REAL TIME INFLOW AND INFILTRATION ANALYSIS – A NEW TOOL TO FOCUS YOUR RENEWAL SPEND

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ABSTRACT

Rainfall derived inflow and infiltration (RDII) in sewers has long been an important aspect in the operation and design of wastewater collection systems. Although wastewater collection systems are generally designed to accommodate RDII these flows often exceed design allowances and cause operation problems. Over the past 30 years monitoring rainfall and flows in wastewater collection systems has become common practice for many water authorities for assessing and evaluating the level of RDII in the system. The collected data can then be used to identify problematic areas within the collection system and calibrate hydraulic models so that operational changes, rehabilitation work, renewal work, and expansions can be planned in a rational and comprehensive manner.

Recent developments in GPRS telemetry and server based cloud computing provide the ability/opportunity to auto process raw monitoring data in near real time and present estimated RDII results on line to any interested stakeholder. This allows the interested stakeholder to view current and historic RDII data under the same context and provide the technical framework which reduction programs can be built.

Essential the tool is constantly keep track of the catchments antecedent wetness and calculating an average dry day for each day of the week. The average dry day is then plotted under the actual data and volume and peak variations from the average dry day are calculated and tabulated. The calculated differences are then normalized based on upstream catchment area and pipe length. The user has the ability to look at any period wet or dry to get a better understanding of the flow in that period compared to the average dry day. RDII values over the entire monitoring period or a group of user selected events is then used to compute an average RDII measurement which can then be compared to other monitored catchments in the area or across the region/country.

This presentation outlines how real time RDII calculation works through example in several recent flow gauging studies undertaken within New Zealand. It discusses the issues that were confronted during the trial such as subtraction catchments and timing between catchments. It also highlights the advantages to the real time approach for operational staff, and planning engineers, and consultants all working on the same catchment.

KEYWORDS

Flow Monitoring, II analysis, Inflow and Infiltration, Real Time Monitoring

1 INTRODUCTION

Rainfall derived inflow and infiltration (RDII) in sewers has long been an important aspect in the operation and design of wastewater collection systems. RDII is the main cause of sewer overflows into the receiving environment, it can also results in serious operating problems at wastewater treatment plant. Although wastewater collection systems are generally designed to accommodate RDII, these flows often exceed design allowances and cause operation problems. The magnitude of RDII is directly associated with the structural conditions of sewers. The majority of cities sanitary sewer infrastructure is aging; with some sewers over 100 years old, these older pipes typically vitrified clay can be a major contributor to RDII in sewer systems.

Over the past 30 years, monitoring rainfall and flows in wastewater collection systems has become common practice for many water authorities for assessing and evaluating the level of RDII in the system. The collected data can then be used to identify problematic areas within the collection system and calibrate hydraulic models so that operational changes, rehabilitation work, renewal work, and expansions in capacity can be planned in a rational and comprehensive manner. This paper outlines recently developed technology that utilising monitoring information in real time to automatically calculate inflow and infiltration and highlight possible issues within the sewer network. This technology can be used not only be used to understand the current inflow and infiltration but also to develop statistics on how the network performed historically over different rainfall events. It also supplements the monitoring data’s value to hydraulic models by on the fly development of standard dry weather profiles, calculating wastewater production rates, and calculating inflow volume across all the events measured.

2 METHODOLOGY

Recent developments in GPRS telemetry, server-based cloud computing, and web based services provide the ability and opportunity to auto-process raw monitoring data in near real time and present estimated RDII results on line to any interested stakeholder. This enables the stakeholder to view current and historic RDII data in the same context, and to provide the technical framework from which RDII reduction physical works programs can be developed.

The tool functions by constantly keeping track of the catchment's antecedent wetness and continually calculating an average dry weather flow (5min basis) for each day of the week. From this average we develop an average dry weather trace for Monday – Sunday in 5 min increments (or any other user defined interval). Following this, a comparison is made between the real time measured flow and the average dry weather flow for that specific day of the week and time of day. If the difference is greater than a user specified value for longer than a specified time, the online system commences logging an RDII event. The event continues until the flow comes back to within a standard deviation of the average dry weather flow. In addition to this, the user has the capability to manually log events based on graphical data presented within the system.

2.1 ANTECEDENT CONDITIONS – SELECTION OF DRY DAYS

The antecedent calculation is a critical part of the tool as it decides which day can be considered dry and included in the calculation for the average dry pattern. We have used a standard exponential decay function defaulted to look back at the last 14 days of rainfall. With the exponential constant default of 0.7 and the exponential coefficient equal to the number of days prior to the day in question. From trial and error and examination of supporting documentation we have used 3.5mm for a low value for the antecedent wetness and criteria to select the suitability of a day for use as a dry day. The selection of a dry day using the antecedent wetness calculation is described below:

$$\sum_{day=0}^{day=14} 0.7^{day} * Rain\ (mm)_{day} < 3.5mm$$

The 7 day look back period and the 0.7 constant is a function of the specific catchment and could be changed depending on the catchment recession time. Although the wetness equation is based on solely on daily rainfall volume the constant allows us to transform rainfall volume into catchment response time and should be set to according to the recession time of the catchment in question. We have found that 0.7 works for most cases and have therefore set it as the default value. Looking back only 14 days as default can also result in issues with catchments with long recession times as the equation basically resets after 14 days. If there was a significant event the recession could be longer than 14 days. These default values have proven to be sufficient in all of the cases that we have examined thus far however we have left them as variables for the advanced users to change if required.

2.2 DEVELOPMENT OF THE DRY WEATHER PROFILE

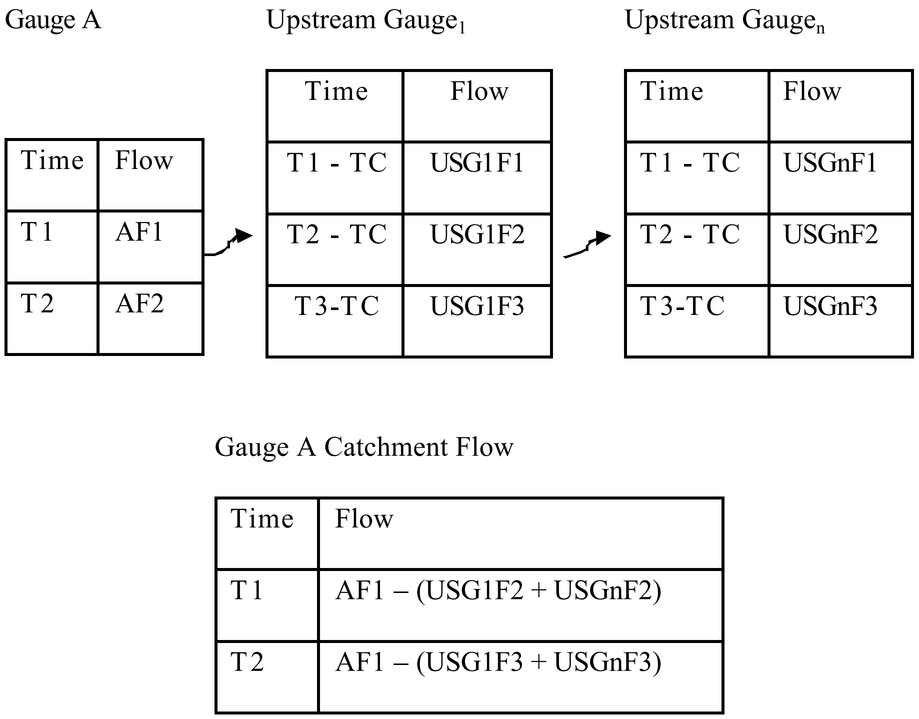
Essentially the system dynamically keeps track of all of the available dry days, as quantified by the equation above, on a daily basis. This allows the measured flow for all available dry days to be averaged into 5 min bins of volume. Each volume bin is uniquely identified by the day of the week (1-7) and time the volume occurred. The volume bins are then aggregated and averaged on each 5 min time step and grouped on the day of the week. This results in a repetitive dry weather profile for each day of the week in 5 min volume increments. If the data set is immature and each day of the week is not adequately represented by a dry day we look to fill the gaps with an average weekday and average weekend profile. If there is still not a suitable differentiation between weekday and weekend in the dry day set the average overall dry day is used to fill the gaps. For example if every day of the week *except* Monday is represented in the dry day set Monday will be populated using the average of all the other available weekdays (Tuesday – Friday), if only Monday - Wednesday are available Thursday – Sunday will be populated using the average of Monday – Wednesday. The longer the gauges flow and rainfall monitoring period persists the more dry days will be available and the computed average dry day profile for each day of the week will converge on the true statistical average.

2.2.1 GROUND WATER INFILTRATION (GWI)

GWI refers to the portion of wastewater embedded in the monitored dry –weather flow data. The rate of GWI depends on the number and sizes of defects within a sewer and the hydraulic head available in the groundwater table. For this tool we simple calculate this using average dry weather night (2 am and 4 am) flows. GWI obviously will vary according to seasons and will likely be highest in late winter and early spring. The tool calculates the GWI on a monthly basis so basically it averages the flow between 2 am and 4 am for every dry day for every month. So you would end up with 12 GWI values for each gauged catchment. If there is not at least 1 dry day available for each month it will use the average GWI for all months that are un-available.

2.2.2 SUBTRACTION GAUGES

The RDII tool has been specifically developed to accommodate flow gauges with upstream gauges. Each gauge that has upstream gauges is linked to all of its upstream gauges using the shortest pipe run between gauges and the average velocity of the upstream gauge. Using the pipe run length and average velocity an average time of concentration between gauges can be calculated. This time of concentration is added to each time step of the upstream gauges and then upstream gauge volume is subtracted from downstream gauge at the adjusted time step. Figure 1 below shows general calculation made for subtraction gauges.



Gauge A

Time	Flow
T1	AF1
T2	AF2

Upstream Gauge$_1$

Time	Flow
T1 - TC	USG1F1
T2 - TC	USG1F2
T3-TC	USG1F3

Upstream Gauge$_n$

Time	Flow
T1 - TC	USGnF1
T2 - TC	USGnF2
T3-TC	USGnF3

Gauge A Catchment Flow

Time	Flow
T1	AF1 – (USG1F2 + USGnF2)
T2	AF1 – (USG1F3 + USGnF3)

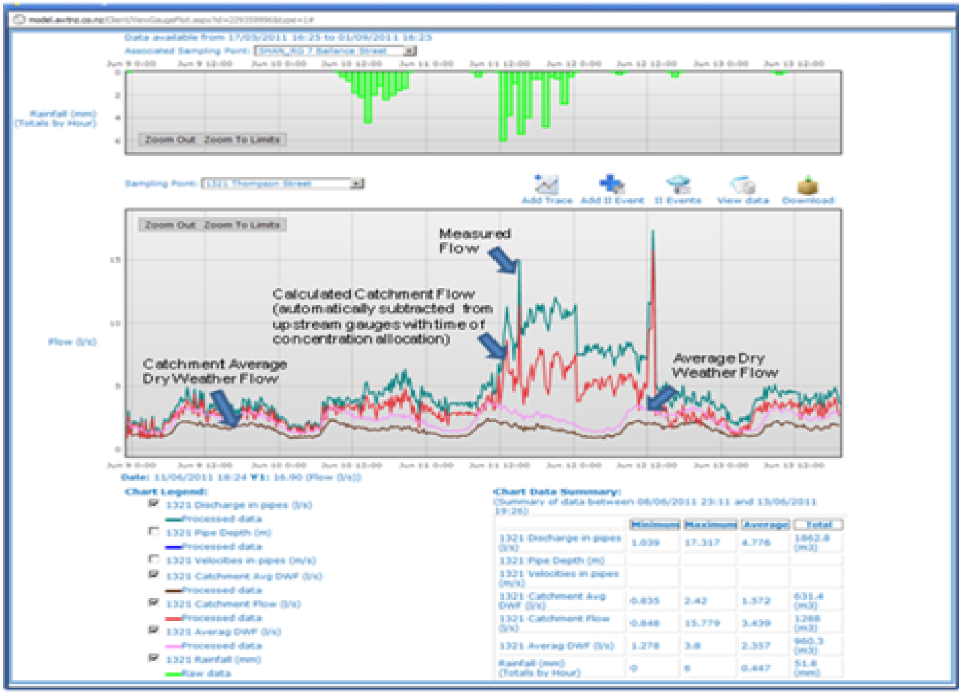
Figure 1 Upstream Gauge Catchment Dry Weather Flow Calculation

2.3 DETERMINING RDII EVENTS

Following the dry weather flow profile selection, a comparison is made between the real time measured flow and the average dry weather flow for that specific day of the week and time of day. If the difference is greater than a user specified value for longer than a user specified time, the system commences logging an RDII event. The event continues until the flow comes back to within a standard deviation of the average dry weather flow for a user specified time when the system will stop the event. In addition to this, the user has the capability to manually log events based on graphical data presented.

2.4 CALCULATION OF RDII

Once an event is selected and the average dry weather flow and catchment average dry weather flow (for subtract gauges) is computed, the RDII for the event can be calculated. The RDII is simply the difference between computed average dry weather flow and measured flow for a specific time period. For subtract gauges the catchment flow is calculated using the same methodology discussed above and shown in Figure 1. Dynamic graphical representation of the event and its components is available in real time on the internet for all interested stakeholders. Figure 2 below shows an example of a plot of a calculated event.



Date: 11/06/2011 18:24 Y1: 16.90 (Flow (l/s))

Chart Legend:

- ☑ 1321 Discharge in pipes (l/s)
  - Processed data
- ☐ 1321 Pipe Depth (m)
  - Processed data
- ☐ 1321 Velocities in pipes (m/s)
- ☑ 1321 Catchment Avg DWF (l/s)
  - Processed data
- ☑ 1321 Catchment Flow (l/s)
  - Processed data
- ☑ 1321 Averag DWF (l/s)
  - Processed data
- ☑ 1321 Rainfall (mm)
  - Raw data

Chart Data Summary:
(Summary of data between 08/06/2011 23:11 and 13/06/2011 19:26)

	Minimum	Maximum	Average	Total
1321 Discharge in pipes (l/s)	1.039	17.317	4.776	1862.8 (m3)
1321 Pipe Depth (m)				
1321 Velocities in pipes (m/s)				
1321 Catchment Avg DWF (l/s)	0.835	2.42	1.572	631.4 (m3)
1321 Catchment Flow (l/s)	0.848	15.779	3.439	1288 (m3)
1321 Averag DWF (l/s)	1.278	3.8	2.357	960.3 (m3)
Rainfall (mm) (Totals by Hour)	0	6	0.447	51.8 (mm)

Figure 2 Example RDII Plot

3 OUTCOMES

As seen in Figure 2 above the average dry profile is continuously plotted under the actual monitored data. Volume and peak variations from the average dry day are calculated and tabulated automatically in the online plot space. The calculated differences are then normalized based on upstream catchment area and pipe length.

The user has the ability to look at any wet or dry period to gain a better understanding of the flow in that period compared to the statistical average dry day. RDII values over the entire monitoring period, or a group of user selected events, is then used to compute an average RDII measurement which can then be compared to other monitored catchments in the area or across the region or country.

3.1 TABULATED PRESENTATION

All identified RDII events are added to a table of events which tabulates standard RDII statistics including:

- GWI Volume
- Dry Weather Flow Production
- Peaking Factor
- Percentage Ingres (II Volume / (Catchment Area * Total Rainfall)
- Leakage Severity (II Volume / Length of Pipe / Total Rainfall

An example of the tabulated results is shown in Figure 3 below. The table is dynamically sortable and filterable. This tabulated view gives the user the opportunity to rank and prioritise catchments based on any RDII statistic providing instant and valuable focus for the network operators rehabilitation program or identify areas where further investigations are required. By frequently monitoring the inflow and infiltration a much better understanding of the network will be gained for all interested stakeholders.

3.1.1 GWI LOADING VOLUME

To assess the level of groundwater infiltration (GWI) a litres/second/ha loading rate is calculated. The data is divided into flow gauge boundaries with an upstream gauge influence subtracted to determine the actual gauge performance. This number can be used to identify leaky catchments where GWI takes up valuable space in the conveyance.

3.1.2 WASTEWATER PRODUCTION

The catchment wastewater production rate is simple calculated by dividing the total volume of calculated dry weather flow (dry weather volume – GWI) for the catchment by the number of days in the event and the population in the catchment. This gives us a measure of actual wastewater flow contribution and can be compared to water consumption figures to understand water return ratios. This value will obviously be skewed in catchments with large commercial and industrial users.

3.1.3 PEAKING FACTOR

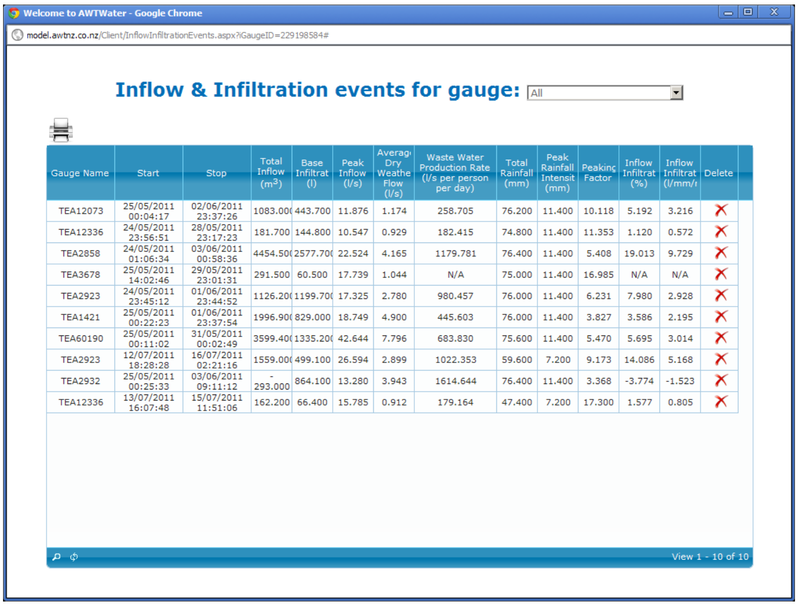
The peaking factor is calculated by dividing the catchments average dry weather flow (including GWI) during the event by the maximum observed flow. Typical peaking factors and wastewater production rates can be utilised as a simple design parameter for pipe design within the catchment.

3.1.4 PERCENTAGE INGRESS

Wet weather performance is also assessed as a percentage of area that contributes to rainfall that ends up in the sewer in the form of infiltration and inflow. This calculation is made by taking the total RDII volume for the catchment (Measured Volume - Dry Weather Volume) and dividing it by the catchment area times the total rainfall for the event.

3.1.5 LEAKAGE SEVERITY

Leakage severity is also calculated by normalising the volume RDII volume per metre of pipe.



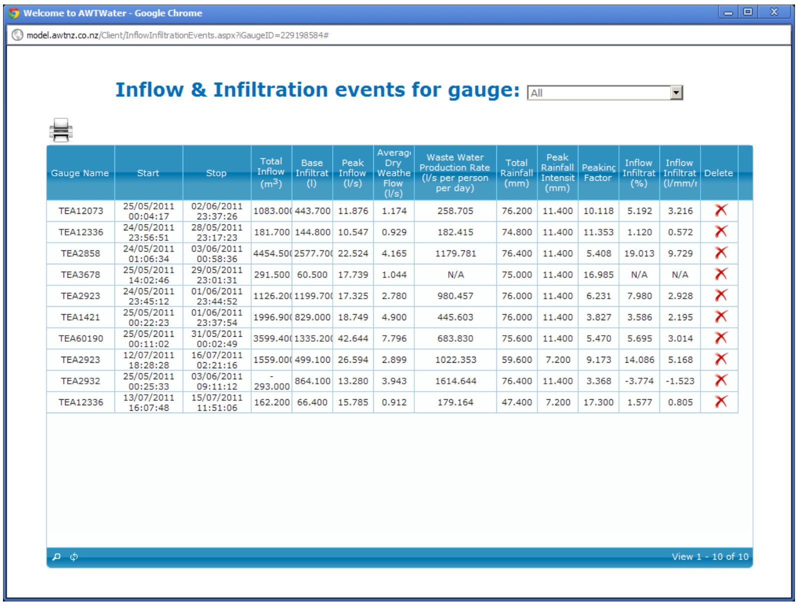
Inflow & Infiltration events for gauge: All

Gauge Name	Start	Stop	Total Inflow (m³)	Base Infiltrat (l)	Peak Inflow (l/s)	Averag Dry Weathe Flow (l/s)	Waste Water Production Rate (l/s per person per day)	Total Rainfall (mm)	Peak Rainfall Intensit (mm)	Peaking Factor	Inflow Infiltrat (%)	Inflow Infiltrat (l/mm/	Delete
TEA12073	25/05/2011 00:04:17	02/06/2011 23:37:26	1083.00	443.700	11.876	1.174	258.705	76.200	11.400	10.118	5.192	3.216	✗
TEA12336	24/05/2011 23:56:51	28/05/2011 23:17:23	181.700	144.800	10.547	0.929	182.415	74.800	11.400	11.353	1.120	0.572	✗
TEA2858	24/05/2011 01:06:34	03/06/2011 00:58:36	4454.50	2577.70	22.524	4.165	1179.781	76.400	11.400	5.408	19.013	9.729	✗
TEA3678	25/05/2011 14:02:46	29/05/2011 23:01:31	291.500	60.500	17.739	1.044	N/A	75.000	11.400	16.985	N/A	N/A	✗
TEA2923	24/05/2011 23:45:12	01/06/2011 23:44:52	1126.20	1199.70	17.325	2.780	980.457	76.000	11.400	6.231	7.980	2.928	✗
TEA1421	25/05/2011 00:22:23	01/06/2011 23:37:54	1996.90	829.000	18.749	4.900	445.603	76.000	11.400	3.827	3.586	2.195	✗
TEA60190	25/05/2011 00:11:02	31/05/2011 00:02:49	3599.40	1335.20	42.644	7.796	683.830	75.600	11.400	5.470	5.695	3.014	✗
TEA2923	12/07/2011 18:28:28	16/07/2011 02:21:16	1559.00	499.100	26.594	2.899	1022.353	59.600	7.200	9.173	14.086	5.168	✗
TEA2932	25/05/2011 00:25:33	03/06/2011 09:11:12	-293.000	864.100	13.280	3.943	1614.644	76.400	11.400	3.368	-3.774	-1.523	✗
TEA12336	13/07/2011 16:07:48	15/07/2011 11:51:06	162.200	66.400	15.785	0.912	179.164	47.400	7.200	17.300	1.577	0.805	✗

Figure 3 Example RDII Statistics Table

3.2 GRAPHICAL PRESENTATION

RDII statistics can also be graphically displayed on a dynamic map using catchment polygons to symbolized (coloured) based on any II statistics measured. Figure 4 below shows an example of the graphical output of the tool.



Inflow & Infiltration events for gauge: All

Gauge Name	Start	Stop	Total Inflow (m³)	Base Infiltrat (l)	Peak Inflow (l/s)	Averag Dry Weathe Flow (l/s)	Waste Water Production Rate (l/s per person per day)	Total Rainfall (mm)	Peak Rainfall Intensit (mm)	Peaking Factor	Inflow Infiltrat (%)	Inflow Infiltrat (l/mm/	Delete
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TEA2858	24/05/2011 01:06:34	03/06/2011 00:58:36	4454.50	2577.70	22.524	4.165	1179.781	76.400	11.400	5.408	19.013	9.729	✗
TEA3678	25/05/2011 14:02:46	29/05/2011 23:01:31	291.500	60.500	17.739	1.044	N/A	75.000	11.400	16.985	N/A	N/A	✗
TEA2923	24/05/2011 23:45:12	01/06/2011 23:44:52	1126.20	1199.70	17.325	2.780	980.457	76.000	11.400	6.231	7.980	2.928	✗
TEA1421	25/05/2011 00:22:23	01/06/2011 23:37:54	1996.90	829.000	18.749	4.900	445.603	76.000	11.400	3.827	3.586	2.195	✗
TEA60190	25/05/2011 00:11:02	31/05/2011 00:02:49	3599.40	1335.20	42.644	7.796	683.830	75.600	11.400	5.470	5.695	3.014	✗
TEA2923	12/07/2011 18:28:28	16/07/2011 02:21:16	1559.00	499.100	26.594	2.899	1022.353	59.600	7.200	9.173	14.086	5.168	✗
TEA2932	25/05/2011 00:25:33	03/06/2011 09:11:12	-293.000	864.100	13.280	3.943	1614.644	76.400	11.400	3.368	-3.774	-1.523	✗
TEA12336	13/07/2011 16:07:48	15/07/2011 11:51:06	162.200	66.400	15.785	0.912	179.164	47.400	7.200	17.300	1.577	0.805	✗

Figure 4 Example RDII Graphical Statistics

4 MOVING FORWARD

We have been further developing two key aspects of the RDII tool to make it more flexible.

We feel that benchmarking catchments with other catchments with similar attributes such as size, population, rainfall statistics, and pipe material profile will be a valuable addition for any water authority. As the database grows the better the benchmarking will become.

We have also been working on integrating population variation into the dry weather profile tool. This is primarily for developing different dry weather profiles as populations vary over time. This is particularly important for very long term sites that have seen major population increases and decreases.

5 CONCLUSION

RDII has long been recognized as having a major influence on the sizing or sewer pipes and wastewater treatment plants. Attempting to quantify and control this extraneous amount of water is an ongoing operational and design issue for almost every water authority.

The RDII quantification techniques discussed in this paper are not new. They are standard calculations that have been around for over 10 years. What this paper does present is the latest technology that enables these standard techniques to be applied in real time and conveyed to a much wider audience through the internet. The tools major advantages are its availability and automation. The tool aims to empower its users by providing easy access to data that allows the user to rank and prioritise catchments based on various RDII severity statistics. The catchment ranking provides instant and valuable focus for development of network operator's rehabilitation program or can be used to identify areas where further investigation work is required focusing precious capital expenditure. The system can also data mine from SCDA systems so deployment of temporarily monitors is not always necessary. Using existing monitoring equipment allows for constant monitoring on the network providing a much better understanding of the network RDII.

The development of this system is relatively immature and already the potential cost savings to water authorities can be seen. Moving forward we see that benchmarking catchments with other catchment with similar attributes (size, population, rainfall statistics, pipe material profile) will be a major benefit to the system so any user can develop a better understanding of how there catchment is performing against other similar catchments. This provides another opportunity for prioritisation of RDII works.

This paper describes another tool in the RDII toolbox that has recently been developed by harnessing recent technological advances. The tool will help manage RDII in sewers by quickly prioritising catchments based on RDII severity. No tool replaces sound engineering judgement but this development in technology simply conveys complex network operating issues to a broader audience which will no doubt drive more innovative and focused solutions for managing RDII.