Chasing Inflow and Infiltration – Is It Worth It?

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1. Introduction

The problem of inflow and infiltration (I and I) impacting the performance of wastewater conveyance and treatment systems is a universal one. Very few, if any, wastewater utilities/companies around the world have been unaffected by this issue. The significance of this issue is further evidenced by the extensive industry established over the past 30 years dealing with such aspects as:

- flow measurement
- field testing to locate and identify sources of I and I
- modelling software to support simulation of the impacts of I and I
- sewer system rehabilitation

Wastewater utilities have spent large amounts of money in attempt to reduce undesired impacts of I and I including:

- reduction in available capacity to support future growth and development
- exacerbation of untreated spill events (e.g. UIDs)
- flooding
- increased operational cost
- regulatory compliance problems

Whether or not a sewer system was constructed as combined or separate excessive inflow and infiltration is not desirable in terms of optimising service and performance criteria. However, the question of whether or not it is cost-effective to attempt to reduce I and I in lieu of other viable options is not straightforward. Results from completed case studies show that in some cases I and I reduction efforts can be cost effective, and in others are not cost effective and/or were not successful in achieving desired targets.

Recent research efforts show that there are a significant number of variables that can impact the viability and/or cost effectiveness of I and I reduction programs. Success is often dictated by such factors as:

- appropriate assessment of I and I characteristics, problems being caused and reduction levels required to achieve targets
- desktop and field techniques for identifying I and I sources and a prioritised relationship to targeted problems
- identification and assessment of non-technical matters such as asset ownership and liability, legal issues and political issues
- application of appropriate technologies to reduce I and I
- application of appropriate tools and technologies to measure the effectiveness of I and I reduction efforts

This paper is an attempt to address these issues in a general manner. Any one of these topics could be a separate paper or report with significant volume and detail. Hopefully the reader will find information provided in this paper useful as a general guideline in the decision making process to embark on I and I reduction efforts.

Note: For purposes of this paper reference to inflow and infiltration (I and I) is inclusive of dry weather infiltration and storm response inflow and infiltration.

2. Assessing Problems, Sources and Feasibility

I and I reduction programs typically involve significant monetary investments to fund the investigation and elimination of sources. Therefore it is important that an initial assessment of problems, sources and I and I removal feasibility be carried out at the outset.

Sufficient information usually exists in the form of drainage areas plans, models, impermeable area surveys, historic flow data and GIS data to allow for initial estimates of cost required to reduce or eliminate targeted problems through I and I reduction measures. Estimates can usually be expressed as unit cost rate factors (e.g. £/m3 or £/l/s) that allow comparison to other alternatives such as storage or expansion of conveyance and treatment capacity. In addition to cost, other factors that should be considered at the feasibility assessment stage include:

- Legal issues related to asset ownership and responsibility – e.g. private laterals, surface drainage connections, etc.
- Political issues
- Legal authority to remove sources
- Quality of surface drainage system and ability to divert source inflows
- Potential impact of source removal on surface drainage problems – does the existing surface drainage system have capacity to accept additional flow?
- Problem location – A general rule of thumb is that the complexity and magnitude of an I and I reduction program increases significantly as a function of the catchment size tributary to the problem. For example, reducing groundwater infiltration rates to regain capacity at a WwTW may not feasible or cost-effective, as sources will likely be distributed throughout the entire collection system.
- Problem characteristics – solutions involving I and I reduction are usually a function of peak flows (capacity) or flow volumes (storage). An early assessment of problems should reveal which elements of I and I are a priority – e.g. peak winter infiltration for WwTW storm tanks, peak summer storm response I and I for UID pass forward rates. This distinction is important as it will drive the reduction measures and thus should be factored into the feasibility assessment.

Assuming an I and I reduction program is deemed to be feasible and presents a cost effective option, it is important to carefully plan and execute information collection efforts to develop relationships between targeted problems and probable sources. The following presents a series of useful information sources and techniques that can be used to relate problems to I and I sources.

Historic WwTW Flow Data

Careful examination of historic WwTW flow data and local rain data can provide a significant amount of information regarding the characteristics and potential sources of tributary I and I. Additionally this information can be used to assess the feasibility of certain options to address WwTW capacity issues.

Figure 1 presents a graph of historic daily WwTW flow data that has been analysed using statistical routines in a spreadsheet. This WwTW was targeted due to ongoing problems with storm tank spillage and consent requirements. The data has been filtered to plot points of flow from days that meet the definition of dry weather flow.

This WwTW has a consented maximum effluent flow of 360 l/s. The theoretical dry weather flow based on population figures is approximately 100 l/s. Conclusions which were drawn from the examination of this data (including wet weather data not shown) are:

- High inlet flows are associated with the catchment's long term infiltration characteristics rather than with its rapid response to rainfall.
- Winter infiltration rates are very high – up to 600% of the theoretical dry weather flow
- Likely sources of infiltration include high water from streams adjacent to tributary sewers.
- Additional primary or storm tank capacity would not be effective in dealing with high inlet flows due to the severity of long-term groundwater infiltration.

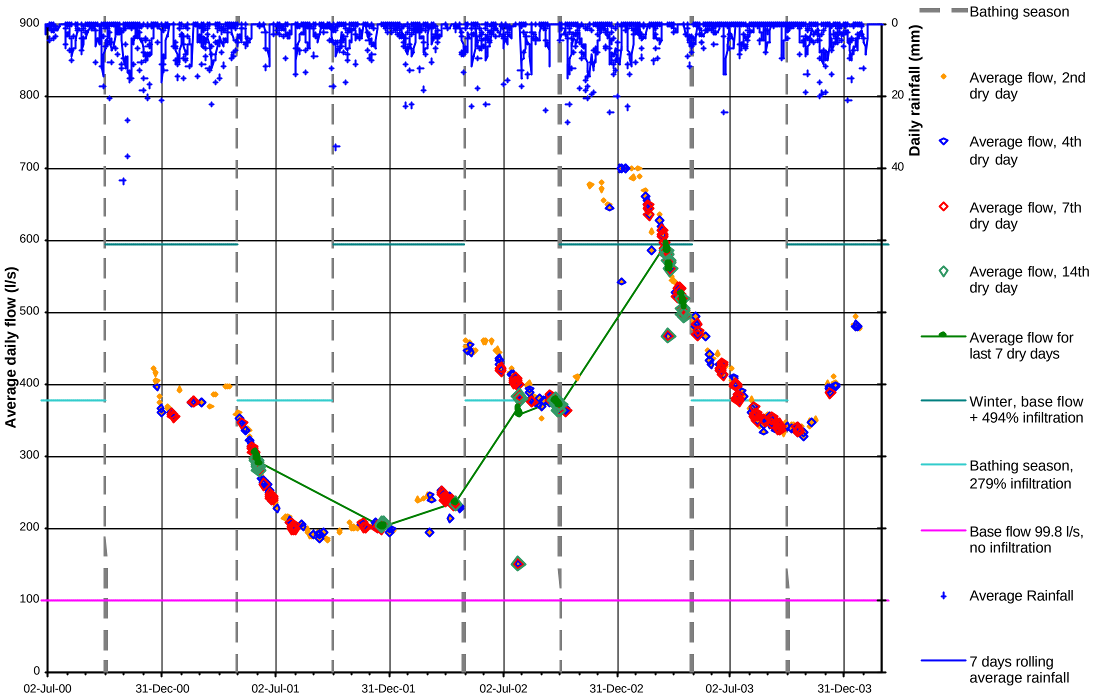

Figure 1

Flow/Rain Monitoring and Water Elevation Data

Flow meters and rain gauges represent one of the most useful means of locating and quantifying I and I sources. Given the location of targeted problems, tributary catchments can be subdivided into smaller catchments based on viable flow monitoring locations. Data collected from a series of representative dry weather days and wet weather events can be used to develop a prioritisation of subcatchments based on rates of I and I. This prioritisation can then be used to target further field investigations to identify specific sources. Examination of data from flow meters can also help to determine probable causes for I and I. Subcatchments that exhibit quick response storm hydrographs with sharp peaks are likely to contain sources of I and I that include directly connected impermeable areas (e.g. rooftops, roads, etc.). Extended storm response recession limbs are indicative of slower infiltration sources such as permeable area land drains. Data from flow meters can also be correlated with surface water level data to indicate sources which may include tidal intrusion or high water in stream and rivers. This information can be used to help guide subsequent field investigations.

An important issue to keep in mind in the use of flow monitoring and rain data is accuracy. Research of case studies shows that in many cases data collected from flow monitoring efforts is not sufficient to accurately quantify I and I problems. It is important to carefully consider issues that impact the accuracy of flow meters when assessing candidate site locations and the basis for delineation of monitoring subcatchments.

GIS Data

Use of GIS data combined with other information sources is extremely useful in identifying probable sources of I and I. Examples of this include comparison of surface elevation data to sewer and manhole elevations to assess potential locations of inflow from streams and rivers. Other examples include analysis of sewer material, terrain, soils, groundwater table elevation data and sewer age information correlated to rates of I and I observed from flow meters. In many cases relationships exist between these parameters and the rates of I and I. These issues should be considered when delineating monitoring subcatchments and selecting monitoring sites.

Smoke/Dyed Water Testing

Smoke and dyed water testing are highly effective means of identifying specific sources of I and I. This form of testing is usually conducted after subcatchments have been prioritised based on flow monitoring data. Smoke testing can be conducted to cover large areas in a small amount of time to screen for I and I sources. It is not 100% accurate, in that not all sources may be revealed. In some cases barriers can prevent the smoke from reaching connected sources. It is important when conducting smoke testing to create as much internal air pressure as possible by utilising a high capacity blower and effectively sealing off sections of sewer in areas being tested. Smoke testing can be conducted on surface storm pipes in separately sewered areas to check for interaction between storm and foul pipes. It is also recommended that smoke testing be conducted during the driest ground conditions as more sources of I and I (e.g. defective private laterals) will be revealed.

Dyed water is one of the most accurate means of testing but is more labour and time intensive than smoke testing. A common practice is to target areas for dyed water testing which exhibit a large number of I and I sources based on smoke testing.

CCTV Inspections

CCTV inspections represent an effective means of locating specific sources of I and I. However, consideration should be given to the following issues when conducting CCTV surveys for purposes of I and I source location:

- Surveys in areas where base infiltration is a concern should be scheduled during times of peak groundwater table elevation (likely winter conditions). Similarly surveys in areas where river or stream ingress is a concern should also be scheduled during times of high water stage.
- Surveys during dry weather conditions may not reveal storm response I and I sources. Cracks and defects are not necessarily sources of I and I if the sewers are not subject to contact with pipe trench water or other sources. Although the

logistics are more difficult, it is better to schedule CCTV surveys to occur during and immediately after rain events so that I and I can be visualised.

Manhole Inspections

Probably one of the easiest methods for assessing I and I sources is to conduct manhole field reconnaissance during periods of high groundwater and immediately following storm events. Data provided from GIS and flow monitoring can be used to focus areas for investigation. Manhole defects and surface water intrusion can represent a significant portion of I and I.

Hydraulic Models

Hydraulic models provide a powerful source of information in the assessment of I and I reduction strategies. First and foremost, models of a sufficient accuracy can be used to quantify the magnitude of I and I problems for a range of targeted design conditions. Models can also be used to determine the required reduction in I and I to achieve desired targets, and also to assess the effectiveness of completed reduction programs.

3. I and I Reduction Strategies and Approach

Figure 2 presents a recommended phased approach to consider when implementing I and I reduction programs. This approach assumes that an area has been targeted for I and I reduction, and that an initial assessment of cost-effectiveness and feasibility has been completed.

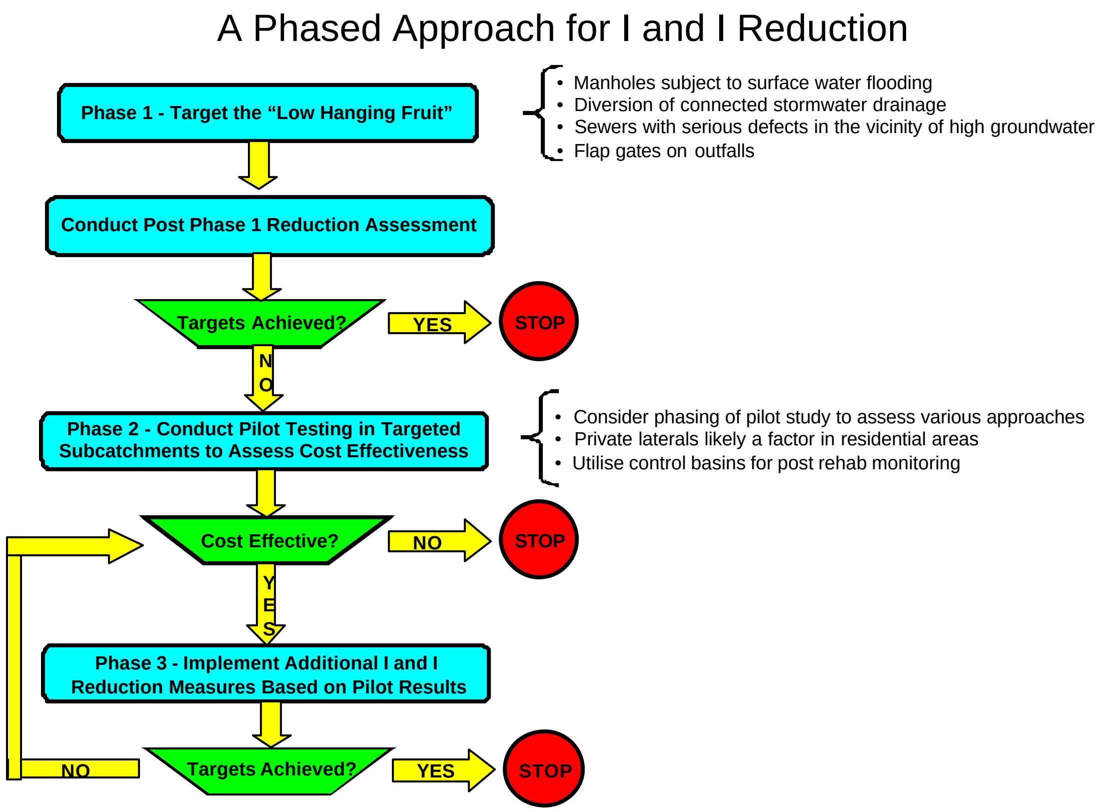

Figure 2

4. Post Rehabilitation Assessments

One of the most difficult aspects of an I and I reduction program is the accurate assessment of post rehabilitation results. Often not enough planning goes into the pre and post rehabilitation monitoring program, making it impossible to determine the effectiveness of implemented measures. This issue is discussed further in the next section.

The following provides a series of recommendations for techniques and approaches to accurately assess the reduction of I and I resulting from implemented measures:

- Use of flow monitors and rain gauges is probably the most common method to determine the effective reduction in I and I. Key to this is ensuring that flow meters and rain gauges are implemented in a way that optimises accuracy of data. Errors in accuracy can be falsely interpreted as reductions (or even increases) in I and I from post rehab surveys.
- Control basin monitoring is a useful means of factoring in changes in I and I rates due to non-rehab factors such as antecedent conditions, rainfall amounts and changes in groundwater table elevations. A control basin should be as close as possible to the target rehab basin and should have similar characteristics (e.g. development type, soil type, pipe material/age). No rehabilitation, or other activities that could impact the hydraulic characteristics (e.g. change in pump settings), should occur at any time in the control basin during and between pre and post rehab monitoring.
- Use of calibrated hydraulic models is an effective means of comparing pre and post rehab conditions given that monitored antecedent and storm characteristics will likely be different. Storm events observed during post rehab conditions can be simulated in models calibrated to pre rehab conditions. Model results can then be compared to post rehab flow monitoring data to assess if I and I reductions have occurred.

5. Case Study Examples

The most extensive amount of I and I reduction work has been completed in the United States. This is driven primarily by the fact that overflows from separate foul systems are considered illegal by US regulatory agencies. As such many US wastewater utilities are being faced with consent orders that require comprehensive I and I reduction programs to eliminate untreated spills from separately sewered systems.

Recently a comprehensive research effort was completed to assess the cost-effectiveness of I and I reduction programmes throughout the US. This research was commissioned by the Water Environment Research Foundation (WERF). WERF is a not-for-profit organisation that funds and manages water quality research through a public-private partnership between municipal utilities, corporations, academia, industry and the US federal government.

The following presents a synopsis of results and conclusions contained within the WERF Report entitled “Reducing Peak Rainfall-Derived Infiltration/Inflow Rates – Case Studies and Protocol”[1]. This report found that most rainfall derived inflow and infiltration (RDII) removal projects in the US go undocumented, and few contain accurate or reliable data to confirm the success of the programs. A total of 12 case studies are used to draw conclusions about RDII removal success and cost benefit.

The data from the case studies was considered to be sufficiently accurate to assess I and I removal efficiencies and cost-effectiveness. Rehabilitation methodologies ranged from manhole rehabilitation alone to complete replacement of all pipes in the study basins.

The following provides a brief summary of case studies included from the following locations:

1. *City of Oak Creek, Wisconsin (in association with the Milwaukee Metropolitan Sewer District)*
   Constructed a stormwater interceptor in a 21 hectare residential neighbourhood to facilitate disconnection of home foundation drains from the foul sewer. New stormwater interceptor consists of 7,273 feet of 6" PVC pipe. Private home laterals were not addressed.
2. *City and County of Honolulu, Hawaii*
   Comprehensive rehabilitation in pilot Basin A and spot repairs in pilot Basin B. Basin A contains 203 homes in an area of 20 hectares. Basin B contains 156 homes in and area of 15 hectares. In Basin A 6,768 feet of 8" VCP was rehabilitated by a cured-in-place (CIPP) liner, 1,565 feet of pipe was rehabilitated by replacement and 44 manholes were rehabilitated. In Basin B spots repairs were completed based on results of CCTV inspections using a CIPP liner. No private home laterals were rehabilitated in either basin.
3. *The Cities of Lacey, Olympia and Tumwater and the County of Thurston (LOTT) – Puget Sound region of Washington State*
   Basin OL22 consist of 268 homes in an area of 53 hectares. Basin OL24 292 homes in an area of 217 hectares. In Phase I of Basin OL22 a total of 10,512 feet of sewer (60% of the system) was replaced and the lower portion (from main connection to edge of public right of way) of 195 laterals were replaced. In Phase II of Basin OL22 a total 210 feet of sewer was replaced and the upper portion of 165 laterals was replaced. In Basin OL24 only the home laterals were addressed. A total of 64 home laterals were replaced.
4. *Cities of Kent and Issaquah, King County, Washington State (near the City of Seattle)*
   The City of Issaquah pilot rehab basin consist of 39 homes in an area of 4 hectares. The City of Kent pilot rehab basin consist of 41 homes in an area of 4 hectares. In the City of Kent basin 100% of sewer mains, manholes and home laterals were replaced. In the City of Issaquah 100% of sewer mains and manholes were replaced, and 92% of home laterals were replaced.
5. *McCandless Township Sanitary Authority – Pittsburgh, Pennsylvania*
   Three basins were selected with the following characteristics:
   - Moreland Road: 26 houses in an area of 5 hectares
   - Woodland Road: 31 houses in an area of 12 hectares
   - Willoughby Road: 17 houses in an area of 3 hectares

   In each of these basins some spot repairs on the main line sewers were made along with the lower portion of targeted home private laterals. In the Woodland Road basin all manholes were rehabilitated.
6. *City of Milwaukee, Wisconsin*
   The City of Milwaukee selected a pilot rehab basin to demonstrate the effectiveness of manhole rehabilitation. Pilot basin 1144 contains 309 homes in an area of 25 hectares. In all 37 manholes were addressed (out of a total of 44) where gasketed water-tight lids were installed. Additional internal repairs were made on a few manholes.

Table 1, taken from the WERF report, provides a summary of each case study assessed along with details of the rehabilitation methods used and the percent reduction in I and I achieved.

Table 1

Project	Type of Rehab Used					5-Year Peak-Hour RDII (liter/hectare-day)				
	Manhole Rehabilitation	House Lateral Rehabilitation	Sewer Main Rehabilitation	Roof Drain Disconnection	Foundation Drain Disconnection	Pre-Construction	Post-Construction	Percent Reduction	Unit Cost of Rehab Program (US$/Gallon-day))	Total Construction Cost
Oak Creek					✓	51,204	26,668	48%	$1.49	$199,556
Honolulu - Basin A	✓		✓			75,421	71,708	5%	$112.40	$2,184,094
Honolulu - Basin B	✓		✓			116,626	116,626	0%	NA	$515,816
Lacey, Olympia, Tumwater, and Thurston (LOTT)-OL22 Phase I		✓ (lower)	✓			178,166	147,859	17%	$4.64	$1,953,936
LOTT-OL22 Phase II		✓ (upper)	✓			147,859	69,416	53%	$0.82	$893,486
LOTT-OL24		✓				11,403	5,360	53%	$0.74	$254,259
King County-Kent	✓	✓	✓			221,503	49,576	78%	$0.93	$169,067
King County-Issaquah	✓	✓	✓			64,327	31,710	51%	$5.47	$188,226
McCandless-Moreland Road Basin		✓ (lower)		✓		-	-	nil	NA	$54,598
McCandless-Woodland Road Basin	✓	✓ (lower)		✓		-	-	nil	NA	$53,835
McCandless-Willoughby Road Basin		✓ (lower)				-	-	nil	NA	$42,699
Milwaukee Basin 1144	✓					563,017	254,831	55%	$0.01	$10,836

Interpretation of results from this table is not straightforward. The following summarises some general conclusions that can be made:

- Some of the case studies had a very low or negligible amount of I and I successfully removed from the system. A general conclusion is that in these basins private home laterals are a major contributing source and were not addressed. This is further demonstrated in the OL22 basin where there was a significant jump in the percentage of I and I removed between Phase I and Phase II.
- In addition to the percent removal of I and I, it is important to assess the cost effectiveness to determine the overall success of a program. For example in the Issaquah basin it might have been more cost effective to install a relief sewer or storage tank depending on the specifics of the targeted problem.
- The Milwaukee Basin 1144 produced surprising results in that only manholes were addressed yet a significant amount of I and I was removed based on estimates. The authors did note that during the post-rehab monitoring only small storms were observed. The post-rehab monitoring was also conducted in the summer where the pre-rehab monitoring was conducted in the fall.

6. Conclusions and Recommendations

Case studies examined in the previous section are based on rehabilitation conducted in fairly confined residential areas with separate sewer systems. In these areas it is not uncommon that private sources (e.g. laterals, foundation drains, roof drains, etc.) represent a significant amount of I and I and must be addressed when this is the case. In cases where private source contributions are significant, careful attention must be given to the overall cost-effectiveness of rehab verses other options that may be feasible.

The following provides a summary of general recommendations for consideration of whether or not to implement an I and I removal program:

- It is important to carefully define targeted problems and relate to known causes based on readily available information (e.g. DAPs, models, flow monitoring, etc.). Are problems being driven by sources spread over a wide area or are there a few large sources? Are private sources an issue? Are problems a function of peak flows, volumes or both? What level of I and I reduction is required to reach the desired targets? Which components of I and I are the dominating factors (e.g. winter infiltration, rainfall derived inflow, etc.)?
- Prior to committing to and I and I reduction program conduct a desktop exercise to assess the following issues:
  - Cost-effectiveness
  - Removal feasibility
  - Comparison to other options (e.g storage, additional treatment capacity)
  - Legal and political issues
  - Stormwater drainage issues

The following are general conclusions and recommendations to consider when implementing and I and I reduction program:

- Carefully plan pre and post rehab monitoring to ensure that reductions in I and I can be accurately measured.
- Isolate probable sources as much as possible using flow monitors, models, GIS data and field test results (e.g. CCTV, smoke and dye testing).
- Implement a phased program that starts with the "low hanging fruit". Examples of this include diversion of direct stormwater sources, sealing/raising flooded manholes, installation/repair of high water flap gates, etc.
- Consider pilot testing more complex rehab approaches if targets are not achieved by addressing "low hanging fruit" sources. Case studies show that I and I removal success (inclusive of percentage removal and cost effectiveness) varies greatly due to many variables which can be unique to specific areas (e.g. groundwater tables, historic construction practices, pipe materials and joints, condition of home laterals, etc.).
- In residential areas carefully assess the role of private source contributions. In many cases defective home laterals represent a significant source and must be comprehensively addressed to achieve significant reductions in I and I.
- Utilise readily available data such as GIS and historic flow information from WwTW. GIS data can provide the basis for correlating high rates of I and I to such factors as vicinity to surface waters, soils, pipe materials, construction time frame, topography and groundwater table elevations. Detailed analysis of historic WwTW flow data (along with relevant rainfall data) can reveal the general characteristics of I and I within the tributary catchment.
- Look for correlation between monitored sewer flows and flows/water levels in adjacent surface waters. Quite often this reveals if surface water ingress/flooding is a significant source of I and I. If this is the case it is then necessary to assess the feasibility for removing these sources.

▪ References

[1] Water Environment Research Foundation, IWA Publishing, "Reducing Peak Rainfall Infiltration/Inflow Rates – Case Studies and Protocol", Report No. 99-WWF-8, 2003.