaches, it is often a combination of these techniques that will comprise the optimised strategy. Several of the common methods are listed in Table 2-1.

Table 2-1 Suitability of Application of System Performance Improvement Options

System Performance Improvement Option	Operational Performance Issue to be Addressed			
	Growth-driven capacity deficiency	Local reticulation overflows exceed target	Treatment plant volume overload exceeds 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, decentralised system	✓	✓✓	✓✓	✓
Alternative Wet Weather Treatment Technologies	×	✓✓	✓✓✓	×
Pressure Sewers	✓	✓✓	✓	✓✓
Key: × Not considered suitable ✓Some suitability ✓✓ Medium suitability ✓✓✓ Considered most suitable				

2.2 Conveyance Augmentation

Augmentation of system conveyance capacity is the conventional approach that has been used by most Authorities.

Historically augmentations have been sized for predicted peak flow rates using static design criteria methods. Over the past 20 years, the use of calibrated hydraulic models has become wide spread as a means to optimise the required conveyance augmentations.

Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-2 Conveyance Augmentation - Advantages and Disadvantages

Advantages	Disadvantages
Widespread understanding and acceptance.	The mobilisation of in-system surcharge storage from pipes and manholes in upstream systems may be reduced during peak events. This can result in the need for additional storage.
If analysed properly, should resolve local problems.	Reduces peak flow attenuation and will generally speed up and increase the magnitude of peak flows downstream, possibly requiring downstream capacity upgrades.
May result in older assets being retired resulting in an improvement to network reliability.	Tends to promote the inefficient investment in ñlazyò assets, whereby the actual installed capacity is only very rarely utilised and otherwise is not required.
	If no capacity is available in downstream sewers or at the treatment plant, it can result in a domino pattern of escalating downstream capital works and costs.
	Potential for major disruptions during construction in built up areas.
	No reduction in pumping and treatment costs associated with I/I.

2.3 Operational Optimisation

A major advantage of having comprehensive calibrated hydraulic network models is the ability to identify issues and explore opportunities to optimise the utilisation of available system capacity and hence avoid ñlazyò assets. Types of such controls that can be used in a wastewater system include:

- integrated control of pumping stations to mobilise in-system storage and reduce peak carry forward flows;
- diverting flows to adjacent pipes or across to adjacent networks with capacity via actuated weirs/penstocks valves or wet weather pumping stations; and
- combination of integrated pump operations and flow diversions.

Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-3 Operational Optimisation - Advantages and Disadvantages

Advantages	Disadvantages
If analysed properly, should resolve local problem and not exacerbate downstream issues.	Requires reasonably well calibrated models of existing systems and well detailed representation of future network expansion.
Optimise use of existing assets.	High reliance on technology, in particular SCADA systems during major wet weather events.
Relatively inexpensive.	System operation can be complex and not immediately intuitive to operators.
Minimal disruption to public.	Backup power generation needed for electrical assets.
Enables deferral of major capital expenditure until absolutely necessary.	Not all systems readily lend themselves to this type of operation.

2.4 Peak Flow Attenuation through Detention Storage

Depending upon the location of the facilities and the potential impact on the surrounding environment, the form of flow detention facilities could be one of the following:

- above ground open or closed tank with automatic cleaning systems;
- in-line linear storage provided by an oversized pipe or tunnel that doubles as a conveyance medium;
- an open basin with upstream screening, similar to a wastewater maturation pond; and
- underground tanks with automated flushing and odour control facilities.

The optimum sizing, location and operation protocols for such a detention facility are ideally developed and confirmed through the application of a well calibrated hydrologic and hydraulic model of the wastewater system. Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-4 Advantages and Disadvantages with Peak Flow Attenuation through Detention Storage

Advantages	Disadvantages
Excess wet weather flows are stored then released into the wastewater system when capacity becomes available.	Perceived to be expensive and high maintenance.
If well designed, their operation and cleaning can be largely automatic.	If poorly designed, can be difficult to maintain.
The need to upgrade downstream receiving systems to increase conveyance capacity is reduced.	Difficult to find suitable sites in mature urban areas. Trade waste discharges within the wastewater composition may create unsafe conditions, particularly in closed tanks which require additional monitoring and controls.
	Odour issues if inadequately designed.

2.5 I/I Reduction

I/I source detection and removal attempts to remove the source of the excess flows by repairing pipes and manholes in the system that permit excessive entry of groundwater and rainfall related inflow and infiltration. Works are done on a catchment-by-catchment basis with priority given to those exhibiting the highest levels of I/I.

Techniques usually involve removal of identified direct stormwater inflow defects such as connected downpipes, road drainage or low gully traps and repair of manholes and pipelines (public sewers and also potentially privately owned house laterals).

Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-5 I/I Reduction - Advantages and Disadvantages

Advantages	Disadvantages
The source of the excess wastewater flows are dealt with directly.	Generally takes longer to implement than other solutions.
Assets can be structurally renewed, thus extending the asset life.	Requires rigorous adherence to investigation process and implementation of quality assurance measures to achieve target reductions in flows.
Potentially makes downstream capacity available.	Extent of works required to achieve a specific target can vary from catchment to catchment.
Flow reductions can potentially result in reduced pumping and treatment costs, and defer the need for capital upgrade of these facilities.	Removal of I/I entering the system through house laterals is made contentious by the various house lateral ownership-responsibility boundaries that exist.

2.6 Provision of Adequate Stormwater System

A further but far less frequently considered form of I/I reduction is to provide a separate stormwater collection system of adequate level of service as a means of draining away direct rainfall runoff. The absence of such a stormwater system has been shown to significantly contribute to I/I due to the inability of retained soil moisture to drain stormwater away and also for illegal direct connections to be made to the wastewater system in the absence of an alternative. Ponding and flooding issues commonly result in significant I/I. It would be difficult to enforce inflow disconnections in areas with an inadequate stormwater system.

Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-6 Provision of Adequate Stormwater System - Advantages and Disadvantages

Advantages	Disadvantages
Decreases flooding which indirectly reduces I/I.	Could require significant funding.
It may be possible to source funding from the stormwater programme.	Water CCOs would have more difficulty implementing stormwater solutions than Councils.
Provides landowners with an alternative to constructing illegal connections.	Could require a significant amount of budget from the I/I Programme.
	Implementing new stormwater systems generally takes longer than rehabilitating existing wastewater assets.

2.7 Controlled Overflows

The primary objective of these facilities is to provide a route for wastewater to be diverted away from the public during extreme events or system emergencies.

With the advent of well-constructed system models, calibrated for both flow and water quality parameters, it is possible to more reasonably predict the volume of overflow and concentration/load of pollutants at an overflow location from a given storm event. By extension, with adequate knowledge of the receiving water sensitivity, the operator can determine the impact that such an overflow will have on the receiving environment.

Advantages and disadvantages associated with this particular approach are shown in the following table.

Table 2-7 Controlled Overflows - Advantages and Disadvantages

Advantages	Disadvantages
An alternative to a rigid, i.e. 1 in 5 year, or similar containment standard that may not be meaningful or economically achievable in some instances.	Guidelines, application and implementation need to be tested on actual case studies to develop the methodology from concept to a point suitable for Council application.
The philosophy of the risk based management of wet weather overflows should result in least cost-maximum environmental / community benefit.	Suitable environmental background information will frequently be unavailable which may necessitate time consuming and costly data collection programs.
Through prioritisation based upon risk and outcome, should result in an expenditure program that achieves maximum benefit per unit spend in early years of program (i.e. low hanging fruit picked in the short-term).	May require input from a diverse range of specialised technical experts such as ecologists, toxicologist, microbiologists etc., who may need to familiarise themselves with sewage and wastewater system management.
	Differentiation between the impact of urban stormwater run-off and sewage overflows on a receiving waterway.
	Consent required.
	Positioning of the controlled overflow may not be possible to give relief in other parts of the system depending on the configuration of waterways and the stormwater system.

2.8 Local Treatment

An alternative that is being explored as part of broader sewerage servicing strategies and integrated water cycle management is the inclusion of decentralised treatment plants into the existing sewerage networks.

Sometimes considered as sewer mining facilities, they could provide the dual function of resource recovery/recycling during dry periods and as an extension to the system treatment capacity during wet weather.

2.9 Alternative Wet Weather Technologies

There are a wide range of existing and emerging technologies that can:

- provide additional treatment capacity either at WWTPs or be deployed out in the wastewater system;
- mitigate the impact of wet weather overflows; and
- provide an alternative wastewater service to areas with excessive I/I.

The following section provides a brief overview of some different technologies that may provide a partial wet weather solution.

2.9.1 Pressure Wastewater Systems

A pressure wastewater system consists of a network of pressurised pipes which are fed by grinder-type pumps located at each dwelling or business in the system. Because of its pressurised nature, the opportunity for I/I is removed.

The grinder pumps create a slurry, which is then pumped through a small diameter pipeline from the house into the reticulation pressure sewer in the street. Pipes are sized to accommodate a limited number of pumps operating at one time.

The wet well associated with each grinder unit has the ability to store between 24 and 48 hours of Dry Weather Flow (DWF). The pipelines required for pressure sewers are considerably smaller than those required for traditional gravity sewers, pipes are laid in a relatively shallow trench and have the added benefit of restricting the amount of flow that can be discharged from an area. If a pump is unable to discharge into the pressure pipe network during peak wet weather periods then the flows are stored at the properties until capacity becomes available. Pressure sewer systems can change the nature of the influent entering the treatment plant resulting in lower screening capture rates.

Several Australian Authorities have reported low wet weather responses in their pressure wastewater systems, including South East Water in Victoria.(Carne, 2014)

The low reported incidence of I/I in pressure wastewater systems may be due to a number of different factors:

- private laterals are often renewed during installation in backlog areas, and are relatively short compared to those connecting into a gravity sewer at the front or rear of a property;
- the reticulation pipe network is pressurised which prevents any infiltration entering the reticulation system; and
- if down pipes are illegally connected or low lying gullies are used to drain a hardstand area, the additional flows may overload the pump and cause an alarm. Extra pump run times can also identify properties with stormwater diverting into the house sewer.

There are no known cases of an existing gravity wastewater system having been converted to a pressure wastewater system in order to eliminate a high I/I problem, although this is currently being considered for parts of the collection system in Levin in New Zealand and also in Christchurch. The intent is not only to reduce possible I/I but also to provide a greater degree of system resilience to future possible earthquakes.

2.9.2 Control of Floatables

There are a number of well-established technologies for reducing the quantity of floatables discharged from the wastewater system into the receiving environment. Combining screening with other processes can be an effective means of reliably reducing the quantity of visible solids and providing a component of a high rate sewage treatment process.

While more commonly associated with Combined Sewer Overflows (CSOs), these technologies can be used in association with other processes to deliver an effective wet weather treatment stream:

- manually raked screens;
- automated screens; and
- micro screening ï as small as 10 µm
- upward flow screens (up to 50% TSS removal)

2.9.3 Vortex Separation

Vortex or hydrodynamic separators are physical treatment devices that encourage the separation of the solid components of the sewage stream from the wet weather flows. Flow enters the circular basin tangentially which induces a vortex. Centrifugal forces encourage solids to aggregate on the outside of the tank where the velocities are slower and as the mass increases the solids settle and can be removed in underflow from the tank. The CDS-type separation units are one such type of unit.

While not a complete wet weather treatment solution, removal of 10-35% Total Suspended Solids (TSS) has been reported, and when combined with other treatment processes, higher TSS removal rates could be expected.

3. I/I Program Management

This section describes good practice I/I Program Management, discusses some of the typical issues and challenges, and presents some solutions to address those challenges.

The program approach to reducing I/I has been recognised as advantageous by many utilities around the world. An effective and successful program could provide the following benefits:

- central leadership and management;
- pooling of resources and funding;
- co-ordinated project planning;
- project and catchment prioritisation;
- standards development to improve consistency in processes and outcomes;
- evaluation and comparison of projects; and
- continual improvement, by passing learnings and good practice onto future projects.

Inflow and infiltration programs often require significant funding, staffing resources, proactive engagement campaigns, and close collaboration with external and internal stakeholders. For these reasons, centralised management and leadership are particularly important and will help to define and keep organised, the many and varied aspects of the program. Especially with large service areas, effective management and organisation is paramount to program success.

A flow chart for good practice Infiltration & Inflow Management is shown in Figure 3-1.

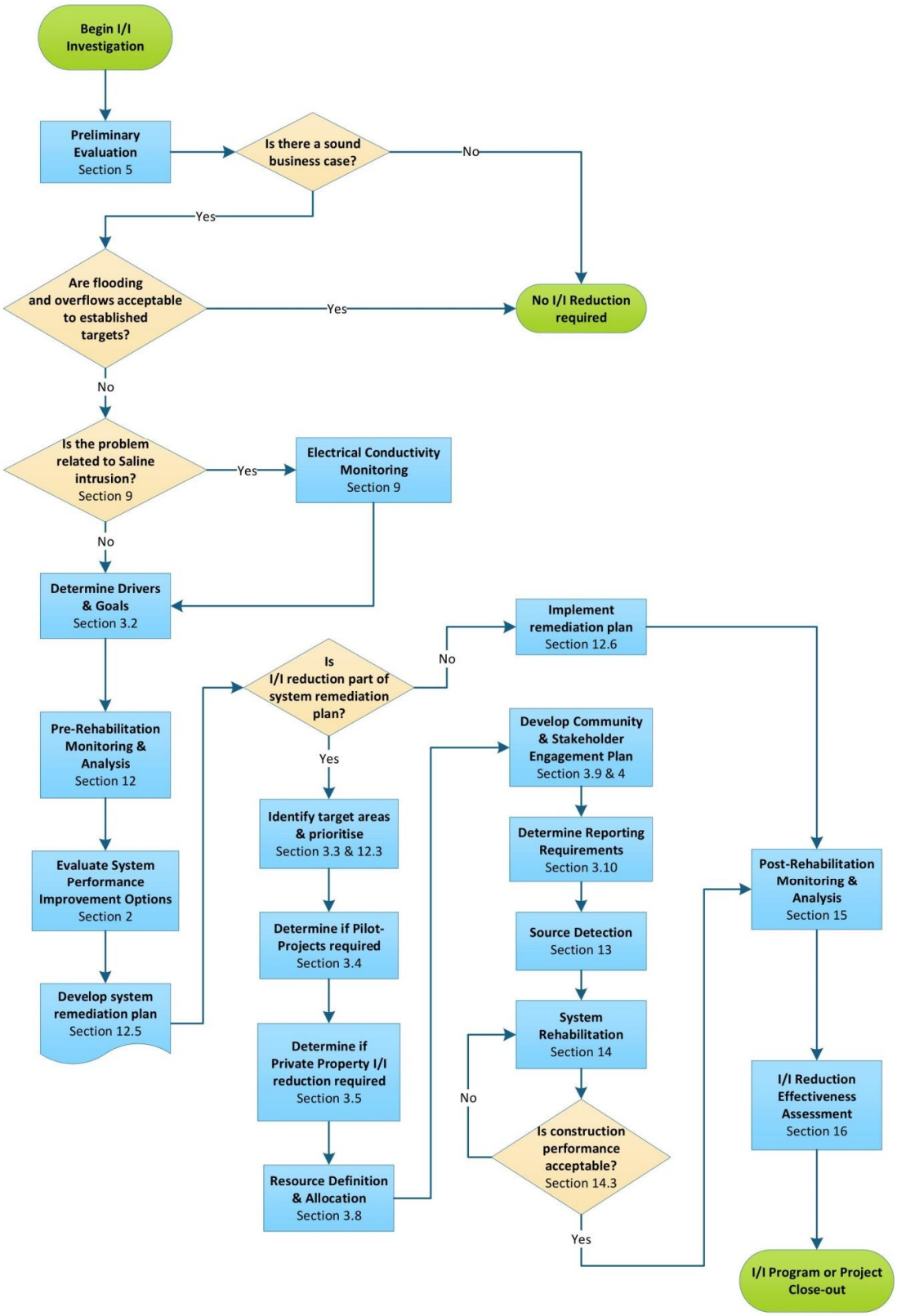


Figure 3-1 Good Practice I/I Management Process

3.1 Links to Other Programs

3.1.1 Relationship with Renewal Program

As outlined in Section 2, the relationship between I/I management and the renewal program can sometimes be complicated. It would be advantageous to prioritise improvements under the renewal program in accordance with the priority areas identified by an I/I program.

Funds set aside for the renewal program can therefore justifiably be used for I/I management. If this approach is implemented, then the amount of already available asset renewal funds should be determined to assist the financial planning of an I/I program.

Some sewer relining programs are driven by issues such as root intrusion. The associated repairs, however, have historically been localised structural repairs such as patch linings, which have had a small impact on I/I reduction. I/I reduction should be considered a goal within relining programs to maximise the effectiveness in terms of I/I reduction and asset renewal. Consideration should be given to requiring full pipe lining instead of patch lining.

3.1.2 Relationship with Maintenance Program

Inflow and infiltration is an on-going issue and a one-time approach will not provide a sustainable or long-term solution. The completion of rehabilitation work must be followed with a proactive maintenance regime. Assets deteriorate over time, and the on-going maintenance program should aim to be proactive instead of reactive. Maintenance records are also a key source of information for I/I management.

3.1.3 Relationship with Stormwater Programs

If an illegal connection to the wastewater system needs to be removed and re-connected to the stormwater system, the lack or absence of stormwater reticulation creates an issue. Left unresolved, reconnection of the storm water discharge to the sewer is likely in the short term. Sometimes, the water agency is a Council Controlled Organisation (CCO) that is responsible for water and wastewater service while the local Council is responsible for stormwater. This could create a significant challenge as the capital works program of the Council may not coincide with the CCOôs I/I rehabilitation program. If the CCO decides to fully or partially fund some form of stormwater solution, there may be policy and legal issues as the agency would be funding works in another authorityôs jurisdiction. The stakeholder engagement strategy should therefore include significant coordination with stormwater jurisdictions to develop a solution for inflow removal and reconnection. More detail on this issue is included in Section 4.

Remediation of groundwater infiltration can also cause springs in adjacent land parcels, as was experienced by Gisborne District Council. Agencies should be aware of this possibility as they evaluate their I/I programmes and manage/resolve it as necessary.

3.2 Determine Drivers and Goals

Undertaking an I/I program, or even the consideration of pursuing one, should begin with determining the key drivers of such an undertaking. Many agencies are under pressure from regulatory action and have determined that the most cost-effective solution is to pursue I/I reduction. Several key drivers and their categories have been described previously in Section 1.

Following confirmation of the program drivers, the program goals need to be determined. These goals may consider:

- regulatory compliance;
  - ï regulation versus performance and understanding of penalties and risk appetite
- affordability;
  - ï least cost/ max benefit

- material environmental benefit; and
    - energy
    - river / stream water quality and ecology objectives
- material social benefit
    - population
    - financial
    - social value of receiving waters
    - internal discharges.

These objectives will inform:

- how much I/I needs to be removed?
- how much reduction in overflows is required?
- what are the targets? and
- is the problem system-wide or only in certain catchments or areas?

3.3 Prioritisation of Catchments and Projects

The scope of the I/I program needs to be defined in terms of the percent of the total system to be rehabilitated. The scope could range from rehabilitating a few problem areas to rehabilitating the entire service area. After the scope of the program is defined, the catchments or project areas need to be prioritised. The prioritisation could take into account some or all of the program goals.

The prioritisation could take into account some or all of the following criteria:

- stakeholder complaints;
- system performance ï overflow frequencies;
- network and customer spatial relationships;
- asset information ï agency and customers;
- maintenance programs;
- geology;
- topography;
- stormwater system;
- ease of repair;
- geographic clustering; and
- flood-prone areas.

3.4 Pilot-Projects

Pilot-projects are used to investigate ways to maximise reduction and gather reliable baseline data for costs and likely outcomes. Because the pilot project outcome affects a relatively small share of the entire network, impacts to the overall network and risk to the water agency is minimised.

Pilot-projects should be used to test variables before implementing a system-wide rehabilitation program. However, managers need to be cognisant to the timing in which information from pilot projects materialise and how this may affect an overall program. Pilot-project objectives need to be balanced with overall main program timing objectives.

It is useful for pilot-projects to include a control area where no rehabilitation works are performed. This will provide a control or null area that can be used for comparison with the pilot-project results.

3.5 Private Property Infiltration & Inflow

An I/I reduction program is not comprehensive unless it addresses I/I sources on private property. Comprehensive I/I rehabilitation, that includes Private Property Infiltration & Inflow (PPII) reduction work, increases the chances of achieving higher reductions as it has been shown that approximately half the removable I/I enters the system through the private laterals (WEF, 2014; WSAA, 2013). For this reason, many of the leading New Zealand and US agencies have considered PPII works as a necessity, and have included it as an integral part of their program (GHD Limited, 2014).

PPII reduction can be challenging, costly, and require significant time to complete. For these reasons, it should be determined as soon as practicable if a program will undertake PPII reduction. Extensive program and project planning, along with considerable resources will be required. The challenges, complexities, and good-practice approaches are described in further detail in Section 8.

On private property, inflow is typically more predominant than infiltration. Public mains are typically buried deeper than private laterals, which makes them more susceptible to infiltration.

3.6 Policy and Legislation Changes

Often, effective I/I management requires changes to legislation or policy. Some examples of potential policy and legal issues include:

- illegality of discharging stormwater into the wastewater system;
- enforcement of illegal connections and/or private lateral repair;
- changes to the ownership boundary of the private house lateral and/or the ownership of the lateral;
- the potential use of public funds to perform work on private assets located on private property; and
- right of access to private property.

I/I management should work closely with the agencyôs legal section to craft effective policies while minimising liability and risk.

Several agencies in New Zealand have the legal basis to enforce the remediation of illegal inflow connections and defective pipes that cause infiltration. However, even with the legal basis to implement strategies, there are a number of risks associated with applying an I/I reduction program, particularly where applied to private sewers. These include, but are not limited to:

- not meeting the project objectives and losing community support; and
- difficulty in gaining the support of property owners and failing to meet the I/I reduction targets.

Agencies in the USA have seen benefit in changing local legislation to provide a legal basis for private property I/I investigation and rehabilitation. Although the use of enforcement on property owners was not reported to be a key tool, the agenciesôability to enforce incentivises property owners to co-operate and participate. Two examples are the Private Sewer Lateral Regulations developed by East Bay Municipal Utility District (EBMUD) in California, and Johnson County Wastewaterôs (JCW) Private I/I Code in Kansas.

3.7 Standards

3.7.1 Development of I/I-Specific Standards

The development and adoption of new standards can be an effective way to proactively control processes and procedures to maximise I/I reduction effectiveness. Many agencies have adopted new standard design drawings and technical specifications, and procedures manuals. These have been applied to source detection and rehabilitation, as well as new network design and construction inspection and sign-off

procedures. The standardisation of methods, procedures, and designs has helped agencies achieve more consistent outcomes.

Detailed further in Section 10, Sydney Water and Queensland Urban utilities have both adopted new engineering standards to implement preventive I/I measures. Sydney Water uses their Leak Tight technical specifications, and Brisbane has the NuSewer specifications.

3.7.2 The Building Code and Gullies

Agencies should be cognisant of Clause G13 of the Building Code so that I/I works on gullies do not violate the Building Code. G13 includes requirements on the design and construction of gullies, and constraints on the elevations of gullies. Section 1.5.5 provides additional detail on the Building Code requirements. Open, non-watertight gullies have been found to be significant sources of inflow (GHD Limited, 2014). G13 states that it is imperative that the waste pipe connections to the gully remain watertight to prevent the ingress of ground/surface water. Although this requirement is listed in the Building Code, agencies commonly find gullies that do not prevent the ingress of surface water. Increased enforcement and issuance of defect notices to address this issue may be an effective means to reduce inflow.

3.7.3 Resource Definition and Allocation

After the scope and requirements of the program have been defined, the required people, financial and system resources should be determined. The following is a list of resources that are typically needed and their typical involvement:

- agency/authority staffing (technical and non-technical);
- consultants (identification of high I/I areas and post-rehabilitation assessment);
- contractors (I/I source identification and remediation works);
- financial (funding); and
- database and information systems (storage and management of data).

If the program approach to I/I reduction is undertaken, then sufficient people resources, specialised in the various aspects of the program, should be centrally managed within the agency. An I/I program could require time and effort from many agency staff working in various departments. The staffing resources typically include personnel who are non-technical. Customer service and legal staff are two examples.

I/I projects and programs commonly require a significant amount of management, planning, and engineering effort as well as construction activity. Moreover, the amount of rehabilitation required to achieve pre-determined targets can be difficult to quantify. For these reasons, I/I work can become quite costly. Effective program financial planning takes into account the total cost, source of funding, and cash flow. One option to fund I/I work is to raise customer rates.

I/I programs can accumulate large amounts of data that are in different formats, requiring new or upgraded data management systems. Sources of data could include sewer defect and repair information, flow monitoring data, and contract documents for consultants and contractors.

3.8 Community and Stakeholder Engagement

Agencies in New Zealand, Australia and the USA that have implemented advanced I/I management programs have found it advantageous and necessary to conduct comprehensive and proactive community and stakeholder engagement (GHD Limited, 2014).

The engagement component of the I/I program should consider all stakeholders involved (external and internal) and how to best garner participation and cooperation as appropriate from those stakeholders.

I/I work, and especially private property I/I work, affects a large number of customers in the service area. The main purpose of community engagement is to clearly give sufficient appropriate information to the customer

to be able to understand the problem and their role and responsibilities in solving it. The most successful communication campaigns also give the customer motivation and incentive to provide the time and effort required for private property rehabilitation, and the motivation to pay for some or all of the cost for the work.

PPII work will inevitably create some level of inconvenience to homeowners. The community engagement should attempt to minimise the negative perception of property owners towards the agency, while also maximising the cooperation.

The message and means of communication are both important factors for successful community engagement. Information should be disseminated to the community through as many forms of media as possible to maximise the reach of the communication engagement.

The success of I/I projects is heavily dependent on the response from the property owners, specifically rectification of private plumbing. As a result, it is important that this is communicated to the community, individual property owners, and key stakeholders. This should include informing the community of the goals and objectives of the project such as system performance targets.

3.9 Effectiveness Assessment and Reporting

It is appropriate to periodically report on program effectiveness to stakeholders who approve funding or have other interests in the program. This necessity should be taken into consideration during program/project planning and could affect decisions on flow monitoring, modelling, program controls, data collection and management, and reporting protocols.

4. Community and Stakeholder Engagement

4.1 Community Engagement

Community engagement and communication is critical to successful I/I management. The multi-disciplinary nature of I/I management means that a wide range of stakeholders are involved and many parties are affected. Engagement planning should take into account everyone who will or may be affected by the program. Both external and internal stakeholders should be engaged. The community and stakeholder engagement strategy should, at a minimum, consider the following external stakeholders:

- regulatory authorities;
- property owners;
- councils; and
- affected industry groups ï plumbers and drain layers.

Effective I/I management also takes into consideration the cooperation and effort required from internal stakeholders:

- Upper Management/Executives;
- Legal Department;
- Asset Managers;
- Planning and Modelling;
- Operations and Maintenance;
- Community/Public Relations;
- Asset Renewal Program;
- Stormwater Group; and
- Building Control or Building Department.

The community and stakeholder engagement strategy, along with the development of communications materials, should be centrally managed by the I/I Program managers. This would facilitate the sharing of resources between different projects within the program, and also standardise communications material for multiple projects.

The following sections describe various methods of community and stakeholder engagement.

4.1.1 Marketing and Branding

An I/I marketing and branding strategy is one approach to õon-boardò the program to customers so that they see its benefits and their roles in achieving these benefits. Successful programs have adopted some form of marketing and branding campaign as part of their I/I reduction strategy.

Watercareós (formerly North Shore City Council in Auckland) program was called Project CARE in order to on-board people with its intent of community and environmental welfare.

EBMUD in California has developed extensive community engagement, or outreach, materials. Figure 4-1 shows the cover of a brochure produced by EBMUD. The brochure cover conveys a message of environmental stewardship. The programôs marketing message is:

- the ultimate goal is to protect a local, culturally and environmentally significant water body;
- regulators have imposed strict regulations that have necessitated the need to reduce wastewater I/I;
- private property I/I reduction is a necessity; and

- the wastewater agency will make a concerted effort to reduce impacts to property owners.

St. Louis Metropolitan Sewer District (MSD) in the USA has named their program Project Clear. The name suggests that the I/I management will make the water more clear, or in other words, improve water quality.

4.1.2 Community Education

The general public typically does not have much knowledge on wastewater systems, let alone the technical issues of wastewater system I/I. It can be effective to educate the community on the basics of inflow and infiltration and the problems that it causes to the community wastewater system and environmental issues associated with overflows. I/I program brochures and websites are two common ways to conduct community education. Gisborne District Council has produced a YouTube video providing basic information about the wastewater system as a whole, peak weather overflows, inflow and infiltration, how it affects the community, and how the viewer could contribute to the solution. The video can be seen at https://www.youtube.com/watch?v=fSGqdG59XTU.

4.1.3 Brochures

A brochure is a portable, hard-copy form of communication that can quickly convey the I/I issues and the program overview to the reader. These can be provided as handouts at a public meeting, and can be provided through mail, included with defect notices or with account billing. Figure 4-1 shows the cover of a brochure produced by EBMUD.

Brochures may also be in electronic e-book form with embedded website links, and they could be sent to property owners through email and/or electronic billing.

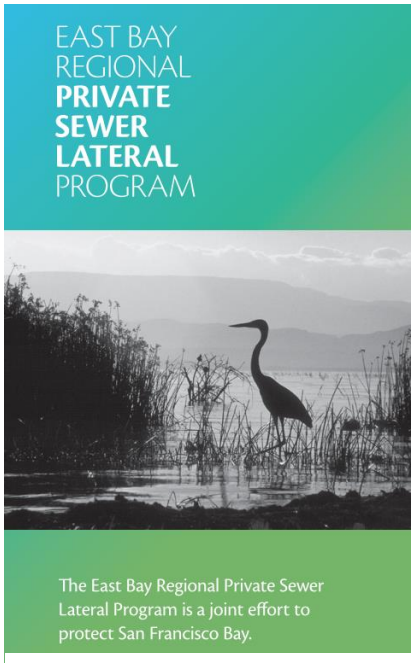


Figure 4-1 Brochure Example
(source: *www.eastbaypsl.com/*)

4.1.4 Website

A dedicated webpage for an I/I program can be an effective source of information for the community. If easily navigable, it has the ability to present a relatively large amount of information in a simple way. One website example that seems to be comprehensive is the St. Louis MSD website, a screenshot of which is shown on Figure 4-2. The website includes background information, Frequently Asked Questions (FAQs), program updates, a Twitter feed, and a YouTube video explaining the program. The website also clearly shows the program brand name which is Project Clear.

4.1.5 Dedicated Email Inbox

Developing a dedicated email inbox for an I/I program creates a single repository for all program inquiries. It also gives the community and stakeholders a single point of contact. The email inbox could become a resource for developing program FAQs. Furthermore, the availability of a website and email could also decrease the number of telephone inquiries, saving staff time.

Figure 4-2 Website Example (source: *www.projectclearstl.org)*

4.1.6 Public Meetings

Public meetings can be an effective way for face-to-face communication that reaches a larger number of people. Holding public meetings can also be useful for soliciting feedback on the program and using the feedback to adjust or improve the program.

4.1.7 Targeted Engagement

Targeted engagement with particular community or industry groups can help clearly communicate program requirements, and also dispel rumours and misinformation. It can also send message that the water agency is taking into account all parties affected by the new requirements.

The drainlayer industry is one group that could be affected by I/I management requirements. If the industry groups hold regular meetings, water agencies could offer to present on new I/I management requirements that may affect the industry. Gippsland Water in Victoria followed this step in its recent I/I reduction project.

EBMUDôs Program requires lateral repair during a property sale. Because this requirement affects the real estate industry, EBMUD conducted targeted engagement of the Real Estate Industry body to not only disseminate information, but also to gather feedback for the adjustment or improvement of program requirements.

4.2 Internal Stakeholder Engagement

Internal stakeholder engagement can help streamline the coordination and collaboration between various parts of the water agency. This internal coordination should be centrally managed by the I/I Program Management team. This would maximise the efficiency and effectiveness of the engagement. Centralised management of internal engagement would also facilitate the sharing of resources across individual projects within the program.

Executive managers have the power to approve or reject major proposals such as the implementation of an I/I program or the appropriation of funds for I/I management.

Legal staff should work closely with the program managers to clarify existing legislation and help craft changes to legislation if required for the benefit of the program. They could also review the program requirements and activities to minimise liability and risk to the organisation.

Building Control units manage and approve building consents, and conduct building inspections. Building inspections could be a critical time to identify I/I defects such as illegal connections and poorly constructed laterals. Close collaboration on building inspections should take place with Building Control.

4.3 Customer Engagement

Customer engagement issues could arise from flow monitoring, source detection or actual rehabilitation works, including, but not limited to:

- refusal of owner to grant consent for access;
- customer complaints in general;
- construction noise, vibration, dust and odours;
- owners, in the future, asking for additional work at no cost;
- smoke-testing causing concerns for local residents and fire department and police personnel; and
- contractor issues, including:
    - contractor inexperience;
    - contractor not performing to required standards;
    - damage to property;
    - allegations of theft; and
    - offers to complete repairs without prior consultation with the water agency.

The community and engagement strategy should seek to manage the potential issues outlined above and should seek to inform and work with the owners as well as the contractors.

One approach to alleviate issues between the contractor and the owners is to develop contractor engagement packages that would outline water agency expectations, rules, and requirements, including protocols on dealing with home owners.

Many water agencies have also found it beneficial to contract with a single contractor for a large scope of work including works for multiple project areas and catchments. The reported benefits have been:

- contractor is familiar with the work type from one property to the next;
- contractor becomes familiar with the construction specifications;
- contractor becomes familiar with performance standards and communications protocol with owners and the public; and
- contractor builds a working relationship with the water agency.

5. Preliminary Evaluation

The following section provides overview of good practice for preliminary analysis and evaluation of the wastewater system.

5.1 Problem Identification and Definition

Inflow and infiltration can cause stress on the wastewater system in a number of ways that can result in problems that need to be addressed. The problems typically include:

- discharge from a constructed overflow in response to rainfall events less than the level-of-service as established in consents;
- discharges from the system in areas unintended for discharge such as manholes or within private property;
- wet weather flows delivered to WWTPs exceeding capacity and resulting in washout of process units or bypass, resulting in failure to meet treatment compliance standards;
- wet weather flows exceeding the capacity of WWTP storages, resulting in the need to schedule emergency discharges to water ways; and
- high levels of total dissolved solids from seawater ingress in the sewage potentially affecting asset deterioration rates and treatment processes.

It is important for practitioners to clearly identify what their problems are at the first stage of the process and not confuse cause and effects.

In the first bullet point above the "problem" is discharge of sewage into the environment at a level-of-service less than agreed with the environmental regulator. The "cause" could be one of, or a combination of many factors.

Correctly defining the problem will help the practitioner develop a cost effective program of activities to be undertaken to quantify and rectify the issues.

5.1.1 Initial Inflow/Infiltration Quantification

The extent to which I/I contributes to the problem needs to be defined and quantified. The I/I rates calculated can then be compared with various I/I key performance indicators (KPIs) proposed in Section 6 that will enable the system performance to be benchmarked. Similarly, knowledge of the magnitude of the average recurrence interval (ARI) can provide an objective perspective of the system performance.

5.1.2 Defining the Flow Components

It is important to understand and define the major components of wastewater flows. The following Figure 5-1 contains a hydrograph illustrating the various components of the flow defined in this analysis.

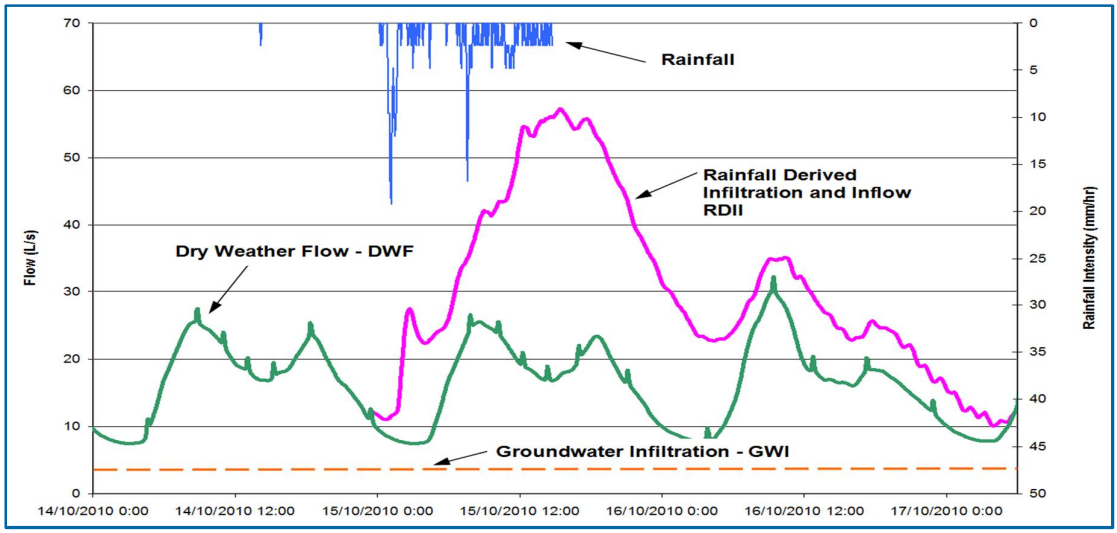


Figure 5-1 Wet-Weather Flow Components

- Rainfall Dependent Inflow and Infiltration (RDII) ï RDII volume is due to inflow from illegally or erroneously connected impermeable areas and infiltration through defects such as pipe or manhole cracks in both sewers and in house laterals during and after a rainfall event. Inflow can be considered as a "fast" response to rainfall. Infiltration generally exhibits a delayed response to rainfall and can occur for many days following a rainfall event. The volume of infiltration can be heavily influenced by antecedent soil moisture, soil type, evaporation and a range of other factors;
- Ground Water Infiltration (GWI) ï generally considered as constant non-time-varying flow, non-rainfall dependent but can change seasonally in response to water table movement or tidal changes in coastal areas; and
- Dry Weather Flows ï residential, commercial and industrial sanitary flows. Generally exhibit a regular diurnal pattern for weekdays with different patterns for Saturdays and Sundays.

Details and examples of how to undertake these calculations are provided in Section 5 of the Volume 2 document.

5.1.3 Flow and Rainfall Data

For the initial quantification of system I/I it is recommended that the Authority use whatever flow monitoring points are available in the system. Typical sources of wastewater flow data include:

- permanent and temporary flow gauges; and
- pumping stations with historic SCADA data.

In general, more flow gauges enables more precise calibration of the wastewater network. A sufficient number of temporary gauges should be maintained for the flexibility to place meters in areas where high I/I has been found. This enables a more precise and accurate analysis of the problem area.

Having sufficient rain gauging is also important for determining RDII.

It is necessary to process a sufficient period of flow data so that both the dry weather and wet weather system response can be analysed.

5.1.4 Determination of Average Dry Weather Flows

The Average Dry Weather Flow (ADWF) is comprised of sanitary flow and GWI. The daily flow pattern will generally be fairly consistent on weekdays with different patterns on Saturdays, Sundays, and holidays. It is recommended that at least 4 weeks of data are reviewed and averaged to create a representative weekday

and weekend hydrograph, with any abnormal days of flow removed from the analysis. This can be compared to customer water demand records to ascertain the level of consistency with gauged flows.

5.1.5 Estimation of Ground Water Infiltration (GWI)

A reasonable estimate of GWI can be made by analysing the minimum night time flows, particularly from monitored catchments higher up in the system which are relatively unaffected by the effects of flow attenuation.

For primarily residential areas, up to 80% of the minimum flows can be due to GWI with the remaining night time flows attributed to domestic use, in particular leaking cisterns (WSAA, 2013). In commercial/industrial areas, the potential for 24 hour industries and automatic urinal flushing needs to be taken into account when making GWI estimates.

5.1.6 Rainfall Derived Inflow Infiltration (RDII) Calculation

The rainfall derived inflow/infiltration hydrograph can be calculated by subtracting the ADWF hydrograph from the recorded wet weather flow hydrograph. The comparison should be extended until the recorded flows return back to dry weather pattern. This can take many days in areas of high infiltration. Summing up the volume under the RDII hydrograph provides the total volume of RDII for the given rainfall event.

The catchment area in the above calculation is generally considered to be the area contributing to the wastewater system. For consistency, it is recommended that large areas such as parklands, golf courses and major transport corridors that are not "connected" to the wastewater system be excluded from the area determination.

5.1.7 Calculation of Storm Event Average Recurrence Interval (ARI)

While not all Authorities have a required level-of-service involving a specific storm return period, if a problem has occurred during wet weather, it is useful to determine the relative severity of the event by determining the ARI of the storm.

The National Institute of Water and Atmosphere website contains useful tools for determining Intensity-Duration-Frequency curves for any location in New Zealand via its website http://hirds.niwa.co.nz/.

5.2 Cost-Benefit Analysis

Calculating the cost-benefit ratio of the I/I reduction, at the planning stage and then recalculated at the post-implementation stage, is a key process that should be followed on every I/I management project. The cost-benefit determination should then be included in a business case to support the I/I improvement programme.

The costs of the actual rehabilitation works can be 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 more complex to define. The benefits are directly connected to a water agency's principal objectives. Reducing controlled and uncontrolled wastewater overflows reduces risk to public health and also helps to protect the environment. In terms of being a successful business, complying with environmental regulations ensures the continuing operation of the wastewater system and allows the organisation to continue serving customers and collecting revenue. Furthermore, implementing effective I/I management is often a significantly more economical option compared to conveyance and storage amplification.

The following list outlines several benefits:

- the reduced extent of infrastructure upgrades (e.g. pump station or pipe capacity upgrades or storage volumes) that would have otherwise been required 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;
- 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 estimated;
- the dilution effects on treatment reaction rates increases the dollars per ML treated. The reduction of these effects due to I/I reduction is a cost savings.
- where appropriate, the reduction in fines or other financial penalties for excessive overflows imposed by the Regulator; and
- other non-tangibles such as the reduction in Council reputational damage image etc. could be valued and included in the assessment.

All of these savings, be they õone-offsò 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[1] 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? The option of replacement of the asset should be considered and a financial comparison against renewal performed. A cost/benefit analysis should also be used to compare the option of re-lining pipes versus replacing pipes, and to determine the most cost-effective method of rehabilitation (re-line vs. replace) for a particular project area.

[1] 30 years is used because after 30 years, the impact of capital that is spent is negligible when converted to present value.

6. Key Performance Indicators

Historically, I/I analysis projects carried out in New Zealand, Australia, and the USA have been done using a range of parameters that quantify the various sources of I/I as referred to previously in Section 5.1.2 (Water Services Association of Australia, 2013).

These parameters, or Key Performance Indicators (KPIs), are commonly defined as follows:

- Groundwater Infiltration (GWI) or base flow;
- Rainfall Dependent Inflow and Infiltration (RDII); and
- Wet Weather Peak Flow factor, defined by stormwater inflow (SWI).

KPIs proposed here are consistent with those outlined in the WSAA Guidelines document (WSAA 2013).

It should be noted that these parameters have been developed for primarily residential areas with contribution from commercial and retail development. Areas with large industrial contributions should be analysed judiciously.

It is recommended that the KPIs be calculated on an individual flow monitor or pump station catchment basis. Refer to Section 12 for information on pre-rehabilitation monitoring and analysis.

6.1 Dry Weather (Groundwater) Infiltration

There are a number of indicators that have been used to assess a systemõs performance with regard to permanent GWI These indicators have tended to evolve based upon the ancillary data sources that are readily available.

In upstream residential catchments, where flows are largely unaffected by attenuation or nocturnal non-residential discharges, approximately 80% of the minimum nightly flows are due to GWI. This approximation is a õrule-of-thumbòfactor that originates from observational experience of past projects. The first indicator for GWI is:

$$GWI_1 = GWI_{(80\% \text{ of minimum flow})} / ADWF$$

If GWI_1 is greater than 20% it is an indicator that GWI is greater than expected.

Population-based flow indicators are also recommended, that is the ratio of the measured ADWF to the estimated population.

$$GWI_2 = ADWF_{measured} / Population_{theoretical}$$,where the unit is l/person/day

As guideline values, when the ratioõs value is below 170 l/p/d, it is indicative of exfiltration and when the value is greater than 270 l/p/d, then significant groundwater infiltration is likely to be occurring.

As a further indicator that can be used, a water consumption-based flow factor, being the ratio of the measured ADWF to the metered water consumption (where available).

$$GWI_3 = ADWF_{measured} / Water\ Consumption_{measured}$$

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 1.1, then significant groundwater infiltration is likely to be occurring.

6.2 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.

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

= (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 greater than 20% indicate high levels of wet weather response.

6.3 Peak Wet Weather Flows (PWWF)

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 ADWF preceding that event.

SWI_1 = $PWWF_{measured}$ / $ADWF_{measured}$.

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.

6.4 KPI Summary Table

The KPIs discussed in this section are summarised in Table 6-1, and the typical range (little to no infiltration) for each KPI is also shown.

Table 6-1 Typical Ranges for Key Performance Indicators

Key Performance Indicator	Typical Range
GWI_1	<20%
GWI_2	>170 and <270 l/p/d
GWI_3	0.5 ï 1.1
$RDII_1$	<20%
SWI_1	<5

6.5 Threshold Trigger Values

Whether pursuing an I/I reduction programme is justified will depend upon the performance and operational problems that are being addressed in the system. In addition, an options assessment on the viability of an I/I reduction programme in comparison to the other I/I management options outlined in Section 2 may be warranted.

It is useful however to have some idea of threshold or trigger values of the various I/I KPIs to determine whether pursuing an I/I reduction program through source detection and system rehabilitation is likely to be successful.

Many water agencies have recognised that when the measurable $RDII_1$ parameter is less than 8-10%, the success of rehabilitation programmes aimed at reducing I/I is much more difficult to quantify and therefore the associated works are more difficult to justify (WSAA 2013).

A threshold value of the $RDII_1$ parameter of 10% is therefore recommended.

Unless there are other one-off reasons such as a localised overflow that would benefit from such a programme, where the $RDII_1$ parameter is less than 10%, consideration of system-wide rehabilitation as an improvement measure to reduce system wet weather volumes is not recommended.

Similarly, the same research has identified that appropriate threshold values exist for the GWI and SWI parameters as follows:

Groundwater Infiltration (GWI_1) - greater than 20% of ADWF

Groundwater Infiltration (GWI_2) ï 280 l/p/day

Wet-Weather peaking Factor (SWI) ï 8.

The threshold trigger values discussed in this section are summarised in Table 6-2.

Table 6-2 Threshold Trigger Values

Key Performance Indicator	Threshold Value
RDII	10%
GWI_1	20%
GWI_2	280 l/p/d
SWI	8

7. Predicting I/I Reduction Levels

There is an increasing amount of reports and case studies from which results can now be used to more reliably predict I/I reduction and its relationship to different levels of rehabilitation (WSAA, 2013).

7.1 Guideline Values

A notable conclusion drawn from a Melbourne Water study stated that unless at least 40% of the total piped system within a catchment is rehabilitated, there is no guarantee of reducing RDII (MWH, 2008). It is clear from this result that complete rehabilitation of the catchment is likely to achieve the maximum I/I reduction outcomes.

The following table and data was sourced from the Melbourne Water study.

Table 7-1 Reduction for Different Extents of Public Sewer Rehabilitation

% of Total Public System Rehabilitated	Reduction in RDII (%)	Reduction in GWI (%)
100	60	80 +/-
80	40	70 +/-
60	20	50 +/-
40	0	30 +/-

A comprehensive review carried out in New Zealand in 2003 for North Shore City Council obtained, through research, the RDII volume reduction results of over 50 projects carried out in Australia, Southeast Asia, New Zealand and the USA at that point in time. Whilst it is acknowledged that these projects may have used vastly different techniques to calculate levels of I/I reduction achieved through these projects, the RDII reduction levels were plotted against the extent of rehabilitation works carried out. Rehabilitation works were categorised into one of the following three categories:

Level 1 ï Removal of all inflow defects identified through a program of house-to-house inspections, smoke testing and manhole inspections;

Level 2 ï Level 1 works in addition to complete sealing of all the public sewers within a catchment; and

Level 3 ï Level 2 works in addition to sealing all the private property laterals up to the house.

Table 7-2 is the result of this data compilation.

Table 7-2 Levels of I/I Reduction Achievable for Different Levels of Rehabilitation

Rehabilitation Level	RDII Reduction (%)	Reduction in Peak Flows (%)
1	0-15	0-25
2	15-50	30-40
3	40-80	No results available

Clearly, and as expected, there is significant variation in the results achieved. Whilst the means of assessing the achieved rates of I/I reduction have varied significantly between projects in this sample, the conclusions that can be drawn from previous research is that with a well advised, planned, managed and controlled program of I/I reduction works the rates of I/I volume reduction as shown in Table 7-2 can be obtained (WSAA 2013).

Both the results in Table 7-1 and Table 7-2 indicate that between 40-60% of the removable RDII comes from the private house laterals in the system. I/I projects with established RDII reduction targets greater than 40% should include rehabilitation of private property I/I. Private property I/I reduction is discussed further in Section 8. Many projects in New Zealand and around the world that have rehabilitated both public mains and private laterals have shown significant RDII reduction (GHD Limited, 2014). This demonstrates the benefit of rehabilitating private house laterals.

To determine if a relationship could be inferred between the percent of a wastewater system catchment rehabilitated and the amount of post-rehab RDII reduction in that catchment, the graph shown on Figure 7-1 [2] was developed. The scatterplot includes actual real project data from water agencies in New Zealand, Australia, the US and Canada. The reported RDII reduction achieved for each project is plotted against the amount of total catchment rehabilitated (in percent of total catchment). Several key assumptions were made to facilitate the comparison of the projects and simplify the graph.

[2] The graph was created using several assumptions to facilitate the comparison of many different projects that used different methodologies. It is assumed that a project wastewater system is comprised 50% of sewer mains and 50% of private laterals. Inflow, manhole, and main junction works are not considered. The agencies calculated RDII using different design storm events, and this is not factored into the graph. All projects, however, used data analysis methods that coincide with, or are similar with that described in *Reducing Peak Rainfall-Derived Infiltration/Inflow Rates – Case Studies and Protocol* published by the Water Environment Research Foundation.

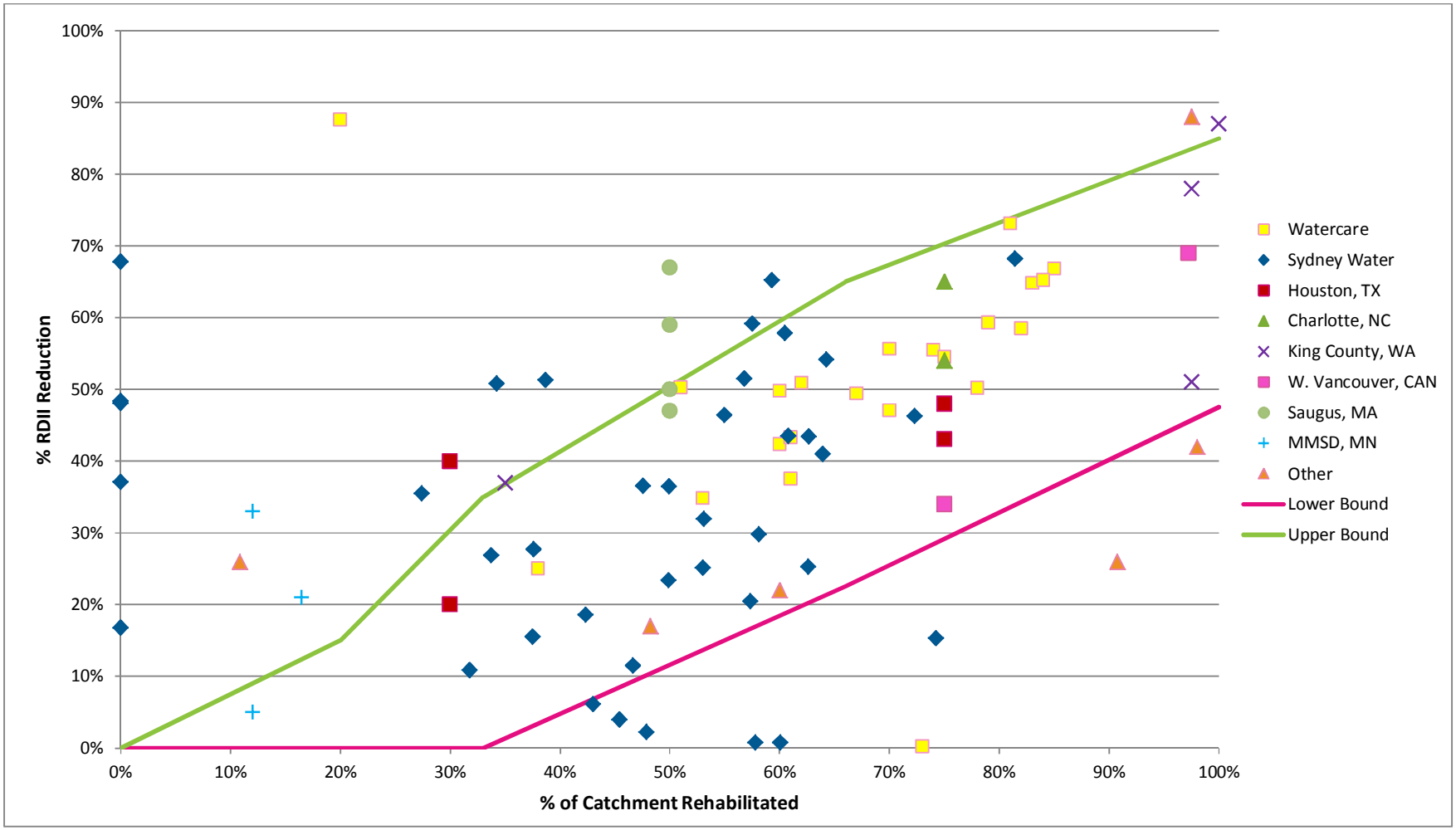


Figure 7-1 Various Project Results - RDII Reduction vs. Percent of Catchment Rehabilitated

Figure 7-1 further validates the guideline values shown in Table 7-2, with the results of Watercareôs previous I/I reduction projects plotted against the envelopes generated by the upper and lower bound values shown in Table 7-2.

7.2 Watercare Predictive Model

North Shore City Council in Auckland (now Watercare Services) rehabilitated more than 34 catchments for their Project CARE programme. Pre and post-rehabilitation results were analysed. During this process it was identified that four variables had the most influence on the reduction of RDII% and PWWF. The four variables were:

- the percentage of the total network rehabilitated;
- the amount of the public system rehabilitated;
- the amount of the private system rehabilitated; and
- the initial leakiness of the catchment (measured in RDII%).

As a result of this analysis, two rehabilitation effectiveness models were developed:

- a model to predict the likely reduction in RDII % (the percentage of the total rainfall falling in the catchment that enters the wastewater sewer); and
- a model to predict the likely reduction in peak wet weather flow (L/sec/ha).
- The analysis also concluded the following:
- at least 40% of the catchment needed to be rehabilitated to produce a measurable reduction in I/I volume;
- the greatest determinant on the level of I/I reduction achieved was the initial pre-rehabilitation level of I/I; and
- there was less of an increase in I/I reduction achieved when more than 80% of the catchment was rehabilitated.

It should be noted that this model was developed using rigorous application of detailed specific calculation processes. It was found that variation in such processes lead to different results. Subsequent use of the model must therefore be cognisant of this.

Levels of reduction in GWI are much harder to predict. Several studies have actually shown an increase in ADWF after system rehabilitation. This is considered mainly due to the possible exfiltration conditions that could have existed prior to the rehabilitation works. It is therefore concluded that whilst reduction in RDII can be more reliably predicted based on results obtained from previous studies, reductions in GWI are currently far more uncertain (WSAA 2013).

7.2.1 RDII Percent Reduction

The Watercare predictive model showing the relationship between initial RDII%, % of total network rehabilitated, and RDII % reduction is shown on Figure 7-2.

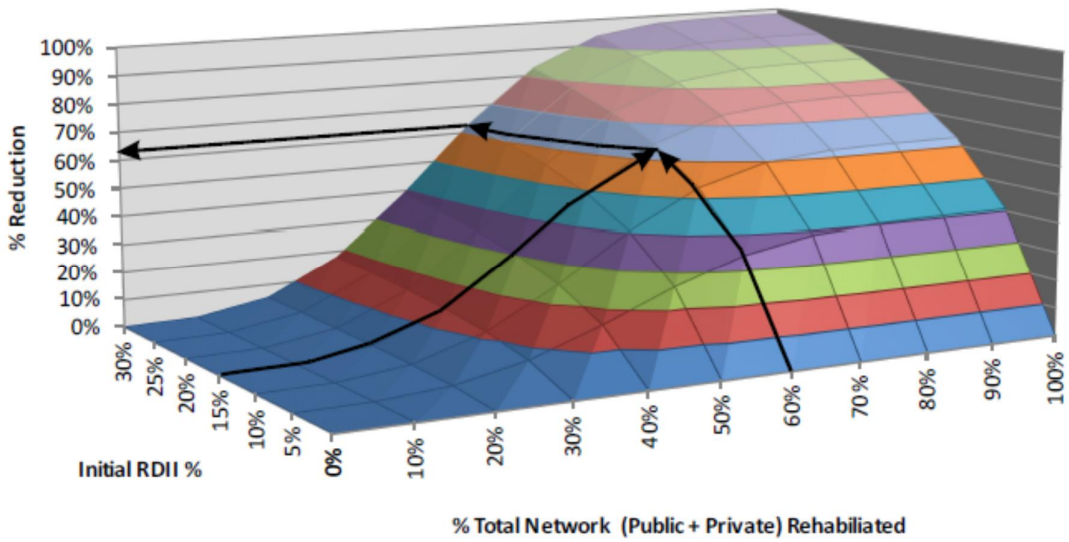


Figure 7-2 ï Model of RDII % Reduction vs. Initial RDII % and Total Network Rehabilitated

The developed model, described above, suggests that:

- an exponential increase in the reduction in RDII occurs
  - ï until approximately 70% of the public sewer is rehabilitated. Beyond 70% the model suggests that the law of diminishing returns kicks-in with little additional reduction in RDII
  - ï as the percentage of private properties increase. When approximately 60% of the private properties had been rehabilitated, the model tapers off quickly. The study also found that the maximum number of properties within a catchment with defective drainage is typically 60-70%. This suggests that the increase in reduction tapers off after 60% of properties have been rehabilitated because after this threshold, the majority of properties with defective laterals have already been repaired
- up to 45% of the RDII reduction came from the public network while the remaining 55% came from the private network; and
- the potential to reduce the RDII starts to drop off at an increasing rate when the pre-rehabilitation RDII drops below 10% RDII.

7.2.2 Peak Flow Precent Reduction

The similar predictive model showing the relationship between peak flow reduction versus initial peak flow and % total network rehabilitated is shown on Figure 7-3 below.

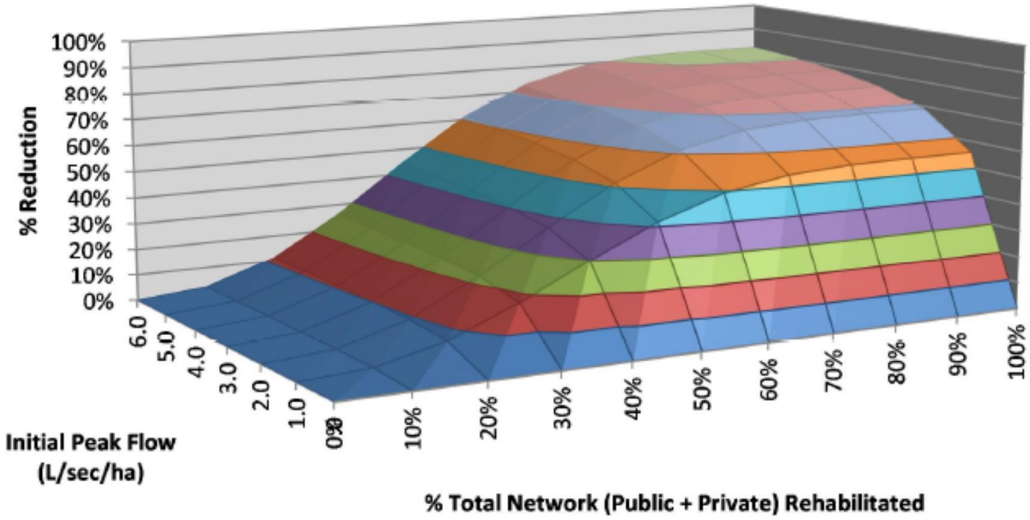


Figure 7-3 - Model of Peak Flow % Reduction vs. Initial Peak Flow and % Total Network Rehabilitated

The developed model also suggests that:

- an exponential increase in the reduction in PWWF occurs until approximately 70% of the public sewer is rehabilitated. Beyond 70% the model suggests that the law of diminishing returns kicks-in with little additional reduction in PWWF;
- an approximately linear increase in the reduction in peak flow until approximately 60% of the private properties had been rehabilitated (those expected to have defective drainage); and
- up to 35% of the PWWF reduction came from the public network while the remaining 65% came from the private network.

The potential to reduce the peak flow through rehabilitation drops off quickly below 1.0 litres/second/hectare. 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 (WSAA 2013).

It should be noted that the predictive models presented above are based on Auckland catchments and should be used as guidelines only, not as precise prediction tools.

8. Private Property Inflow and infiltration

Due to the complex nature of Private Property Inflow and infiltration (PPII), and its potentially significant influence on I/I programs, this section has been provided to discuss the many important aspects of PPII reduction. This section includes a discussion on the complexities and challenges of PPII, and also the good-practice strategies that water agencies have used to address these challenges.

8.1 Background

Given published outcomes stating that half the removable I/I enters the system through private laterals, an I/I reduction program cannot be considered comprehensive without addressing I/I sources on private property.

When earthenware and concrete pipes have been used, it is generally recognised in most studies referred to above that a significant source of house lateral I/I is at the actual junction of the lateral with the sewer. The heavy pipes drop vertically over time, shear off the joint and create a major source of entry for infiltration.

Tree root intrusion in shallower house laterals is also considered to be a major source of house lateral I/I.

The North Shore I/I Programme, conducted by Watercare (formerly North Shore City Council) in New Zealand, is considered to represent the most advanced catchment-wide program aimed at lateral repair in Australasia (WSAA, 2013; Strategy Squared Limited, 2012). This program has worked within the paradigm of the conventional ownership arrangement of private ownership from the property boundary. It has shown the challenges that even with dedicated resources applied to lateral repair, it has taken 2 years to get 75% of identified house lateral defects repaired.

Few agencies have actively pursued system-wide PPII rehabilitation programs. Three examples from the US are East Bay Municipal Utility District, St. Louis Metropolitan Sewer District, and Johnson County Wastewater (GHD Limited, 2014).

Low participation and completion rates in private lateral rehabilitation and repair programs have been reported by New Zealand water agencies as well as those around the world.

8.2 Program Approaches

The program approach to solving PPII must be tailored to the specific circumstances and constraints of each water agency service area. A specific approach in one agency may not be appropriate for another. Forming a program approach can be complicated and challenging, but addressing the issues described in the following Sections (Section 8.3ï Section 8.5) will help to shape the program.

Some important considerations include the following:

1. What is the required timeframe to achieve the target I/I reduction and/or comply with regulatory requirements?
    - If targets need to be met in a short timeframe, then it is good practice to fully-fund or partially-fund the private property work.
2. Does the property owner own the entire length of house lateral?
    - If so, then lateral ownership transfers should be evaluated, at the very least the management of the portion of the lateral from the owner to the agency, particularly where part of the lateral is located on public land. This will simplify the process of repairing and maintaining the lower lateral, while avoiding the political sensitivities of taking over ownership of an asset on private property. Furthermore, rehabilitating all defective lower laterals in a project area may provide appreciable I/I reduction without performing on- property work.
3. Have participation rates been historically low?

- If this has been true, then the community engagement strategy should be re-evaluated and, if necessary, revamped. The full-funding of private property work should also be assessed.
- Factors found to improve participation and completion rates include:
  - ï full funding or cost-sharing options;
  - ï proactive engagement and education to homeowners as outlined in Section 3;
  - ï changes in legislation to require mandatory participation;
  - ï the contracting process ï agencies that have simplified the contracting process for homeowners have reported positive results in terms of participation rates. More specifically, the agency selects and engages the contractor for the work, relieving the owner of the responsibility of scoping and negotiating contracts; and
  - ï the payment process ï agencies that have simplified the payment process for homeowners have reported higher participation rates. In this scenario, the owner pays the agency for the contractorôs work.

8.3 Legal and Policy Issues

It is good practice to consider several critical factors when crafting PPII management policy. The following are important issues that may need to be addressed:

- limits of house lateral ownership;
- legal basis for illegal inflow source disconnection;
- use of public funds;
- right of access; and
- the following sub-sections will describe the issues in more detail.

8.3.1 Limits of house lateral ownership

The ownership boundary is typically located at one of the following:

- the first inspection opening (I/O);
- the property boundary; or
- the lateral connection to the main sewer (can be located either inside or outside the property boundary).

The historical problem with reducing RDII at the private lateral is that in all jurisdictions studied, the ownership of the house lateral by the property owner and subsequent responsibility for rectifying the problem has resulted in difficulties in getting laterals repaired. Hence removal of RDII sources arising from faults in the laterals has been problematic. The absence of the enforcement of existing legal levers, the existence of political sensitivities and the responsibility for private drainage frequently falling under the remit of the local government agency, as opposed to the Council, results in difficulties enforcing defect notices and further complicating factors.

A common feature shared by several US and Victorian (Australia) programs is the agency ownership of the portion of the lateral in public land, which is considered helpful in rectifying I/I-causing defects on house laterals. This is considered to facilitate repair of the lower part of the lateral which is best done by a public agency. In doing so, this resolves the apparent inequity in property owners being responsible for the repair of parts of the lateral under the road, kerb and channel and nature strip. Furthermore, the owner has no ability to control impacts to the sewer in public property (e.g. traffic loads, trees, etc.).

Portions of laterals that are shared provide a unique challenge. This situation occurs with apartments, condominiums, multi-family homes, and town homes. Because the ownership of that section is shared, it is

difficult to determine who is, and should be, responsible for the lateral repairs and/or the allocation of the responsibility.

The UK underwent a change in 2011 where they received ownership of the lateral between the property boundary and the main, and also portions of laterals that are shared by multiple dwellings. This ownership transfer has facilitated the water agenciesôability to maintain and rehabilitate laterals.

8.3.2 Legal basis for illegal inflow disconnection

If a water agency decides to enforce the removal of inflow source connections, there must be a sound legal basis that states it is illegal for stormwater to enter the wastewater system.

Councils have rights under the Local Government Act to:

- create bylaws which prohibit substances such as stormwater from entering the private sewer laterals.
- remove works that violate the bylaws mentioned above.
- require landowners to provide private stormwater drains that drain the private land and discharge to a public main.
- require landowners to clean, repair or relay existing stormwater or wastewater pipes on their private land.

Gisborne District Council uses Section 459 of the LGA 1974 to require private landowners to repair their defective laterals. See Section 1.5.2 for additional information on the LGA.

8.3.3 Use of Public Funds for Private Sewer Works

Before funding PPII rehabilitation, it should be determined if there are any restrictions on the use of public funds on private property. Another concern is the use of utility rates to disproportionately benefit certain customers (WEF, 2014). It may be perceived that this is an unequitable use of public funds, and the political sensitivities surround this issue should be considered.

Agencies in North America that have funded private property works have noted that although public funds are used on private property, the main beneficiary of such improvements is the community as a whole due to the I/I reduction improving the public wastewater system performance (GHD Limited, 2014).

Adoption of a funding model which includes the repair of private assets would need to demonstrate the strategy is the lowest cost option compared to other strategies and is consistent with organisation objectives.

8.3.4 House Lateral Renewal Protocols

The EBMUD Private Sewer Lateral (PSL) Program has been identified as the most comprehensive procedural, legal and financial arrangement that has been developed and implemented to address the difficulties related to a system-wide lateral rehabilitation program that does not involve full-funding from the water agency.

Under the program, a property owner that meets a trigger condition is required to obtain a certificate from EBMUD indicating that their private laterals are without defects and have proper connections. The three triggers are:

- the sale of a property;
- renovations in excess of capital value of $100,000; or
- changing the water meter size or adding an additional meter.

Failure to provide such a certificate necessitates repair or replacement of the lateral when one of the triggers is reached.

In EBMUD, it is envisaged that approximately 70-75% of house laterals would be renewed over 30 years. 16,000 properties were certified from 2009 to 2012. It is envisaged that using this criteria, all house laterals will be renewed over a period of approximately 35-40 years.

The program also provided financial assistance to properties located in areas where public wastewater main rehabilitation was taking place. This scheme helped private and public wastewater works to be undertaken at the same time and by the same contractor. This also helped to provide cost-savings as there would be less mobilisation costs with a single contractor performing the works.

The case study and additional details on the program is provided in Section 17.

8.4 Funding Strategies

Funding considerations include the source of funds, what is eligible for funding, limitations on funding, and program cash flow.

Some water agencies will decide that property owners should pay the full cost of their private property repairs. Often, water agencies will determine that sharing the cost of private property works would increase participation rates and be beneficial to the program. Alternatively, some agencies would find it difficult to fully fund the private property works. These three options have their advantages and disadvantages and they are shown in Table 8-1. The Table assumes the rehabilitation of the entire private lateral, and that the ownership of the rehabilitated asset remains with the private landowner.

Table 8-1 Comparison of Funding Options

	Option	Advantages	Disadvantages
1	Owner pays full cost	• Low funding commitment from agency	• Lower participation rates • Long timeframe for complete rehabilitation • Low-income owners are disadvantaged
2	Agency pays full cost	• Higher participation rates • Relatively shorter timeframe for complete rehabilitation	• May be cost-prohibitive • Legal issues with using public funding for private assets.
3	Agency pays partial cost	• Higher participation rates than 1 • More affordable than 2 • Increased funding for low-income owners could create more equitable situation	• Legal issues with using public funding for private assets. • Lower participation rates than 2 • Less affordable than 1

It should be noted that the most successful private lateral rehabilitation programs have involved agency funding (GHD Limited, 2014). Many agencies have raised sewer rates to fund the I/I programs.

In cases where a more targeted program of lateral repair is warranted to reduce I/I in certain concentrated areas, it is good practice to develop a lateral replacement policy informed by an economic business case

analysis that considers each and all of the issues outlined in the Table above as the three options for funding the lateral replacement:

8.4.1 Owner Pays

Water agencies and councils could consider carrying out the repair on the property ownerôs behalf and charging them for this work by one of three methods:

- a separate charge;
- a ñsoft-loanò incentive by the Council to the property owner, reimbursable to the water -authority by separate payment of an on-going levy on their water-wastewater bill or local government rates; or
- where owners are unable/unwilling to pay, place a lien/caveat upon the property for the cost of the works, accruing interest at an agreed rate recoverable upon sale of the property.

The disadvantage of putting the full cost on the property owner is:

- some owners are financially unable to pay for the work; and
- unwillingness of owners to cooperate would hinder the program success.

The repair policy of Project CARE, a programme of the former North Shore City Council, placed the financial responsibility of private property rehabilitation on the property owners. Project CARE included system-wide private inflow and lateral rehabilitation, and rehabilitated 75% of the sewer catchment.

8.4.2 Cost-Sharing

Cost-sharing could provide a feasible compromise to funding the rehabilitation; however, implementing a cost-sharing scheme also introduces complexities and numerous parameters that need to be defined. The following are several of the considerations:

- the percentage of the cost the agency will fund;
- the dollar amount of the financial incentives to be offered to each property;
- if different properties receive different amounts;
- if properties in critical project areas should be offered higher amounts;
- if the amount offered depends on the level of rehabilitation required;
- the capped dollar amount per property;
- if low-income homeowners receive a higher amount; and
- the maximum amount of funds that can be offered per annum.

The agency also needs to determine what type of work is eligible for funding. Some agencies have decided that private property inflow disconnection costs are the responsibility of the owner, but house lateral repairs are to be funded by the agency.

A reimbursement limit per property could be established to control costs and to ensure properties do not receive a disproportionately high amount of public funds.

The program may be subject to annual spending limits. To address this, some agencies have provided funding on a ñfirst come, first servedò basis until the annual limit is reached.

8.4.3 Contracting and Payment Process

Some agencies have adopted a direct-contracting approach where the property owner has the option to use a pre-approved agency contractor and pay the agency directly; the contractor is directly contracted to the

agency. Agencies have found that the direct-contracting approach has increased participation rates and improved the consistency of construction performance (GHD Limited, 2014). This approach relieves the property owner of the responsibility to scope and negotiate contracts, and therefore reduces the time and effort required of the owner. When the agency uses well-written standard specifications within the contract documents, this process also allows contractors to schedule the work in clusters, and helps ensure consistent construction performance.

8.5 Inflow and Stormwater Service Deficiency

There are several options that could be considered to solve the issue of inflow disconnection in areas with deficient stormwater service. If the situation involves a CCO that is responsible for wastewater service, while the local Council is responsible for stormwater, then there would be some added difficulties with stormwater provision.

One option would be the Council extending the stormwater network to accommodate the properties requiring inflow disconnections and also bearing the full cost. As it may be difficult for Councils and CCOs to agree to such terms, the CCO could consider sharing the cost of the works. Paying for the full cost of a stormwater network extension is cost-prohibitive and politically unfeasible for many utilities as the utility would be contributing significant funds for works that are another organisationôs responsibility.

Another option would be to provide stormwater detention works instead of new pipes. Rainwater tanks could serve this purpose and could be significantly more economical than new reticulation.

The following are several key questions.

- How critical is the particular catchment/project area to the overall I/I program?
- How soon does the I/I work need to be completed?
- Would the Council agree to provide and fully-fund the stormwater works?
- Would providing rainwater tanks be a more cost-effective option or at least address the likelihood of property owners reconnecting to the sewer at a later date?
- Would the CCO fully-fund or share the cost of the tanks solution?

8.6 Community Engagement

As outlined in Section 4, proactive and comprehensive community engagement is critical for effective PPII reduction. Source detection and rehabilitation works on private property can create a nuisance to the owner; hence effective community engagement is needed to minimise nuisance. Effective engagement will also help increase participation rates from property owners. Community and stakeholder engagement issues and strategies are discussed in detail in Section 4.

8.7 Current Status Elsewhere

Low participation and completion rates in private lateral rehabilitation and repair programmes have been reported by water agencies around the world. It should be noted that the most successful private lateral rehabilitation programmes have involved agency funding. Further, community engagement and communication is critical to a successful programme. Several overseas agencies have made the commitment to implement system-wide programmes.

Strict regulation from the US Environmental Protection Agency has been a primary driver for utilities in the USA to undertake aggressive and comprehensive I/I management. Sydney Water is also under pressure from regulators, and its primary driver is meeting system performance targets set by the New South Wales EPA, its environmental regulator.

Agencies in the USA have seen benefit to changing local legislation to provide a legal basis for private property I/I investigation and rehabilitation. Although the use of enforcement on property owners was not

reported to be a key tool, the agenciesôability to enforce incentivises property owners to cooperate. Two examples are the Private Sewer Lateral Regulations developed by East Bay Municipal Utility District (EBMUD) and Johnson County Wastewaterôs (JCW) Private I/I Code.

A common feature of US and Victorian (Australia) programs is the agency ownership of the portion of the lateral in public land, which is considered helpful in rectifying I/I-causing defects on house laterals. This is considered to facilitate repair of the lower part of the lateral which is best done by a public agency. In doing so, this relieves the burden on the homeowner to pay for works associated with assets it does not own such as the road, kerb and channel and nature strip.

The EBMUD approach where certification of existing house plumbing is required at key trigger points provides a method of addressing sources of inflow and infiltration. It also provides a disincentive for property owners to connect or re-connect illegal connections and adjustment of overflow relief gullies to manage stormwater issues.

Pilot-projects were used by external agencies and are proposed by Sydney Water to investigate ways to maximise reduction and gather reliable baseline data for costs and likely outcomes.

Water agencies have found advantages to streamlining the contracting and payment processes for homeowners. The direct-contracting method is used by Johnson County Wastewater in Kansas and EBMUD in California. In both systems, the contractor is selected and paid for by the agency, and the owner pays the agency directly. This method saves time and effort for the owner and the contractor.

Well developed and calibrated hydraulic models have been the foundation of effective I/I analysis for numerous agencies.

Source Detection and Rehabilitation methods appear to be similar around the world with a few exceptions, as outlined below:

- pipe-bursting is more common with North American utilities; and
- no US agencies reported to be currently using spiral-wound lining. This technology originated in Australia, and it has not yet become a common method in the US.

9. Seawater Ingress

Many agencies near coastal areas, have encountered the issue of high levels of seawater ingress in their wastewater systems. This seawater ingress affects the management and operation of a wastewater system in a number of different ways:

- increased base flows resulting in additional pumping and treatment costs;
- the high salinity is corrosive and increases the wear and cost to maintain pumping stations and other associated facilities;
- high salinity can adversely affect wastewater treatment processes;
- increased flows that can wash out treatment units; and
- high salinity can compromise the suitability of the sewage stream for potential sewer mining applications or the use of treatment plant effluent for reuse without energy intensive desalination modules.

Some inland Councils are affected by saline groundwater infiltration and the issues are similar to those listed above.

The following section illustrates methods that have been used to identify, isolate and quantify saltwater ingress. The rehabilitation approaches detailed in Section 2 can also be used for remediation of seawater ingress.

9.1 Electrical Conductivity Monitoring

9.1.1 Electrical Conductivity Measurement Basics

Salinity is the measure of total dissolved salts. As the salt concentration in water rises, so does the level of TDS and Electrical Conductivity (EC). A number of Authorities use EC monitors to measure the electrical conductivity of wastewater to provide an indication of the level of TDS and salinity from seawater ingress and/or ground water infiltration.

Sanitary sewage from mixed residential, commercial and retail sources will generally have a TDS in the range of 400 to 800 mg/l (WSAA, 2013). Industrial flows can register very high readings of TDS with values up to 20,000 mg/l for some food processing and metal finishing industries.

There are many EC monitors available in the market place however many are designed for clean water applications and can have problems if permanently installed in the sewer flow. The range of the monitor also needs to be adequate for the application. Conductivity readings could spike up to 40,000 µS/cm at locations experiencing significant saline intrusion.

TDS in milligrams per litre (mg/l) can be calculated from EC readings, in micro-Siemens per centimetre (µS/cm), by multiplying by a factor, and the relationship can vary greatly depending upon the quality and nature of the constituents of the sewage flow. Sources have quoted conversion factors ranging from 0.45 up to 0.9 with the majority of sources indicating a factor between 0.6 and 0.7.

The following table used by Sydney Water provides a broad indication of the relevant significance of seawater ingress.

Table 9-1 Indicative Salinity

Peak Conductivity (mS/m)	Peak Conductivity (mS/cm)	Salinity Indicator
<200	<2	**Normal** ï Drinking water
200 - 600	2 ï 6	**Slightly Saline**
600 - 2000	6 ï 20	**Moderately Saline** ï Brackish water
2000 - 6500	20 - 65	**Highly Saline** ï Significant seawater

Note: "Peak Conductivity" = 2 mS/cm = 2,000 µS/cm = 1,200 mg/l TDS
Source: Sydney Water

9.1.2 Instantaneous EC Monitoring

Getting an instantaneous EC reading from a sewer can provide a quick and inexpensive indication of the extent of saline intrusion in a sewer length. A number of different approaches have been trialled for getting instantaneous EC readings of the sewage quality including:

- extracting a grab sample with an approved sampling "bucket" and inserting the EC monitor into the sample at the surface;
- affixing the EC monitor to a length of PVC conduit and dipping the sensor directly into the sewage stream; and
- affixing the EC monitor to a length of chain or steel cable and dipping into the sewage stream.

Care should be exercised with the last two methods as results can be skewed if the sensor makes contact with the manhole or pipe.

Maximum TDS readings due to GWI will occur during the minimum morning flows, when the GWI is diluted with minimal sanitary flow, or during high tide in coastal areas.

Multiple grab samples could be taken with the timing coinciding with low, high, and intermediate tide levels. The grab samples could then be plotted against a flow hydrograph to evaluate the correlation between tide levels, flowrates and EC levels. A peak EC level coinciding with a peak of flow and high tide suggests that there is significant seawater ingress at the sampling location. Figure 9-1 is a flow hydrograph based at Marne Street in Dunedin with salinity grab samples plotted.

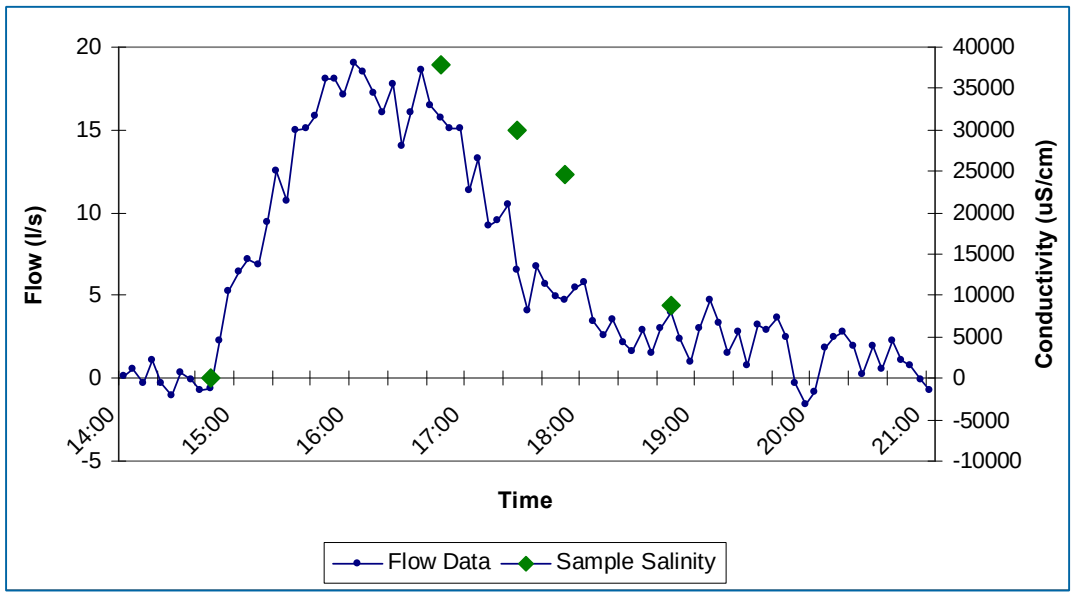


Figure 9-1 Example Salinity and Flow Correlation

The graph shows a spike in salinity coinciding with a spike in flow. This correlation suggests that seawater ingress is causing the increase in flow and salinity.

A local baseline EC value could be determined by measuring EC at several sites known to have no or low I/I. Also, there should be no major industrial discharges into the sampling sites as these would hinder the development of a representative baseline.

TDS readings below 800 mg/l can generally be considered "acceptable" while readings above 1000 mg/l indicate the presence of salt water ingress.

9.1.3 Continuous EC Monitoring

A number of authorities have undertaken extensive flow and EC monitoring surveys to identify the source and quantity of seawater ingress and/or saline GWI, including Wellington Water and Dunedin City Council (DCC). As described in Section 17.5 of Volume 2, DCC successfully implemented a saline intrusion program to reduce influent salinity levels entering the wastewater treatment plant to acceptable levels. DCC conducted system-side EC monitoring to identify problem areas. Flow and tide levels were compared against EC readings to evaluate seawater ingress into the wastewater system. DCC now maintains 20 permanent EC monitors to continually monitor suspect areas in the network.

Combining the flow data with the TDS concentrations at each time step enables calculation of a time series of the mass of salt per time step over the day, from which a quick estimate of the daily salt load from the GWI can be deduced. This exercise also generates the hydrograph and volume of GWI.

The hydrograph in Figure 9-2 illustrates a comparison of the TDS results from an EC monitor with 24 hour grab sample data and the calibrated hydraulic model.

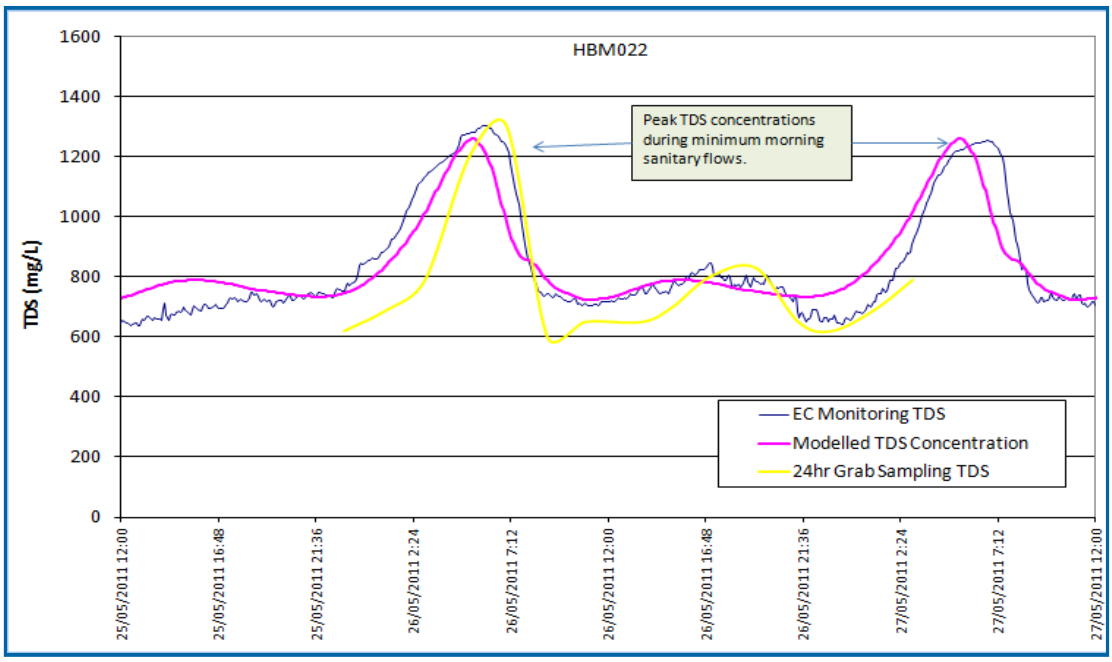


Figure 9-2 Example Comparison of Modelled, Sample and EC-derived TDS

The graph shows a typical TDS pattern for saline groundwater ingress, with TDS peaking during the minimum morning flow periods, where there is reduced sanitary wastewater to dilute the saline ingress.

10. Preventive I/I Measures

For new wastewater systems, it is possible to significantly reduce inflow and infiltration by adopting improved or alternative approaches in the design and construction of pipes, appurtenances and maintenance structures.

Investigations undertaken by Authorities into I/I in new developments have also indicated that a new wastewater system can be highly vulnerable in the period post sewer construction while building works are undertaken. There is also a growing push to require a re-inspection of private house drainage 2-3 years after a new house has been constructed and landscaping is complete.

The following section provides some background on some of the low I/I sewerage construction methods currently being implemented as well as some approaches to mitigate I/I in the early stages of a sewerôs life and from on-property sources.

10.1 Alternate Low Infiltration Specifications

Alternate low infiltration specifications have been developed such as Low Infiltration and Leak Tight (used by Sydney Water) and NuSewers (used by Queensland Urban Utilities) systems with the specific aims to:

- to provide a sealed system capable of avoiding root intrusion and stormwater infiltration; and
- to eliminate or minimise the need for personnel entry into confined space manholes.

10.1.1 Leak Tight

The Leak Tight specifications have been trialled in several locations including, but not limited to, Edmondson Park and West Dapto, Sydney. The implementation of these specifications is relatively recent; therefore, medium-term performance has not been assessed yet.

The scope of the Leak Tight specification is limited to property connection sewers and reticulation sewers with nominal diameters (DN) 110 to 315. However, the principles used may also be applied to the planning, design and construction of branch sewers and trunk sewers DN400 and larger.

10.1.2 NuSewers

NuSewers was introduced in 2006 by Brisbane City Council, which is now Queensland Urban Utilities (QUU). In response to QUUôs initiative, Iplex launched its SewerPlex product range that includes extruded PE100 pipes and associated electro-fusion fittings with a white internal surface to facilitate remote camera inspection.

10.2 Low I/I Measures

The following measures are used to prevent inflow and infiltration and are incorporated into the specifications discussed above.

10.2.1 Pipe Material

Low Infiltration (LI) wastewater systems are known as systems incorporating Polyvinylchloride (PVC), Polypropylene (PP) or Glass Reinforced Plastic (GRP) sewers with rubber ring joints (RRJ) or solvent weld joints (SWJ). Clay pipes are not permitted. Mild steel and ductile iron pipes may be used under special circumstances. Plastic lined reinforced concrete pipes may be used for trunk sewers of size DN750 and larger.

Polyethylene pipe is used in both the Leak Tight and NuWastewater systems.

Vinidex Sewertech polyethylene (PE) pipe was selected as the R & D material for NuSewers pipelines. Its advantages are:

- the pipe is flexible;
- comes in lengths of 6 m or 12 m;
- large radius bends that can be formed in situ horizontally and vertically;
- it reduces the number of bulkheads needed for stability on steep slopes; and
- it is manufactured with a white internal surface to assist CCTV inspection.

The SewerPlex pipe is complimented with a range of electro-fusion fittings including:

- couplings;
- caps;
- sweep junctions;
- sweep bends;
- puddle flanges;
- backdrops;
- maintenance shaft drops; and
- saddles.

10.3 Construction-Phase Measures

A particularly vulnerable period for I/I issues to occur is in the period near the finalisation of the sewer construction and the completion of building construction. The following identifies some common problems and solutions that have been used.

10.3.1 Damaged / Low-Lying Property Connections

In a development where lots lie vacant for some period before building construction starts, the property connection points / inspection openings may be prone to damage, particularly during grass slashing and site excavation. Damage can also occur to the property connection junction if struck by a backhoe during excavation for the house drain.

Figure 10-1 illustrates the approach used in Baton Rouge, Louisiana, USA. A capped 100 mm diameter PVC riser extends approximately 1m above ground level to clearly identify the location of the property connection point. The purpose is to prevent unintentional damage to the inspection openings.

Figure 10-1 PVC Risers on inspection openings in new development

10.3.2 Low-Lying Manholes

The WSAA Sewerage Code recommends a 75 mm clearance between the top of a manhole cover and the surrounding natural surface in a new subdivision where manholes are located within a property. It has been observed, particularly in relatively flat areas, that following foundation excavation (and spreading of excess spoil) that the surface level of the yard can raise and take up the provided clearance to the top of the manhole cover. This issue can be further exacerbated when topsoil is brought onto the site for final landscaping and the maintenance cover can end up as a low point in the yard.

Consideration of the probable overland drainage path should be considered when setting the cover levels for manholes.

10.3.3 Low-Lying Gullies

A common problem observed in many established areas is inflow through gullies. In many cases the gully may have been constructed correctly when installed, 75 to 100 mm above the surrounding surface area. Once landscaping works are completed however, the gullies may effectively provide drainage for the landscaped and court yard areas.

Figure 10-2 shows two examples of gullies.

Figure 10-2 Low-Lying Gullies

The gully to the left is raised and is less susceptible to flooding. The gully to the right is slightly below the grade of the surrounding surface, creating a low point for inflow ingress.

Figure 10-3 shows a non-compliant gully with typical defects.

Figure 10-3 Gully Defects

There is a gap between the concrete ring surrounding the gully and the building wall, which allows stormwater ingress. The top of the gully is at the same elevation as the surrounding surface. This violates the Building Code and also allows stormwater ingress.

The New Zealand Building Code, *Acceptable Solution G13 Drainage*, requires that the overflow level of gully dishes be no less than 25 mm above paved surfaces or 100 mm above unpaved surfaces. New Zealand Standard AS/NZS 3500 also specifies constraints on the elevations of gullies. See Section 1.5.1 for additional details. The enforcement of these requirements during building inspections would help prevent inflow.

As a solution to gully inflow, Yarra Valley Water in Melbourne have started the trial of fitting very low cost one-way valves on overflow relief gullies that permit discharge of wastewater from the system but which prohibit entry of stormwater runoff into the wastewater network.

10.3.4 Building Construction Inspections

The following are several critical requirements that should be included in building and infrastructure inspections:

- manholes are properly constructed, defect-free and are not low points for drainage;
- gullies are properly constructed, defect-free and are not low points for drainage;
- building and house laterals are constructed properly with no cracks, damage, or open joints;
- stormwater drainage pipes are connected to the stormwater network, not the wastewater network; and
- roof downpipes do not discharge to the wastewater network.

In addition, if the following inflow prevention measures become Council requirements in the future, then they should also be inspected before granting building consent approval:

- gully caps or lids; and
- one-way valves in gullies.

10.4 Post-Construction Measures

10.4.1 Two or Three-Year Property Inspection

It has been suggested that a number of the on-property I/I issues could be resolved by a "final" inspection of the property 2 to 3 years after building works have been completed. By this time landscaping and associated works will generally have been completed. The ground will have also gone through several wetting and drying cycles that may cause shrinkage-related cracks to occur.

11. I/I Reduction Methodology Overview

Many water agencies who have achieved effective I/I reduction have used methodologies that could be divided into five main stages. On the basis of replicating these outcomes, the common five-step methodology is defined herein as the Good Practice I/I Reduction Methodology. These five stages are summarised in Figure 11-1.

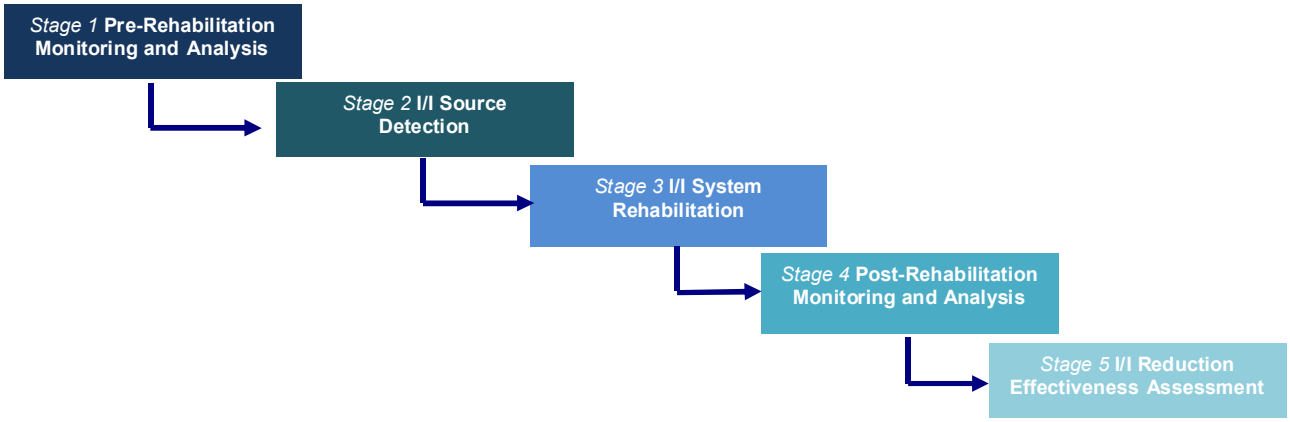


Figure 11-1 Good Practice I/I Reduction Methodology

11.1 Reduction Program Stages

11.1.1 Stage 1 ï Pre-Rehabilitation Monitoring and Analysis

Using a network of flow data sources as outlined in Section 12, the levels of I/I within the wastewater system are quantified by the KPIs as outlined in Section 6.

A robust monitoring and analysis regime should be developed as the backbone of the pre-rehabilitation monitoring and analysis stage as well as post-rehab monitoring and analysis.

Additional detail on pre-rehabilitation monitoring and analysis is provided in Section 12.

11.1.2 Stage 2 ï I/I Source Detection

The source detection phase represents works aimed at better understanding the nature and sources of I/I through a program of physical condition inspection works. As outlined in Section 13, there are numerous and varied source detection methods, but they typically consist of the following main forms of inspection and testing:

- visual and smoke testing to identify direct stormwater connections;
- manhole inspections;
- CCTV inspection of sewers and house laterals; and
- hydraulic testing of sewers and house laterals to determine typical water tightness.

The results of the Stage 1 - Monitoring and I/I Analysis are used to scope the extent of source detection works. Usually, because of their greater cost than the flow monitoring works, only a representative sample of the study area is tested or inspected. Once the general condition of the system is known, a program of rehabilitation works can then be developed and carried out that is aimed to achieve the desired level of I/I reduction.

11.1.3 Stage 3 ï I/I System Rehabilitation

The structural condition of the sewer determined from the source detection works will be the main factor in determining what rehabilitation technique should be used to achieve the I/I reduction levels required.

The predominant techniques used in Australasia at present for pipeline rehabilitation are:

- cured-in-place pipe liner;
- spiral-wound pipe liner;
- pipe-bursting or pipe-cracking
- sealing/lining of lateral connections to the main

Manhole rehabilitation is undertaken using;

- mortar patch repair;
- resin-impregnated felt patch repairs;
- PVC plastic lining systems;
- epoxy lining systems;
- complete manhole replacement; and
- manhole ring and lid replacement.

Section 14 summarises the different rehabilitation techniques and their applicability.

11.1.4 Stage 4 ï Post-Rehabilitation Monitoring and Analysis

Once all works are complete, undertake a further round of flow monitoring to assess the impact of the works undertaken.

Ideally, flow monitors and all data points need to be located in the same manhole locations as the pre-remediation survey. The number of flow monitors can generally be reduced to those sub-catchments where I/I remediation has been undertaken plus sufficient monitors in other parts of the system to enable assessment of the effectiveness of conveyance upgrades / storage implementation.

A survey period of 12 weeks or until 3 to 4 suitable rainfall events have been recorded should be adequate.

The normal range of I/I assessment parameters calculated in the early part of the project are recalculated based on the post rehabilitation flow monitoring data.

The accurate calculation of the post-rehabilitation I/I KPIs is critical to the success of the project objectives of reducing I/I.

11.1.5 Stage 5 - I/I Reduction Effectiveness Assessment

During this phase, the actual amount of I/I reduction achieved through the rehabilitation works program is quantified.

This involves calculating the differences in I/I levels for each of the I/I KPIs pre and post-rehabilitation.

The general equation to calculate the effectiveness of reduction is as follows:

Level of Reduction = $(KPI_{pre}$ ï $KPI_{post}) / (KPI_{pre})$

Additional detail is provided in Section 16.

12. Methodology Stage 1 - Pre-Rehabilitation Monitoring and Analysis

Once it has been established that the indicative levels of I/I exceed the benchmark KPIs defined in Section 6, or other levels of service are not being met, there are a number of steps to planning an effective detailed investigation which are described in this section.

The following phases represent good practice in pre-rehabilitation monitoring and analysis:

- network data collection and verification within a Geographical Information System (GIS);
- data acquisition using flow monitoring ï planning and implementation;
- data acquisition using other means;
    - ï pump station run hours
    - ï EC samples and monitors
    - ï tidal data
    - ï manhole surveys
    - ï CCTV surveys
    - ï customer complaints
    - ï maintenance records;
- development of a network of permanent and temporary flow monitors, and rain gauges.
- the placement of temporary flow monitors in areas where high I/I has been found.
- time Series data management (if applicable); and
- hydraulic model development, calibration and verification.
- the gauging network is used to regularly calibrate the sewer hydraulic models, and the calibration is done to a relatively high degree.

These steps will enable the agency to develop an accurate picture of the existing wastewater system, I/I problems, and help to create the informational backbone of the I/I program.

Monitoring and analysis of the wastewater system should be performed in accordance with the latest version of Water New Zealandôs *National Modelling Guidelines – Wastewater Network Modelling*.

12.1 Monitoring and Analysis Planning

The results from the preliminary evaluation phase, as described in Section 5, should be used as an aid to the planning and implementation of the flow monitoring programme.

12.1.1 Network Plans

Most New Zealand water agencies have their wastewater network assets stored within GIS. The quality of the network connectivity and attribute data will vary from organisation to organisation and in some cases from catchment to catchment. Prior to developing a monitoring plan it is important to ensure that all significant cross connections, diversions and bifurcations are identified and understood to enable effective catchment subdivision. Ideally this pre-planning review can be undertaken as part of the model network validation.

12.1.2 Flow Monitoring Planning

Good practice for flow monitoring planning can be found in the *Guide to Short Term Flow Surveys* manual published by the UK-Based Water Research Centre.

12.2 Monitoring

Additional detail on monitoring is provided in Section 12.1 of Volume 2.

12.2.1 Monitoring Equipment

There is a range of equipment types available in the New Zealand marketplace to measure flows in sewers. The equipment used generally has two or more sensors to measure depth and velocity from which the flow rate is a calculated product.

12.3 Analysis

Additional detail on data analysis and hydraulic modelling is provided in Section 12.2 of Volume 2.

The preliminary evaluation of I/I in the wastewater network and its general system performance is detailed in the previous Section 5. The data analysis taking place during the Pre-Rehabilitation Monitoring and Analysis phase is more detailed. The objectives are to identify I/I problem areas in the system, assess the magnitude of inflow versus infiltration, updating the hydraulic model and then using it to assess scenarios and develop a remediation/rehabilitation plan.

Hydraulic modelling of the wastewater system should be performed in accordance with the latest version of Water New Zealandôs *National Modelling Guidelines – Wastewater Network Modelling*.

12.4 System Options Assessment

The use of a calibrated hydraulic model as the platform to undertake options assessment is seen as the most cost effective means of achieving an optimal upgrade strategy.

Prior to committing to the expense of any further field work, the engineer/asset planner can develop and test the likely effectiveness of a range of options with different levels of I/I reduction to achieve the required level of service.

Section 2 provides an overview of the range of system improvement options that could be considered during this phase.

While the reason for undertaking the study would be to address an existing problem, it is advisable to also take into account the needs of future growth and any proposed future capital or operational modifications in this analysis to ensure the required level of service will be attained into the future.

General steps in this process are as follows.

1. Upgrade the calibrated model to incorporate future growth and proposed system improvements.
2. Undertake simulations on the future model with rainfall events/time series and compare predicted dry weather and wet weather system performance with the required level of service.
3. Identify shortcomings and develop costed system improvement options to achieve the required level of system performance. This is an iterative process that will include:
    - developing and refining conveyance upgrade/storage options with consideration of system performance options identified in Section 2 until the required level of service performance is achieved;
    - in catchments where I/I reduction has been identified as viable, modifying the wet weather response in the model to reflect different levels of I/I reduction. Re-run simulations and assess whether the reductions in wet weather flow result in the required level of service being achieved;
    - where I/I reduction alone is insufficient, incorporating conveyance and other types of upgrade solutions as required; and

- undertaking preliminary costings for each solution and refining until an optimal cost-benefit is achieved. The most cost effective solution will often be a hybrid of a number of different I/I management techniques.

The output from this process will be a preferred option that will be carried through to the development of the remediation plan.

12.5 Develop System Remediation Plan

The outcomes from the options development phase lead in to the functional and detailed design phase of the solution procurement cycle.

Components of the preferred option involving conveyance upgrades and storage solutions shall be put through the normal design cycle for capital upgrades:

- functional design and refined cost estimate;
- acquisition of additional data such as survey, geotechnical etc.; and
- detailed design and final cost estimate.

If the estimated cost "blows out" from the initial estimate due to unforeseen complications, it may be necessary to review the preferred option and modify the plan accordingly.

Components of the plan where Inflow/Infiltration remediation is identified as the preferred option involve the following stages which are described in greater detail in Section 11.

- Development of a source detection plan which will be tailored to each catchment (refer Section 13 for additional information on source detection).
- Management and analysis of inspection data.
- Develop a costed rehabilitation / remediation plan for implementation (refer to Section 14).
- Review the refined plan and cost estimate and confirm that it fulfils all performance requirements.

12.6 Implementation of System Remediation Plan

The over-arching peak flow reduction program is responsible for implementing the system remediation plan. The program approach, including centralised leadership and management and sharing of resources, should be used to effectively deliver the various projects included in the remediation plan.

The remediation plan will generally be put out to tender or in the case of minor works, they may be undertaken by the agency work crews. Whichever way the works are undertaken, it is important to accurately monitor and record costs throughout the process and to ensure the quality of works undertaken.

12.7 Benefits Realisation Review

The post-implementation review enables an objective assessment of the success of the project in achieving the desired project goals and the actual costs that can be fed back into the system for future projects.

Section 15 describes the approach to undertake a post-rehabilitation monitoring program. In addition to providing an estimate of the reduction in I/I of areas selected for I/I remediation works, the flow data can be used to update the calibration of the options model and then assess whether the works program has been successful in achieving the level of service objectives of the project.

13. Methodology Stage 2 - I/I Source Detection

As outlined in Section 12, Source Detection is the second of the five stages of the defined Good Practice I/I Reduction Methodology.

Source detection activities described herein are aimed at identifying sources of inflow and infiltration with a view to their subsequent removal by rectification of their causal defect.

Refer to Section 13 of Volume 2 for additional information on I/I Source Detection.

13.1 Inflow

Inflow sources are generally easier and less costly to detect and repair than those of infiltration.

13.2 Infiltration

Infiltration sources are more likely to be contributing the greater proportion of total RDII volume to the network, resulting in overloading of the downstream parts of the system. Infiltration sources can be due to either groundwater or rainfall.

Infiltration source detection needs to be as comprehensive as possible and should include both public and private sewers. Location and repair of only selected sources or defects can cause localised changes to groundwater levels and óimigrationôof either groundwater or rainfall-dependent infiltration to non-repaired sections of the public sewers or private lateral drains.

Access is not always straightforward when investigating private drains and lateral connections. It is also seldom possible to accurately quantify the amount of infiltration arising from a particular source. The increased difficulty in detection of infiltration (as compared to inflow) is such that smaller investigation areas are likely to be required, as defined by monitor density in the preceding flow surveys.

13.3 Summary of Methods and Techniques

The various methods of Source Detection, their applications, and their advantages and disadvantages, are shown in Table 13-1.

Table 13-1 Summary of Source Detection Methods

Method	Applications	Advantages	Disadvantages
In-Sewer Flow Monitoring	Used for initial assessment of high flow areas.	Good as an initial and cost effective analytical approach to determining areas with high I/I.	Covers large areas and is an indicator only - does not identify specific defects or connection points.
Salinity Monitoring	Determines locations and extent of infiltration or inflow of highly saline flows - either groundwater or sea water intrusion.	EC / Salinity levels can be readily measured. Grab sampling from surface can provide a quick indication of elevated TDS levels in sewage sample.	Need contractors experienced in operation of EC - salinity probes in conjunction with normal sewer flow monitoring for quantification of GWI and TDS loads.
Night-Flow Isolation	Used to determine the extent of groundwater infiltration in sewer mains.	Simple, low-tech method.	Need staff trained in taking presence/absence tests or weir measurements. GWI in private lines would be estimated instead of directly measured.
Visual Inspections	Used for the location of likely inflow sources such as downpipes, low gullies, manhole surface defects etc.	Simple. Quick. Lower cost.	Significant private property access required.
Smoke Testing	More useful for inflow detection. Its use for identifying infiltration depends on depth of asset, soil type and the water table level.	Quick and simple. Minimises time spent on private properties. Lower cost.	Effectiveness can depend on climatic conditions (clear vs cloudy day) and soil moisture levels when considering laterals. Does not necessarily locate exact point of defect.
Dye Testing	Used to confirm inflow sources identified by smoke testing or cross connections between stormwater and wastewater system.	Simple. Lower cost.	Significant private property access required.
CCTV	Used for location of infiltration sources as well as structural condition assessment in both public and private sewers.	Useful for structural assessment location of infiltration. Locates point of defect. Medium cost.	Difficulty using with high flow. Infiltration sources are less visible in dry soil conditions. Subject significantly to operator skill and consistency in coding defects. Flow diversion, cleaning, root cutting may be required.
Laser / Sonar Profiling	Used to survey the physical condition of sewer mains, including infiltration defects. The profiler is typically attached to a CCTV robot.	Objective survey results. Can be used in surcharge conditions. Can provide condition, deterioration, ovality of entire pipeline.	Currently, can only be used for larger pipes. New technology and not commonly used yet.

ElectroScan	A new technology that can be used to assess the likely leakiness of public and private sewers with non-conductive pipes.	Locates the leak. Can be used in surcharge conditions. Likely to pick up more defects than CCTV.	New technology, few experienced operators. Limited track record. Cannot be used for conductive pipes.
Hydrostatic Isolation Testing	Used to give qualitative indication of likely extent of infiltration and exfiltration in both public and private sewers.	Provides simple indication of the leakiness of pipes- either exfiltration or infiltration potential.	Requires isolation of section of sewer to be tested (i.e. bypass pumping etc. may be required). Does not reliably quantify likely exfiltration or infiltration levels. Doesn't pin point location or nature of defects.
Rainfall / Wet-weather simulation	Can provide an indication of likely infiltration rates in shallow house laterals. Typically used with CCTV.	Simple procedure to confirm infiltration. Gives an indication of likely infiltration rates in private sewers in saturated soil conditions.	Time consuming. Need to isolate the house lateral under test. Difficult to measure flows in laterals.
Ground Assessment (GAP and GIG)	Assesses voids and unstable ground created as a result of pipe damage and infiltration.	Non-invasive, environmentally safe and cost effective.	Does not identify all sources, only those which have resulted in the creation of a void.

14. Methodology Stage 3 - System Rehabilitation

14.1 Introduction

This section describes the methods and techniques used for the rehabilitation of public and private sewers. Refer to Section 14 of Volume 2 for additional information on System Rehabilitation.

The structural condition of the sewer determined from the source detection works is often the main factor in determining what rehabilitation technique should be used to achieve the I/I reduction levels required. However, for illegal connections and gully-traps, the structural condition is not as important.

In a recent study (GHD Limited, 2014), source detection and rehabilitation methods were found to be similar around the world with a few exceptions, as outlined below.

- Pipe-bursting is more common with North American utilities.
- Spiral-wound lining is not common in North America; this technology originated in Australia, and it has not yet become a common method in the US.

14.2 Methods and Techniques

14.2.1 Manhole Rehabilitation

The following lists various methods for manhole rehabilitation:

- complete manhole replacement
- frame, cover, and lid repair or replacement
- pan lids
- lid grade adjustments
- manhole base reconstruction
- tree root removal and subsequent patching
- cement grouting
- chemical grouting
- spray-on liners ï cementitious, epoxy, urethane
- liner inserts (plastic)
- patch repairs
    - ï mortar

14.2.2 Pipe Rehabilitation

The various methods of pipe rehabilitation, their pipe parameters, Internal Diameter (ID) range, work requirements, and special features, are shown in Table 14-1.

Table 14-1 Summary of Pipe Rehabilitation Methods

Method	Pipe Parameters		Work Requirements						Features				
	ID Diameter Range (mm)	Max. Repair Length (m)	Plugging / By-passing	Pit Excavation	Resin/ Coating Cure Time	Annular Space Grouting	Structural Repair	Excavation for Laterals Reopening	Cross-Section Change	Removal of I&I	Corrosion Protection	Public System	Private System
Level of Cleaning required: Good / Very Good													
CIP, standard	100-2400	400	Yes	No	Yes	No	Yes	No	Decrease	Yes	Yes	Yes	Yes
CIP, Top Hat	100-200	0.5	Yes	No	Yes	No	No	No	Decrease	Yes	Local	Yes	No
Reinforced gunite			Yes	No	Yes	No	Yes	No	Decrease	Yes	Yes	Yes	No
Spraying, epoxy	80-1000	<100 typ.	Yes	No	Yes	No	No	Varies	Decrease	Yes	Yes	Yes	Yes
Robotic repairs	200-1000	10	No	No	Yes	No	Local	No	Same	Yes	Local	Yes	No
Level of Cleaning required: General													
Slip-lining	100-2400	<2000	No	Yes	No	Yes	Yes	Yes	Decrease	Yes	Yes	Yes	Yes
Close Fit - Fold and form	80-1000	<500	Yes	No	No	No	Yes	No	Decrease	Yes	Yes	Yes	Yes
Close Fit - Deform-reform	80-1600	<300	Yes	No	No	No	Yes	No	Decrease	Yes	Yes	Yes	Yes
PVC Spiral Wound	150-2400	Varies with	No	No	No	No/Yes	Yes	Yes	Decrease	Yes	Yes	Yes	No
Spot repair sleeves	150-2400	300-2000	Yes	No	No	Varies	Local	Yes	Decrease	Yes	Yes	Yes	No
GRP panels	Man entry	No Limit	Varies	Yes	No	Yes	Yes	No	Decrease	Yes	Yes	Yes	No
Level of Cleaning required: None / Not Applicable													
Pipe-bursting, static	80-1500	<250	Yes	Yes	No	No	Yes	Yes	Same/ increase	Yes	Yes	Yes	Yes
Pipe-bursting, pneumatic	80-1500	<250	Yes	Yes	No	No	Yes	Yes	Same/ increase	Yes	Yes	Yes	Yes
Pipe-bursting, hydraulic	80-600	<250	Yes	Yes	No	No	Yes	Yes	Same/ increase	Yes	Yes	Yes	Yes
Pipe-reaming	100-600	<250	Yes	Yes	No	No	Yes	Yes	Same increase	Yes	Yes	Yes	Yes
Open-Trench	80-2400	No Limit	Yes	Open-trench	No	No	Yes	Yes	Same /increase	Yes	Yes	Yes	Yes

Note: Table entries should be considered indicative of applications but not definitive for all products available in the local market.

The table indicates which methods are suitable for public main rehabilitation and which methods are suitable for private lateral rehabilitation. The rehabilitation of both the public and private sewers in a catchment would provide a higher chance of achieving higher reduction, as mentioned in Section 7. Undertaking public and private rehabilitation concurrently would provide cost-savings due to less mobilisation and less contract administration. Further, concurrent completion of public and private works would yield more immediate I/I reduction results instead of the delay in results due to private works being completed at a later date. The main disadvantage with this scheme is that there would be a significant upfront cost to undertake them both concurrently.

14.2.3 Method Selection

Selection of the most appropriate method for a particular application is based on consideration of site-specific issues such as:

- condition of the existing pipe (if structural repair required);
- the nature and extent of defects;
- cost considerations;
- site space constraints;
- track record of technology/method;
- location and depth of pipe;
- implications of by-passing of flows;
- future maintenance;
- useful life of rehabilitated asset;
- traffic management;
- community impacts;
- environmental considerations; and
- historical value of original asset.

Engineering judgement should be used to select the most appropriate method to rehabilitate a particular sewer. Afterwards, a prescriptive specification should be written if a standard specification has not yet been developed by the water agency. This approach enables more control of methods and outcomes in comparison with performance specifications. Furthermore, the potential problems are more predictable and hence simpler to manage and mitigate.

A performance-based or outcomes specification could be written that is cognisant of all of the factors listed above, but which permits tenderers to propose one or a range of actual pipeline rehabilitation techniques. However, this approach provides less control of the outcomes. When the construction contract is tendered, a number of alternative technologies may be offered from different tenderers.

The following methods are common amongst utilities in New Zealand and Australia:

- spiral-wound lining;
- CIPP;
- open-trench replacement;
- manhole grade adjustments;
- gully raising;
- roof downpipe disconnection.

14.2.4 Open-Trench versus Trenchless

The conventional open-trench or open-cut method has become increasingly less common due to its social impact in terms of disturbance to residents. Further, the need for excavation sometimes makes open-trench less cost effective than trenchless methods. However, a few advantages of open-trench are:

- heavily damaged/fractured or broken pipes can only be repaired using open-trench; and
- the open excavation facilitates the rehabilitation or replacement of lateral connections to the main.

The useful life of pipe rehabilitated using CIPP is expected to be 50 years, while pipe replacement (open-trench or pipe-bursting) is 50 ï 100 years.

14.2.5 Grouting

Until approximately 2005, grouting of pipe joints and cracks had been used for over 20 years as a means of sealing wastewater systems and reducing infiltration. Anecdotally, there has been much debate over the longevity of grout particularly in relation to continual wetting and drying cycles that it may be subjected to. Sydney Water has carried out extensive investigations and has concluded that the expected life of polyurethane grout is no more than 5 years, and hence has abandoned grouting as a means of sealing sewers (Sydney Water Corporation, 2004). Therefore, it is recommended that grouting not be used for I/I rehabilitation.

14.2.6 Contractor Selection

Selection of the preferred tenderer should be selected upon the basis of the following:

- price;
- track record and past performance;
- familiarity with selected rehabilitation method;
- licenses and insurance; and
- contractor reputation.

14.3 Construction Performance and Quality

Construction quality assurance and quality control are critical tools in effective I/I reduction. Agencies that have used well-written construction specifications and have conducted a strong construction inspection program have found better results in terms of I/I reduction and consistency of outcomes (GHD Limited, 2014). This claim is not surprising considering how this strategy is typical for more routine infrastructure works.

Many agencies have standard specifications and/or codes of practice for source detection and rehabilitation works that were developed for previous I/I programs and projects. These should be used for future projects as a basis. However they should also be re-visited and updated from time to time to include new, or modify existing, requirements. New technologies may also necessitate the updating of standards/codes. The continual improvement of specifications is important for continual improvement of work outcomes. The same methodology should also be applied to approved materials and approved contractors lists.

15. Methodology Stage 4 - Post-Rehabilitation Monitoring and Analysis

15.1 Monitoring

Post-rehabilitation flow monitoring and analysis should be performed in accordance with the procedures taken during the pre-rehabilitation stage. There should be a sufficient number of storm events, at least three or four, included in the data collection to enable an acceptable level of confidence in the model calibration. The quantity and locations of gauges and monitors (flow, rainfall, EC, etc.) should also be similar to the set out established during the pre-rehabilitation phase.

16. Methodology Stage 5 - I/I Reduction Effectiveness Assessment

16.1 Reduction Determination

I/I reduction effectiveness is the quantification of the actual amount of I/I reduction achieved through the rehabilitation works program.

This involves calculating the differences in I/I levels for each of the I/I KPIs pre and post-rehabilitation.

The general equation to calculate the effectiveness of reduction is as follows:

Level of Reduction = $(KPI_{pre} – KPI_{post}) / (KPI_{pre})$

Three popular calculation methods are outlined below. They range in terms of complexity and therefore cost:

1. linear regression (R% vs. Rainfall volume);
2. linear regression ï control/target; or
3. calibrated computer hydraulic model

The calibrated model technique has several advantages over the other two techniques, represents good practice, and is the standard method for several agencies (WSAA, 2013). Further detail is provided in Section 15 of Volume 2.

16.2 I/I Reduction Cost-Effectiveness Assessment

After the I/I reduction has been quantified, the cost/benefit analysis for the project/programme, initially determined in Section 5.2, should be recalculated to assess the cost-effectiveness.

16.3 Other Reduction Metrics

Water agencies have used a wide range of metrics to aid in analysing results and for use in future project planning; these include:

- dollars spent per litre of I/I reduction;
- dollars spent per peak flow reduction;
- dollars spent per overflow reduction (in number of overflows or cubic meters of overflow);
- average cost per property;
- average costs according to work type;
- cost per private lateral repair;
- cost per inflow disconnection; and
- cost curves that can show the level of rehabilitation that provides the most value for money.

Maintaining a database of project costs would facilitate the cost estimating of future works and projects. Furthermore, these costs could be used as a cost-control measure by estimating the cost to rehabilitate the remaining properties within a project area.

17. Case Studies

Table 17-1 shows the case studies included in this manual and also indicates their relevance to various system issues. The case studies are provided in full in Section 17 of Volume 2.

Table 17-1 - Relevance of Case Studies to Various System Issues

Project	City-Wide Program	Small System Program	Use of hydrologic and hydraulic Model	Saline GW I Intrusion	Different levels of Rehabilitation	Use of SW system as a means of reducing I/I	Economic Cost benefit analysis	DWF increased after system rehabilitation	Seasonal effects during monitoring
Hillsborough Pilot Study, Auckland		✓			✓			✓	
North Shore City Council Project CARE, Auckland	✓		✓		✓				✓
I/I Management Programme, Palmerston North	✓		✓			✓	✓		✓
I/I Reduction Programme, Gisborne	✓		✓	✓	✓	✓			
Saline Intrusion Program, Dunedin			✓	✓					
EBMUD Private Sewer Lateral Ordinance Program, San Francisco Bay Area USA	✓								
Project CLEAR I/I Program, St. Louis, Missouri USA	✓		✓		✓		✓		

18. References

1. MWH. Melbourne Water Corporation (2008). *Inflow and Infiltration Management Strategy for Melbourne's Metropolitan Wastewater system.*
2. WERF (2003). *Reducing Peak Wet Weather Flows through I/I Reduction.*
3. WEF (2009). *Existing Sewer Evaluation and Rehabilitation MOP FD-6 3rd Edition.*
4. GHD Limited. North Shore City Council (2003). *Devonport I/I Analysis.*
5. GHD Limited. Metrowater (June 2007). *Hillsborough I/I Pilot Study.*
6. New Zealand Water and Wastes Association (1996). *Inflow and Infiltration Control Manual.*
7. GHD Limited. North Shore City Council (June 2003). *Expert I/I Review Draft Report.*
8. Shaw, N. Water New Zealand Annual Conference Paper (September 2009). *Developing a Predictive Model for I/I Reduction.*
9. Sydney Water Corporation (August 2004). *The Effectiveness of Rehabilitation in Reducing Rainfall Derived Inflow/Infiltration, Volumes 1 and 2.*
10. Melbourne Water Corporation (June 2011). *Hobsons Bay Main Infiltration Investigation Report.*
11. UK Urban Water Research Centre (1987). *Guide to Short Term Flow Surveys.*
12. Water Services Association of Australia (2013). *Management of Wastewater System Inflow and infiltration. Good Practice Guideline.*
13. Water Environment Federation (2014). *Private Property Inflow/Infiltration Fact Sheet.*
14. Australia/New Zealand Standard (2003). *AS/NZS 3500.2:2003 Plumbing and Drainage.*
15. GHD Pty Limited for ENSure JV. Sydney Water Corporation (October 2014). *Wolli Creek – Source Control. Draft Technical Engagement Report.*
16. Water New Zealand (2009). *National Modelling Guidelines – Wastewater Network Modelling, Draft Version 01 Revision 05.*
17. Carne, S.C (2014). *Do Low I/I Sewers Really Work ? Water New Zealand Annual Conference,* Hamilton, October 2014

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