Edinburgh Long Term Flow Monitoring – The Uses and Benefits
Allan Hill, ESW Waterway Consultancy
Stephen Friend, Montgomery Watson

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Introduction

In March 1999, East of Scotland Water (ESW) awarded its first Private Finance Initiative Services Contract to Stirling Water for the Almond Valley and Seafield PFI Contract. As part of the data collection for the PFI contract, long term monitoring was carried out in the Edinburgh sewerage system. This was primarily to understand the interface issues between the catchment and Edinburgh WwTW enabling long-term flow risks to be analysed.

This paper describes the implementation of the flow monitoring system, the uses of the data obtained and the key benefits that have been derived from the exercise.

Background

Edinburgh WwTW (Seafield) receives waste water from the Edinburgh catchment and parts of East Lothian. This amounts to a population of approximately 500,000. Most of the flow arriving at the works is transferred through the Eastern and Western Interceptor Sewers, which were constructed in the late 1970s / early 1980s. These major sewers are key parts of the collection system and form part of a critical interface between the sewerage network (operated and maintained by ESW) and the Waste Water Treatment Works (operated and maintained by the PFI Contractor).

A long-term flow monitoring contract was originally commissioned in March 1997. Its main purpose was to monitor and assess the actual hydraulic performance of the Edinburgh Sewerage Network, including the interceptor sewers for the purposes of the Almond Valley and Seafield PFI project. At the time of commissioning it was recognised that additional benefits would be gained, as the survey would provide valuable information to support possible improvements and capital improvements in the Edinburgh sewerage system. This included the management of flows to Edinburgh WwTW.

The flow information has allowed critical decisions to be made on increasing the capacity of Edinburgh WwTW and to allow the Eastern Interceptor Sewer to be used to convey additional flows to Edinburgh WwTW from outwith the catchment; in particular the transfer of flows from the Esk Valley catchment previously treated at Wallyford WwTW.

It has given valuable information to the PFI Bidders to allow them to make a robust assessment of dry weather flow. As the PFI Contractor is paid on the volume of waste water treated it was important that the Bidders had a thorough understanding of how the sewerage system performed. Infiltration is a key component of the flow arriving at Edinburgh WwTW, amounting to some 60% of the dry weather flow. Long term monitoring would highlight seasonal variations.

Implementation

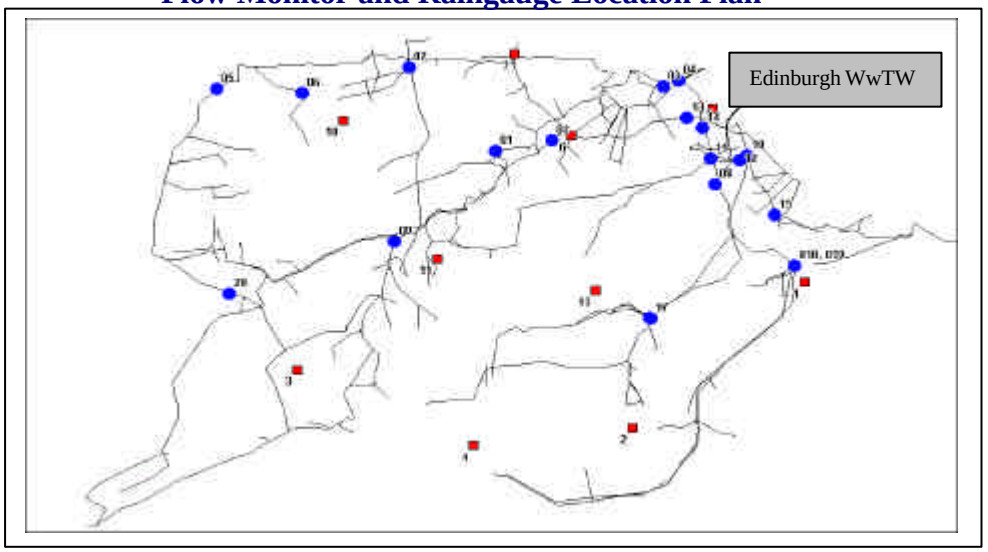
East of Scotland Water purchased the necessary equipment to undertake the flow monitoring programme (20 ADS flow monitors and 12 raingauges) from Integrated Hydro Systems separately from the offer to tender for the 'Service Contract' to undertake the survey.

This 'Service Contract' (survey) involves the maintenance (weekly data retrieval; analysis; calibration; relocation; site visits; data processing; equipment repair, etc) of the 20 ADS flow monitors and 12 raingauges installed within the Edinburgh Sewerage Network and the monthly reporting (summary; event identification; failure; maintenance report; flows and rainfall weekly plots; digital data in QuadraScan and PMAC format; and digitised data [STD] format) of all data collected. All the equipment is connected to the ESW computer network via modems and telephone lines.

Two Contractors were invited to tender for the Edinburgh Long Term Sewer Flow Survey Contract. At that time, only these two UK contractors had the capability and experience of installing, operating and maintaining the ADS flow monitor equipment. It was impractical to consider using contractors outwith the UK. Integrated Hydro Systems was awarded the contract.

The flow monitoring and raingauge equipment was installed in various key locations within the Edinburgh sewerage network, during 1997. All of the proposed flow monitoring sites were inspected by IHS, to confirm if they were suitable for long term installation. This considered the hydraulics of the site and also the ease of installation of telemetry for downloading of all data. The pipe diameters ranged from 600mm to 3070mm. Routine maintenance was carried out at each site every 6 months or when the telemetry indicated that there was a problem with the data.

Flow Monitor and Raingauge Location Plan



The actual cost of carrying out this work in Year 1 was £64k, which included the installation of the survey.

Telephone line rental payments were made to the telephone operators directly by ESW – the value of this was of the order of £4,000.

ESW Operations staff were utilised to assist with maintenance and service of some of the larger sites which required more men. They also assisted with the undertaking of various flow diversion works. The Capital cost of this work was of the order of £5,000.

Uses of the Long Term Flow Survey Data

The Long Term Flow Survey data was used to undertake the following:

- Review maximum flow to Edinburgh WwTW
- Edinburgh macro model verification
- Impact Assessment of Increased Flows to Eastern Interceptor Sewer
- Infiltration analysis
- Flood Analysis

Review of Maximum Flow to Edinburgh WwTW

The PFI contract was initially written such that the maximum flow permitted to reach Edinburgh WwTW is 16.67m^3/s, which is the original design flow. Following the Esk PFI decision to transfer flows into the Edinburgh catchment, this value was increased to 17.245m^3/s. For flows above this value, both ESW and Stirling Water are obliged work co-operatively and use reasonable endeavours to deal with them.

ESW operations had always indicated that they considered that 20m^3/s regularly arrived at Edinburgh WwTW. Flow measurement data, recorded by ultrasonic means, was available at the WwTW in order to substantiate these flows. The modelling work that MW undertook on the catchment had always indicated that flows of 20m^3/s would not be achieved. A review of the WwTW flow data was therefore undertaken. The full dataset for the year 1998 was examined and the largest storms in terms of recorded flows at these sites were reviewed.

The results of this analysis can be seen in the table below. This indicated that for the largest events during 1998, the maximum measured flow to Edinburgh WwTW was 17.1m^3/s and the lowest was 14.05m/s.

Storm	Edinburgh WwTW Model Data Max Flow	Edinburgh WwTW Flare Data Max Flow	Model Accuracy	Edinburgh Siphon Penstock Positions	Comments
02/11/98	14.80m^3/s	15.54m^3/s	-5%	All Open 30%	< 1 in 1 Year Storm
16/10/98	16.67m^3/s	17.07m^3/s	-2%	All Open 100%	1 in 2 Year Storm
19/07/98	16.22m^3/s	16.60m^3/s	-3%	All Open 100%	< 1 in 1 Year Storm
12/07/98	15.92m^3/s	16.04m^3/s	-1%	All Open 25%	1 in 12 Year Storm (3 Hr)
29/06/98	14.52m^3/s	14.05m^3/s	+3%	All Open 100%	< 1 in 1 Year Storm
05/04/98	16.08m^3/s	14.83m^3/s	+8%	All Open 100%	< 1 in 1 Year Storm

This analysis was able to prove that Edinburgh WwTW did not receive 20m^3/s regularly. It also showed that for the largest storm events recorded during 1998, on only one occasion was the flow of 16.67ms/3 exceeded. This gave ESW increased confidence in the PFI contract flow values set for Edinburgh WwTW.

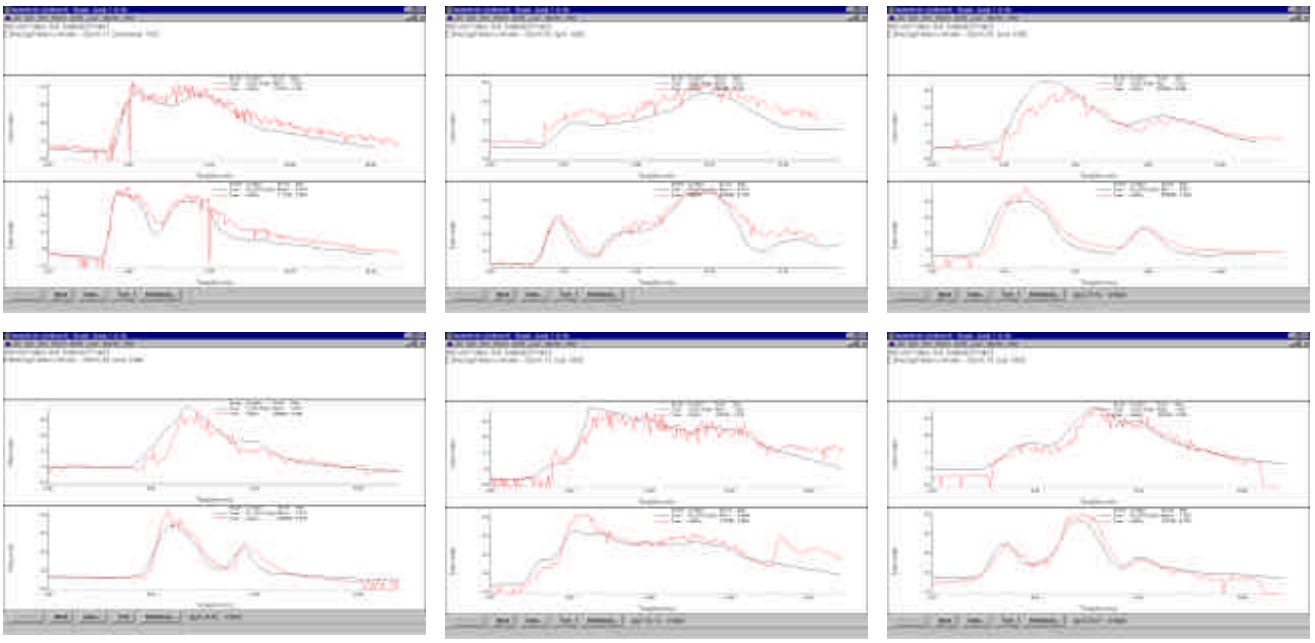
Since the award of the PFI Contract, ESW have initiated a change in the capacity of Edinburgh WwTW by incorporating a storm by-pass at the works which will increase the capacity to 21m^3/s. This is estimated to be the maximum capacity of the sewers delivering flow to Edinburgh WwTW. This has provided increased flexibility in the management of flows within the catchment.

Edinburgh Macro Model Verification

The Edinburgh Macro model was constructed in 1996 and partially verified in 1997 utilising a 50 flow monitor survey. From this flow survey, 3 events which met the WaPUG criteria for depth and intensity were selected for verification purposes. These events however were all less that a one year return period.

The provision of the Long Term Flow Survey Data has enabled additional verification of the macro model to be carried out. This exercise has been carried out only at a small number of critical sites, to aid with the predictions of the maximum flow to Edinburgh WwTW.

Detailed below are the flow hydrographs for sites 13 and 14 at the end of the Western and Eastern Interceptor Sewers, just upstream of Edinburgh WwTW.



The results detailed in the hydrographs above can also be seen in the table below.

Storm	11/12/1997		05/04/1998		06/06/1998		29/06/1998		12/07/1998		19/07/1998	
	13	14	13	14	13	14	13	14	13	14	13	14
LTFM Data Flow	8.7	7.5	8.2	6.7	4.9	7.9	5.5	8.5	7.4	8.5	7.6	8.2
Model Flow	7.4	6.9	7	6.4	5.5	6.6	5.9	7.1	7.9	6.7	7.5	7.4
% Difference	-15	-8	-15	-4	12	-16	7	-16	7	-21	-1	-10

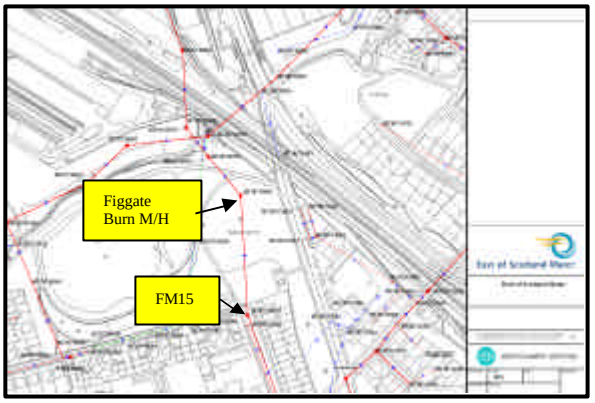
It can be seen from this table that the variation in % difference for FM 13 is 7% to –15% with an average of 1%. Also for FM 14 the variation is –4% to –21%, with an average of –13%.

From the table previous it can be seen, comparing the model results with the data recorded at Edinburgh WwTW, that the overall % difference is much smaller. This can be put down to the flow monitor inaccuracy at these high flows and the value taken being the highest spike from the hydrograph.

Overall, the verification at these sites can be considered to be good considering the large flows and the use of 12 raingauges to generate the modelled flows.

Impact Assessment of Increased Flows to Eastern Interceptor Sewer

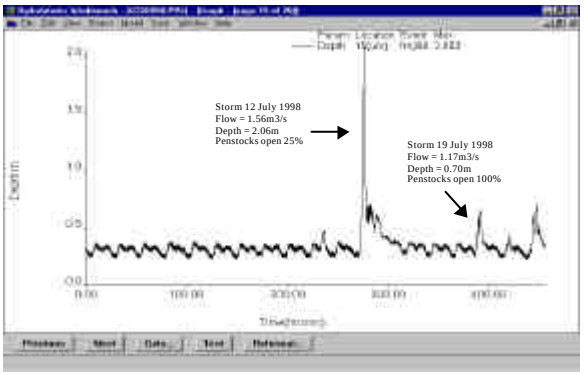
The PFI proposal was to transfer flows previously treated at Wallyford WwTW, to Edinburgh WwTW for treatment via the Eastern Interceptor Sewer. ESW were concerned about the increase in surcharge within the sewer caused by this increase in flow. In particular there was a risk of flooding at the shallow Figgate Burn manhole on the sewer, which was only 2.5m deep; the sewer being 1350mm diameter. Surcharge levels had been measured on site to within 0.5m from cover level. Long Term Flow Monitor No. 15 was located in the manhole upstream from this manhole and there was only 100mm fall between manholes.



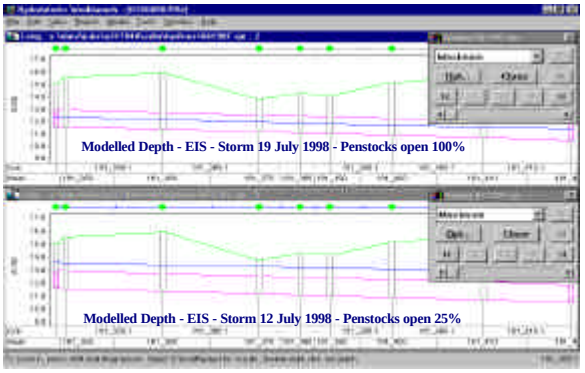
Detailed in the table below is the flow and depth data returned from Flow Monitor 15 for the largest recorded storm events during 1998. It can be seen from this table, that under normal operating conditions, the depth of flow is only approximately 0.71m. Under the largest flow conditions on 29 June, where the flow is 1.69m^3/s, this depth of flow increases to 1.17m. Most significant however, is the larger depth of flow on 12 July and 9 October, when flow are much less. Investigation revealed that during these significant storms, the penstocks at the head of the Edinburgh WwTW siphons had been closed to restrict flows to the works to avoid potential flooding at the Works.

Date	Max Flow (m^3/s)	Max Depth (m)	Comments
16/10/98	1.06	0.71	
9/10/98	**1.02**	**1.24**	**Edinburgh WwTW Penstocks open 20%**
September 98	1.22	0.71	
August 98	1.23	0.71	
19/07/98	1.17	0.70	
12/07/98	**1.56**	**2.06**	**Edinburgh WwTW Penstocks open 25%**
29/06/98	1.69	1.17	**Edinburgh WwTW Penstocks open 100%**

This is illustrated in the 1st hydrograph, which shows the measured depth at FM 15. During the 12 July event the penstocks were open 25%, whereas they were fully open for the 19 July event.



The 2nd image shows the Edinburgh macro model long section for the same July events.



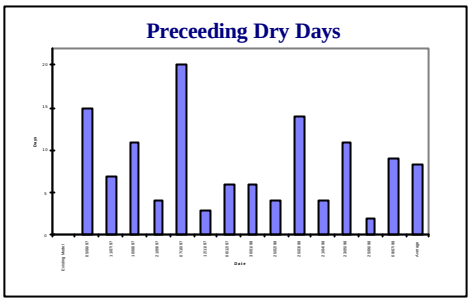
It is interesting to note that FM 15 is located approximately 3km upstream from the siphons and also 5m higher.

The overall benefit from this assessment was a better operational understanding of the sewerage system and also an increased confidence in surcharge levels in the Eastern Interceptor Sewer and the ability of the sewer to take increased flows.

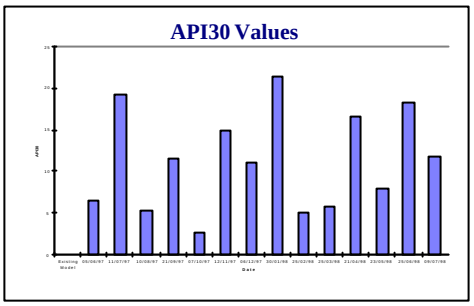
There are provisions within the PFI Contract restricting the use of the siphon penstocks during times of storm to control flows arriving at the WwTW, thus safeguarding ESW's obligations in meeting CSO consents elsewhere in the catchment.

Infiltration Analysis

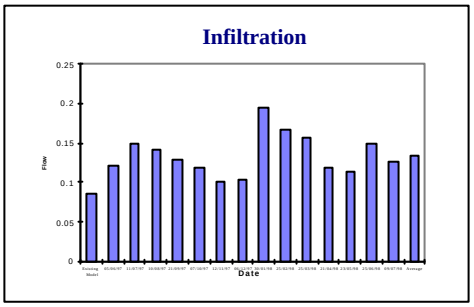
Infiltration analysis was carried out to give the maximum information to the Almond Valley and Seafield PFI Bidders. The PFI payment stream is based on flows receiving full treatment at Edinburgh WwTW, hence infiltration is a very important element of this flow. This is particularly true within Edinburgh, where infiltration is approximately 60% of the total Dry Weather Flow. Therefore, for the total payment over 25 years, approximately half is infiltration based !!



Following an assessment of daily rainfall totals, 14 dry days were chosen for the analysis to be carried out on. Ideally, one day per month was chosen and minor rainfall of less than 1mm was ignored when totalling the number of proceeding dry days. Generally it is expected that infiltration will be lower when the number of proceeding dry days is high.



The catchment wetness for each of the dry days chosen was also determined by calculating the Antecedent Precipitation Index (API30) values. The API30 value is a factored total of the rainfall which fell during the 30 days prior to the dry day. The rainfall occurring each day is factored such that rainfall closer to the dry day chosen gives a higher API30 value. Generally it is expected that infiltration will be higher when the catchment wetness is higher.



The measured daily flows at each monitor were disaggregated into population generated and infiltration components using the methodology set out in the Wastewater Planners Users Group, User Note 33.

Firstly, flow hydrograph files were created from the standard flow survey data, using Hydroworks and these files were then imported into Excel for analysis. Minimum and average flow values for the day were calculated using Excel. Due to problems with velocity drop out at low flows, best fit curves were drawn onto the hydrographs and the minimum flow values were taken from these plots.

The standard factor value used within the calculation in 0.90, however this value reduces as the catchment area draining to the flow measurement position increases. This makes allowance for the time taken for night time population generated flow to reach the monitoring position. In order to obtain these factors, a Dry Weather Flow simulation is carried out using the hydraulic model, without any infiltration flows or trade flows. The factor is then calculated at each monitor position by dividing the minimum flow by the average flow and subtracting this from one.

The outcome is that it indicated the difficulties involved in undertaking this type of analysis. The lowest infiltration does not necessarily occur after the largest number of dry days or when the API30 value is lowest.

The results of the analysis however gave the PFI bidders a range of infiltration flows over the year, indicating the maximum, minimum, average and existing modelled flows. This enabled them to develop their own assessment of Dry Weather Flow and the risks associated with payment by volume treated.

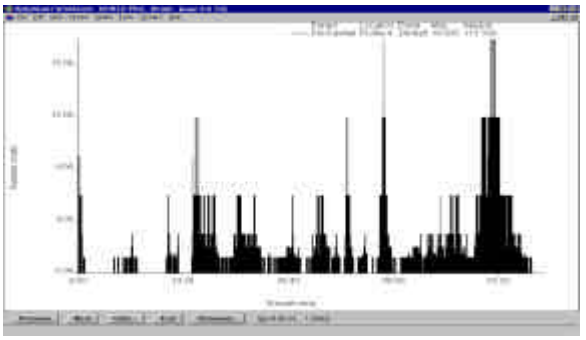
Flood Analysis

As detailed previously there are 12 raingauges located within the catchment. Four major storms were recorded between April and August 2000, which caused significant recorded flooding and which caused concern from a number of MSP's in Edinburgh.

ESW were concerned about this flooding and wished to review the rainfall data to determine the return period of the storms and also to determine if these events were outwith the ESW Level of Service for flooding. Detailed in the table below is an examination of two of these events.

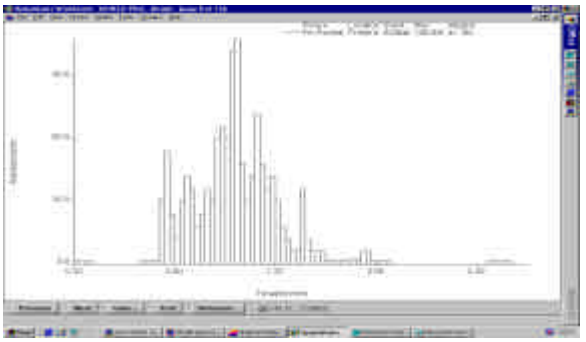
		Storm 240400 13:00 - 270400 00:00 (59 hrs)			Storm 270700 14:20 - 16:20 (2 hrs)		
Raingauge	Location	Max Intensity (mm/hr)	Total Depth (mm)	Max Return Period	Max Intensity (mm/hr)	Total Depth (mm)	Max Return Period
1	Niddrie	12	53.0	1	60	8.8	3
2	Alnwickhill	12	77.0	14	90	6.6	1
3	Westerhailles	18	99.0	69	7	1.8	0
4	Fairmilehead	15	115.0	100	36	4.6	0
5	Seafield	6	22.0	0	54	13.6	6
6	McDonald Rd	12	60.0	6	84	22	100
7	Trinity	6	24.4	0	30	13.2	5
9	Balerno	No Data	No Data	-	No Data	No Data	-
10a	Davidsons Mains	12	66.0	6	No Data	No Data	-
11	Dalry	18	80.0	25	54	20.4	91
12	Levenhall	6	39.2	1	42	8.8	2
13	Newington	18	85.0	25	48	10	2

It can be seen from the above table that the April event lasted for approximately 60 hours and that the return period varied from over 100 years to less than one.



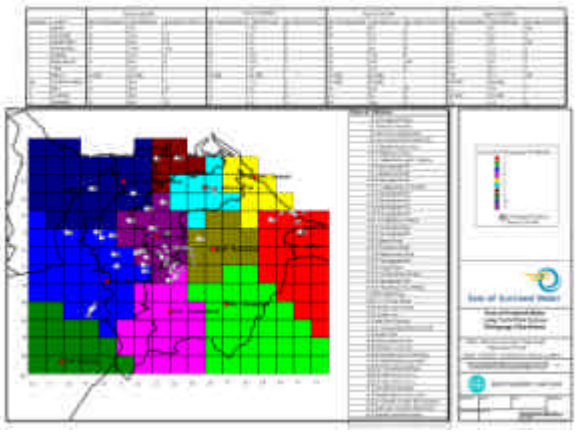
This event caused major river flooding and Edinburgh District Council are currently developing flood prevention measures to ensure that this does not happen in the future.

It can also be seen from the above table that the July event lasted for approximately 2 hours and that the return period again varied from over 100 years to less than one.



This event caused significant internal flooding to properties and also garden and carriageway flooding. It did not however cause river flooding. A large proportion of the internal flooding was not historic.

ESW developed a report on these flooding incidents. Drawings were included which indicated the rain gauge coverage, max intensity, max depth and the flooding locations.



The benefit of the Long Term Monitoring is that 12 raingauges gives a better catchment coverage than was previously available. This allowed a more accurate return period analysis to be carried out. For example, SEPA raingauges for the 3 shorter duration events indicated less than one year return period. This therefore gave ESW a better understanding of flooding Level of Service failure.

Benefits

The benefits of obtaining the Long Term Flow Survey data were as follows:

- Maximum information for Almond Valley and Seafield PFI Bidders
- Improved Edinburgh macro model verification
- Increased confidence in assessing the maximum flows to Edinburgh WwTW
- Increased confidence in surcharge levels in Eastern Interceptor Sewer
- Better operational understanding of sewerage system
- Reduction in CSO spills to Firth of Forth
- Understanding of variable catchment infiltration
- More accurate flood analysis

Conclusions

It can be concluded that the Long Term Monitor data has been extremely beneficial to ESW.

It has provided ESW with a dataset of rainfall at 12 locations and flow, depth and velocity at 20 critical locations within Edinburgh. This dataset has only partially been interrogated to date and has already provided a range of answers to the operation of the sewerage system.

Fundamentally however, its main use was to provide the PFI Bidders with the maximum amount of data available. Considering that both the Almond Valley and Seafield and the Esk PFI schemes amount to a total Capital Value of approximately £120M, then the £170k spent to date on the Long Term Monitoring is very small in comparison. In addition, the data provision has given comfort to Bidders and lenders that the historical and forecast flows are sustainable and fully auditable. This inevitably has resulted in reduced risk with reduced charges.