INFILTRATION AND LEAKAGE IN THE TAY PPP CATCHMENT

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ABSTRACT
The commissioning of the Tay Public Private Partnership (PPP) drainage and treatment scheme has placed increasing focus on the volumes of sewage treated. A study was initiated to investigate the perceived high levels of catchment-wide infiltration flows. This study highlighted the potential for infiltration flows to be reduced via improved water supply system leakage management. Repairs were undertaken for the water supply system with parallel monitoring carried out in the sewerage network. The flow reductions observed indicate a significant link between leakage and infiltration flows. The cost impacts of the study were also investigated, with a noticeable impact on the sewage treatment and water production costs and also the traditionally calculated economic level of water supply leakage.

KEYWORDS
Infiltration; Leakage; Public Private Partnership

INTRODUCTION
Infiltration flows have in the past been generally underestimated although their impact of reducing the performance of combined sewerage networks is generally well known (G. Weiß, Brombach and B. Haller, 2002). The mechanisms and cost implications of infiltration flows are also currently being studied within the English water structure. In Scotland, the significance of infiltration flows has recently been increased through the advent of Public Private Partnership (PPP) drainage schemes. In these schemes, Scottish Water retain responsibity for the operation of the existing sewerage network, with a private group responsible for the conveyance of flows from the network, treatment of flows and ultimately their discharge.

The Tay PPP scheme is a large Public Private Partnership drainage scheme involving the transfer of sewage flows from Dundee, Broughty Ferry, Monifieth, Carnoustie and Arbroath to large-scale treatment facilities at Hatton. The charges made by the private consortium for operating the treatment plant and pumped transferring main are based on a unit volume of flow arriving at the works inlet. Consequently, contractual obligations and tariff rates are linked to flow rates delivered to the treatment plant.

Field observations at the outlets from various subcatchments in the Dundee area have indicated flow rates in excess of those expected to be produced by foul inputs and a “normal” background level of infiltration. Consequently, high rates of infiltration have generally been assumed in the past for much of the Dundee catchment. This assertion is also supported by the observation of “weak” sewage arriving at the newly constructed Hatton Wastewater Treatment Works. It has therefore been proposed to actively identify areas of high infiltration within the Tay PPP scheme in order to reduce the overall impact of infiltration flows.

Little proactive leakage detection work has been carried out for the water mains in the Tay PPP area. This has resulted in an average leakage rate in Dundee of approximately 55%. Given the large amounts of potable water this equates to (25 Ml/d in Central Dundee alone), it has been hypothesised that a portion of this leakage must infiltrate into the sewerage system. This leakage derived infiltration flow is subsequently conveyed to the treatment works and treated at an additional cost to the Water Authority. The infiltration routes have been shown in this study to vary from the direct discharge of valves, to the artificial recharge of groundwater levels through a collection of small-scale leaks.

The combination of high infiltration and leakage rates therefore creates the opportunity to reduce both potable water production costs and more significantly, wastewater treatment costs with a single management strategy.

METHODOLOGY

The principal aim of the study was to reduce infiltration flows arising from the catchment of Dundee's City Centre. It was hypothesised at the outset of the study that infiltration flows are derived from 5 main types of source:

- Natural watercourses;
- Natural groundwater;
- Tidal ingress;
- Water system direct inputs (open valves, hydrants & bursts etc);
- Artificial recharge of water table through a collection of small-scale leaks.

As a result of the diverse nature of infiltration sources detailed above, a flexible approach was developed during the study using a variety of data sources.

Desk Study

Prior to planning the flow surveys & rehabilitation works, a desk-based study was carried out to ensure that the correct catchment areas were targeted. Previous studies and reports were re-evaluated with a critical eye in order to highlight problems previously encountered and significant issues not previously addressed.

Although modelling and drainage area plan reports were able to provide indications of problem areas, a new analysis of the existing data was found to provide the most detailed results at a low financial cost. In this analysis, the previous short-term flow surveys were used to provide minimum night flows at a particular location and time of year. The subtraction of a legitimate domestic night flow and contributing trade flow resulted in an unaccounted flow rate for each monitor. This information was then also expressed as both a percentage of the daily minimum flowrate and as a flow per unit area in order to highlight areas of uncharacteristically high unaccounted flow. The catchment areas and results were then digitised into MAPINFO to allow a strategic plan for investigative works. The catchment areas for flow monitors exhibiting "higher than expected" unaccounted flows were then investigated for potential sources using Ordinance Survey maps, water table records, burst records and an evaluation of potentially un-consented trade discharges. Operational staff were also be interviewed to provide details of areas historically known to produce infiltration problems.

The results of the desk study were then used to provide guidance on which areas should be most likely to benefit from additional investigation and rehabilitation.

Survey Teams

Flow survey, sewer inspection and leakage detection teams were then mobilised into areas believed to contain significant infiltration and/or leakage flows. The planning of survey schedules was required to be flexible, as the findings of one survey team would often impact on the proposed activities of the others. Once the observations and measurements of all the survey teams had been carried out the rehabilitation and further monitoring plans were determined.

Measurement

At the outset of the study it was strictly stipulated that any benefits to the system should be measurable. As a consequence of the consideration of both the sewerage and potable water systems, a strategy of measurement must also consider both systems.

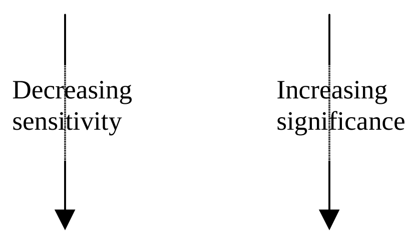
Ideally, a District Metered Area (DMA) structure should be in place prior to carrying out the study in order to provide a baseline of water system performance against which any system improvements can be measured. This was unfortunately not the case in Dundee as delays in establishing the DMA boundaries resulted in the availability of Water Supply Zone (WSZ) data only.

In a similar way to the water supply system, the baseline behaviour of the sewerage system should be established prior to carrying out repairs or performance enhancing changes. This is best done using accurate long-term flow monitors located at strategic points throughout the catchment. Long-term studies are most suitable in order to gauge the seasonal variability of baseflows in a particular catchment. Seasonal influences can be particularly significant in suburban and rural catchments, or (as is the case in Dundee) if local watercourses contribute to, or run in close proximity to the combined sewerage system.

With broad scale monitoring in place, the impact of individual repairs can only accurately be established using local measurement. The programming of the Drainage Area Plan (DAP) for the Dundee Central catchment allowed a detailed network of over 100 flow monitors to be used to record the short term impact of rehabilitation works. Where significant repairs were planned to be carried out outwith DAP monitoring coverage, additional survey work was scheduled.

This therefore provided a four-tier strategy of measurement of decreasing sensitivity but increasing significance (as the impact of repairs must ultimately be felt at the treatment works):

1. Local measurement
2. DAP flow loggers
3. PFL flow loggers
4. Treatment plant inlet



Each flow data set is then assessed and an overall benefit to the system determined using knowledge of the work carried out and the system monitored.

Data Management and Analysis

A significant challenge in this project involved the co-ordination of a number of working parties including:

- Sewer flow survey teams;
- Sewer rehabilitation contractors;
- Water supply operations;
- Water network rehabilitation contractors;
- Drainage Area Plan consultants;
- Drainage Area Plan contractors.

In addition to regular co-ordination meetings, work was generally planned and recorded through a "live" programme and database, which was accessed by all planning groups and updated daily.

Records of all repairs and corresponding flow impacts were kept in a centrally accessible GIS format in order to correlate catchment flow characteristics with the various rehabilitation works. Following completion of the rehabilitation work, monitoring continued at a coarse level using the permanent flow monitors in order to assess the long-term impact of the repair work. This was especially important for the water system repairs, as evidence has suggested that a one-off pass of repairs raises water system pressure temporarily, encouraging new leaks and bursts to develop until an equilibrium state is again reached with high leakage. Active leakage control should therefore also continue to ensure the continued integrity of the water supply network.

RESULTS

Wherever possible, operational staff were requested to record observations where a leak or burst was clearly discharging to the sewer. This normally involved the visual checking of sewer manholes (from the surface) in the vicinity of a potential repair.

The discharge of leaks or bursts to the sewer was recorded in 28 cases. These 28 locations make up 13% of the total number of leakage detection sites. However, the actual number contributing to the sewer is likely to be much higher as the detection teams did not initially check for sewer infiltration and only cursory manhole checks from the surface were made during the study. It is notable that the number of mains contributing to sewer flows was disproportionately large. This may be as a consequence of the mains running in close proximity to sewers and the ease of detection as a result of typically larger leakage flows than communication or supply pipes.

As a result of the large quantity of data collected in this study, a summary and sample data set of results are presented.

Individual Repair Flow Impacts

Table 1 shows a summary of the flow reductions recorded immediately following individual water supply network repairs.

LOCATION DETAILS	BURST / LEAK DETAILS			SEWER FLOW REDUCTION
Street	Type	To	Fixed	(l/s)
Harefield Road	COMM	unknown	23/11/01	1
Victoria Road	COMM	unknown	10/01/02	2
Adelaide Place	COMM	unknown	30/10/01	1
Clepington Road	COMM	unknown	12/11/01	0.75
Clepington Road	COMM	unknown	12/11/01	0.75
Roseangle	SUPPLY	sewer	07/01/02	4
Thomson Street	MAIN	sewer	23/04/02	1.5
Thomson Street	MAIN	sewer	23/04/02	1.5
Albert Street	MAIN	sewer	02/05/02	10
Muirfield Crescent	COMM	unknown	15/04/02	1
Rodd Road	MAIN	unknown	19/04/02	0.25
Old Craigie Road	MAIN	unknown	24/04/02	0.25
Clepington Road	MAIN	sewer	23/04/02	5
Roseangle	MAIN	sewer	30/04/02	5
Janefield Place	MAIN	sewer	24/04/02	3
Main Street Invergowrie	MAIN	unknown	30/12/01	0.5
Main Street Invergowrie	MAIN	unknown	31/12/01	0.5
Helmsdale Place	MAIN	sewer	03/01/02	0.25
Peep O' Day Lane	MAIN	sewer	10/01/02	1.25
152 Hilltown	MAIN	unknown	14/01/02	3
298 Clepington Road	MAIN	sewer	28/01/02	0.25
6 Forfar Road	MAIN	sewer	15/01/02	4
Wishart Place	MAIN	unknown	08/01/02	2
St Boswells Tce	MAIN	sewer	22/02/02	0.5
Station Road, Invergowrie	MAIN	sewer	11/02/02	0.25
			TOTAL	**49.5**

Table 1 - Summary of sewer flow reductions following water main repairs

In most cases the flow reduction was immediate. The remaining cases showed a gradual draw-down of flows in the first 2 days following water main repair. In total the water supply network was observed to contribute 49.5 l/s of flow to the sewerage system. In reality this total will be significantly greater as a result of the combined total of smaller repairs whose individual contribution cannot be readily measured or in locations where the flow path was not obvious.

An example of the flow reduction recorded at one of the DAP monitoring sites is shown in Figure 1. The repair was carried out on 2/5/01 with an immediate and dramatic effect on sewer flows. The increase in sewer baseflow prior to the repair is also believed to be related to water main rehabilitation activities as a number of repairs were carried out within the same water supply zone from 23/4/01 to 25/4/01. These repairs were believed to have raised zonal pressures resulting in increased leakage volumes.

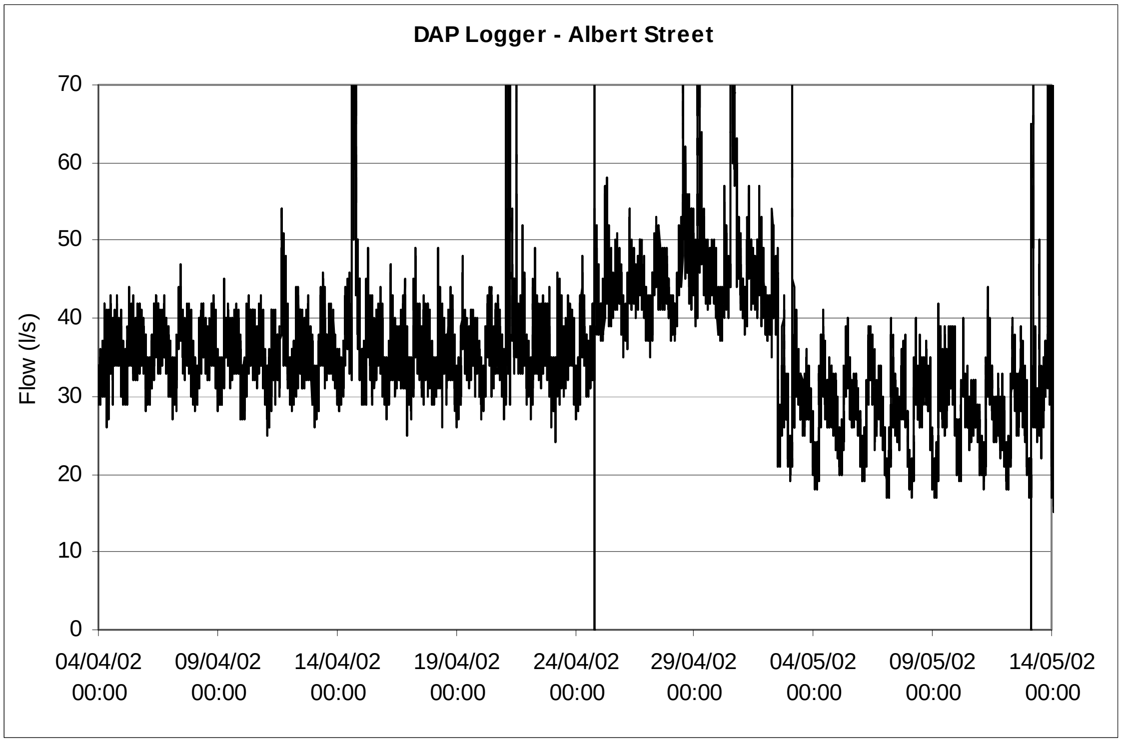


Figure 1 - Albert Street DAP logger sewer flow reduction

Cumulative Effect of Repairs & Long Term Monitoring

The phasing of the repair works made their cumulative effect difficult to measure. However, an intense period of water main rehabilitation was carried out from 29/10/01 to 23/11/01. During this period, sewer flows at the base of one of city centre catchments (east) were analysed for any impacts.

Figure 2 shows a number of the measured elements over this period.

The dates and quantities of fixes are shown as black bars and are read using the secondary y-axis. The rainfall data for the period (grey bars) are read as daily totals also using the secondary y-axis.

The outputs from the supply reservoir are shown as the grey dashed line. These outputs, although subject to daily variations, were found to reduce sharply from the outset of the repair period. Following this sharp drop, the reservoir output was found to raise gradually over a 3 week period. A long-term analysis of these outputs has shown the temporary reduction to be outwith the range of flows normally experienced. It is believed that the rise of reservoir outputs to original levels arises as a result of the low level of proactive leakage detection work previously carried out in the Dundee area. It has been hypothesised that the poor condition of the network, coupled with a sudden rise in water pressure following the repairs has resulted in increased leakage from existing bursts and the springing of new leaks until a new equilibrium is reached.

The daily minimum flows recorded at the permanent flow monitor for the catchment are shown in Figure 2 as the solid black line graph. A long data series containing a dry period during

September is shown to allow a comparison of dry period flows to be made. In the weeks leading up to the repairs being carried out, daily minimum flows were observed to fluctuate around approximately 70 l/s. Following the repairs, the recorded baseflows dropped significantly by nearly 40%. Baseflows were then observed to rise back to original levels over the following 3 weeks.

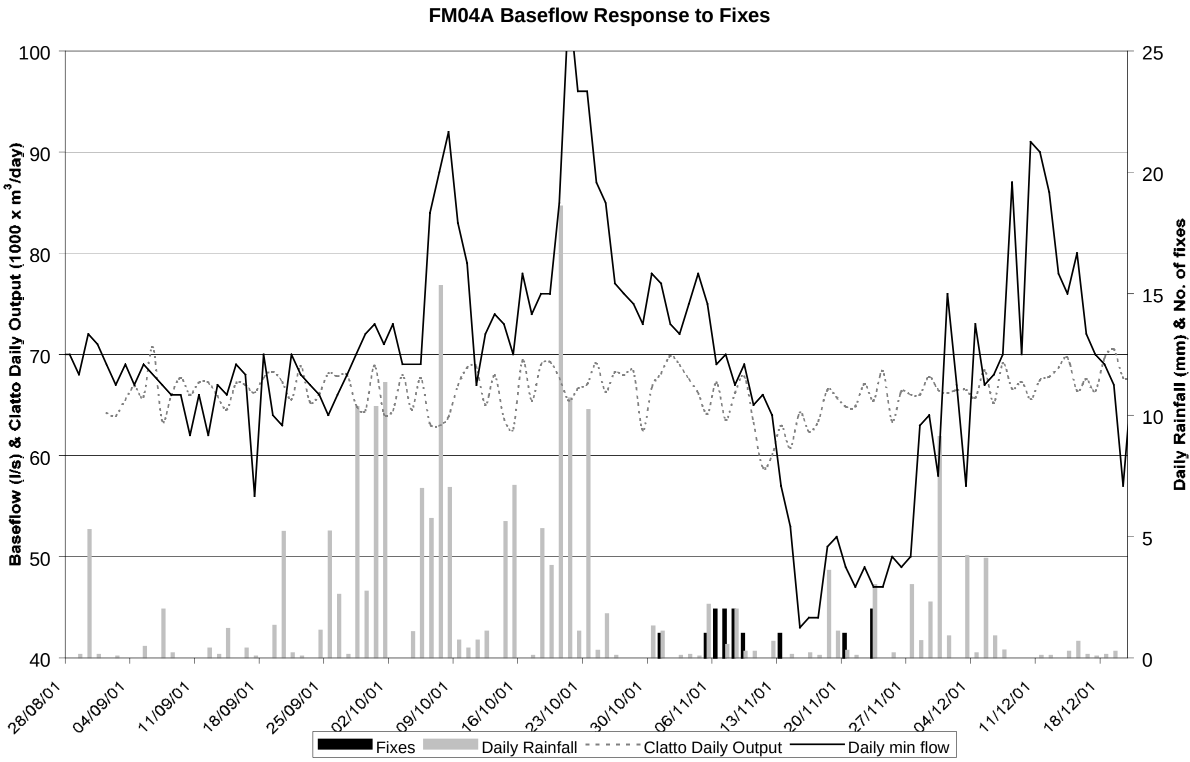


Figure 2 - FM04 response to baseflows

This flow pattern closely follows that of the reservoir output flows but exhibits a 1 to 2 day time lag. The previous data indicate no correlation between the recorded sewer flows and reservoir outputs. The gradual climb of flows to their original levels reinforces the need for a long term strategy of leakage management to be put in place in order to feel any benefits of the initiative.

The distribution of the repairs between the Clatto water supply zone and the catchment for FM04 were analysed. It was discovered that ten repairs in the catchment resulted in a sewer flow reduction of 25 l/s (average 2.5 l/s per repair). Comparing this with the 3.5 l/s per repair reduction in water supply output calculated using clean water production figures, suggests that potentially 70% of leakage flows infiltrate to the sewer in this catchment. These averaged calculations are however sensitive to the natural variability of the baseflows and water demand.

As a result of the phasing of the repairs over 7 months and the large volumes of flow at the inlet to Hatton Wastewater Treatment Works impacts of the repair works at the WWTP could not be assessed.

COST IMPACTS

The long-term impact of the project could not be assessed from this initial work as the flow reductions were found to be only temporary. However, an indication of the potential savings that could be made, can be assessed by considering the flow drop observed in the central area east catchment. In this area a total drop of 27 l/s was observed. Alone, this represents an annual water production and wastewater treatment saving of approximately £375,000. If the average figures from this subcatchment are applied to the whole catchment area used in the study, infiltration flows of up to 200 l/s can be associated with leakage derived infiltration. This figure was determined using an analysis of the measured repairs, their characteristics and the characteristics of the unmeasured repairs. The halving of leakage rates would in that case result in a cost saving in excess of £1 million per annum. This saving would of course be partially offset by the investment required to keep leakage levels at a more desirable level.

The traditional concept of the economic level of leakage (ELL) is therefore skewed as a result of considering wastewater treatment costs which are significantly greater than water production costs. Figure 3 shows the significant impact that considering infiltration flows can have on the economic level of leakage. The curve is determined using the sum of the cost of leakage control and marginal costs for a given level of leakage. As the costs of leakage control and leakage levels are highly variable, modelled and typical values were used to derive the initial curve (WRc, 1994). Where available real data were used to allow the correct proportions of costs to be represented. In each of the cases below, the marginal costs are indicated in Figure 3 as a greyed series.

The ELL cuves are shown below for:

1. The marginal costs of water lost;
2. The marginal costs of water lost + authority owned treatment costs;
3. The marginal costs of water lost + PPP scheme treatment costs.

The greatest impact on ELL is felt in the case of a PPP treatment scheme. In this case the high wastewater treatment costs (up to 10 times the water production costs) are seen to move the economic level of leakage costs to approximately ¼ of the traditionally determined value.

In the absence of a private organisation, the savings are more marginal, with treatment and pumping costs in a similar order of magnitude to those of water production. In this case, the ELL is found to be approximately 60% of the original.

A further important financial impact of leakage derived infiltration arises when a fully privatised model is considered. In the case of different companies owning and operating the wastewater and water networks, the “pollution” of one organisation imparts additional cost to the other company through increased pumping and treatment costs. In this situation, the question of responsibility for ownership and flow associated costs is unclear but could in the future be interpreted as a trade input issue.

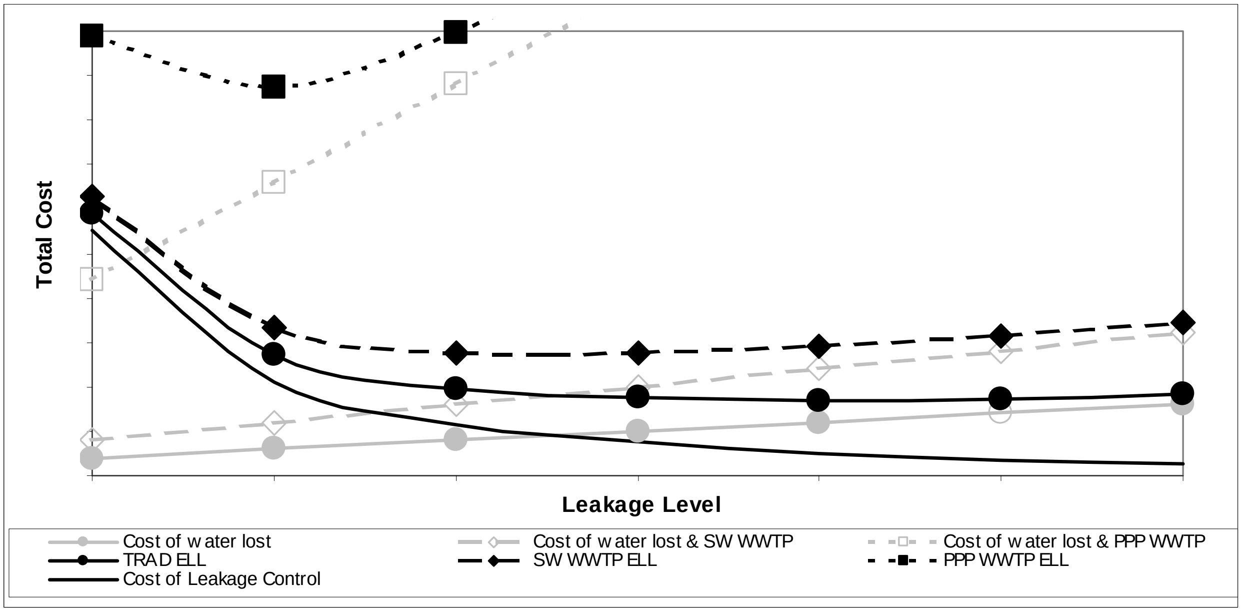


Figure 3 - Effect on calculation of economic level of leakage

ADDITIONAL IMPACTS

In addition to the principal aims of the study (reduction of infiltration flows) a number of indirect benefits have been gained during the investigation.

The knowledge of the water and wastewater systems has been enhanced at key locations. Knowledge of the variability of dry weather flows throughout the year has also been increased significantly, with measured seasonal ranges far in excess of previous estimations. This large seasonal variation has significant implications for design procedures, as it is likely that a single estimate of dry weather flow will be unsuitable for an entire year. Other long-term studies have indicated that the results of Dundee are not atypical (Poole, 2002).

This variability has further implications for the verification of modelling tools. As complex modelling tools are likely to be sensitive to the wide seasonal ranges in dry weather flow and catchment characteristics noted in this study. Large variations in catchment wetness and groundwater levels are likely to impact not only the dry weather flows (as shown here), but also storm peaks and durations (Davidson & Margetts, 2002).

The reduction of leakage derived infiltration will have further operational benefits such as freeing up hydraulic capacity and increasing the strength of sewage arriving at treatment plants (where necessary).

The use of long-term permanent flow monitors has also had additional benefits as an early warning system to potential operational problems. Incorrectly set gates in the city centre have been identified on two occasions throughout the study, preventing potential surface flooding and operational problems. This allows increased, proactive control of the catchment on a regular basis.

The study has additionally highlighted the importance of considering the water and wastewater networks as a single system, with the outputs from the water system (foul and leakage) operating as inputs to the drainage network. These "artificial" inputs have been demonstrated to be significant and should be considered in the assessment of sewage strengths, dry weather flows and the targeting of problem infiltration areas (i.e. checking against areas of high leakage).

SUMMARY & CONCLUSIONS

Infiltration levels have been assessed throughout the Dundee Central and IRDS catchments. This has been done using principally two sets of data:

1. Long-term strategic monitors used to provide coarse spatial data over an extended period;
2. Short-term drainage area plan monitors providing a detailed snapshot of the spatial variation of infiltration flows.

Localised sources have been identified and a seasonal variation of up to a factor of 5xDWF identified in certain catchments. The potential repercussions of this large dry weather range on new works design, wastewater modelling and system operation have been assessed in each of the catchment areas.

The rehabilitation work carried out on the water network was found to significantly reduce sewer flows in the short term, with a total flow reduction of nearly 50 l/s measured in the vicinity of individual repairs. However, in the medium term, wide-scale flows were observed to increase towards their original levels. This pattern was mirrored in the clean water system, suggesting a strong link between the leakage and infiltration levels. The assertion of this strong link was supported by observed evidence of flow paths at water supply bursts and leaks.

As a result of this link a methodology for combining drainage and water system rehabilitation studies was carried out and a co-ordinated approach developed. The long term application of co-ordinated leakage and infiltration management strategies is likely to produce significant benefits in the Tay and other PPP schemes and will affect traditional concepts such as the economic level of leakage, sewage treatment and pumping costs and the responsibility for the effects of additional infiltration flows.

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