1. Introduction and Background

Ewan Group Plc (EGP) were commissioned by Scottish Water (SW) to carry out a Drainage Area Plan for the Partick Pumping Station catchment, Glasgow in May 2001. It was later noted that it would be necessary to include further catchments, due to the hydraulic connectivity, looped connections to Partick Pumping Station and inflows from the Kelvin Valley Sewer. The decision to carry out a DAP for the entire catchment draining to the Dalmuir Wastewater Treatment Works (WWTW) was made by SW in February 2002.

A Phase 1 report covering the entire Dalmuir catchment was issued in July 2002 which contained details of the proposed scope and programme for the Phase 2 study. The Phase 2 for the Dalmuir DAP subsequently started in August 2002 with a scheduled completion date in December 2005.

For a number of the sub-catchments within the study area eg Kilsyth, Birdston, Bishopbriggs South, Anniesland and Old Kilpatrick, DAPs have been completed separately. The verified models from these DAPs were included within the overall model of the Dalmuir catchment.

This paper describes the detailled modelling and verification of the Dalmuir catchment as part of the Phase 2 study. Topics covered includes the data collection, modelling and verification and sewerage assessment processes for such a large and complex catchment. This model will now be taken forward into the major Glasgow Strategic Drainage Plan project.

2. Catchment Description

The Dalmuir catchment is located north of the River Clyde covering areas within the areas of Glasgow City Council, East Dunbartonshire Council, West Dunbartonshire Council and North Lanarkshire Council. The catchment area covers approximately 11800ha stretching from Glasgow City Centre in the east, to Old Kilpatrick in the west and up to the outlying towns of Birdston, Kilsyth and Cumbernauld in the north.

The topography of the Dalmuir catchment rises from sea level at the River Clyde up to approximately 135mAD in Kilsyth. The upper part of the catchment falls from the hills surrounding Kilsyth along the Kelvin Valley towards the River Clyde. Many watercourses are located within the catchment boundary. Major watercourses include the River Clyde from its tidal weir adjacent to Glasgow Green, the River Kelvin draining from Kilsyth southwards eventually connecting into the River Clyde to the west of the City Centre and the Forth and Clyde Canal which also drains along the Kelvin Valley eventually connecting into the River Clyde to the west of Old Kilpatrick. Other watercourses within the catchment include Yoker Burn, Duntocher Burn, Manse Burn, Luggie Water and Allander Water. As part of the development of the catchment, many of the historic burns have been culverted with some of them now serving as combined sewers eg Possil Burn. The Dalmuir catchment is bisected by many major transport routes, including the M8 motorway at the edge of Glasgow City Centre, the M80/A80 running from the City Centre to the north-east towards Cumbernauld and various other major roads towards the City Centre. Various railway lines are also within the catchment, including the Glasgow SPT Subway.

Figure 2.1 shows the extent of the Dalmuir catchment, including some of the major characteristics of the catchment.

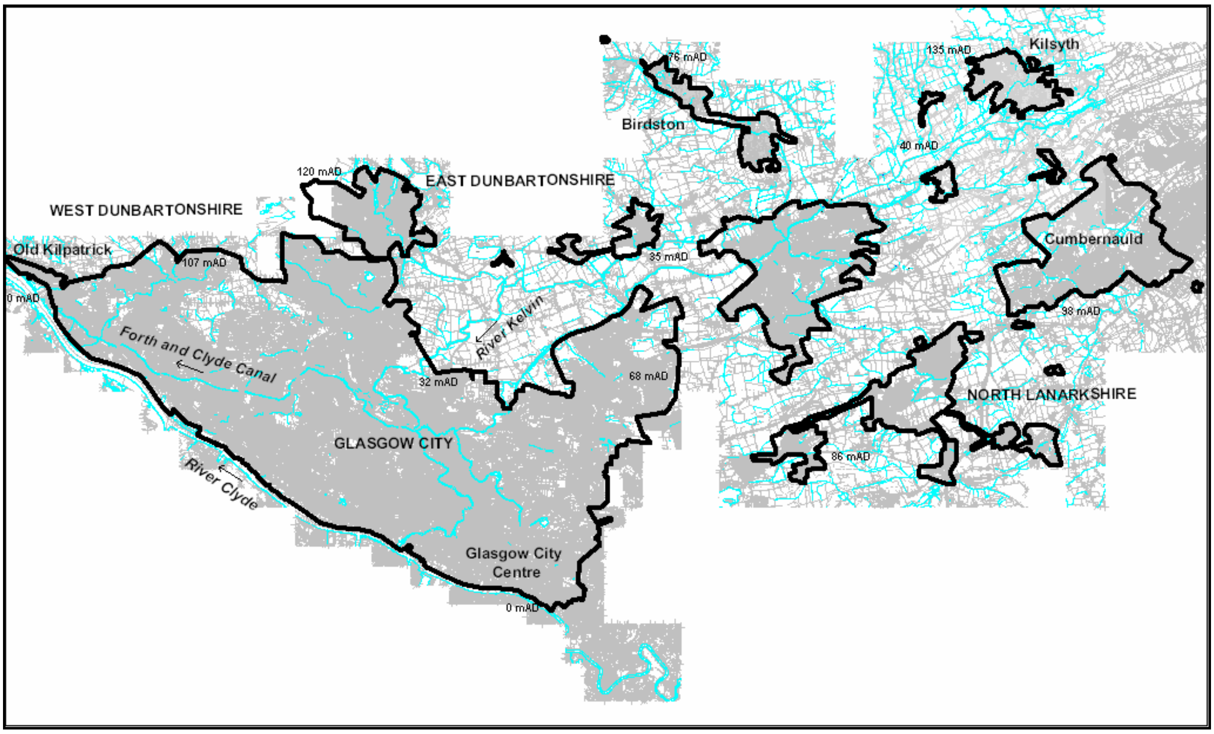

Figure 2.1 –Dalmuir Catchment

The Dalmuir catchment serves a residential population of 404,000 which accounts for nearly 40% of Glasgow City's population. The sewerage system is predominately combined, although some separate and partially separate areas exist. On top of the large domestic discharge to the Dalmuir catchment sewerage system, large amounts of trade discharges are also collected. Most of these trade discharges are located within Glasgow City Centre eg office buildings, restaurants and hotels. However, some additional large trade discharges exist outside the City Centre, normally at business parks, hospitals and industrial developments.

The Dalmuir sewerage system comprises of three main sewers, respectively the Great Western Outfall Sewer, the Clydebank Interceptor and the Glasgow Sewer No. 1. All three of these main sewers connect into the inlet works at the Dalmuir WWTW in Clydebank.

The Great Western Outfall Sewer collects the flow from Partick Pumping Station and the River Kelvin Interceptor. The River Kelvin Interceptor collects flows via gravity from catchments to the north of the City Centre eg Maryhill, Kelvingrove, Lambhill, Possil Park, Springburn Park and Port Dundas. This sewer drains along the east bank of the River Kelvin, eventually forming the start of the Great Western Outfall Sewer within the Kelvingrove Park. After crossing the River Kelvin underneath the Partick Bridge, the Great Western Outfall Sewer receives the flows from the Partick Pumping Station. The Partick Pumping Station receives flows from both the Glasgow Interceptor, which drains the Glasgow City Centre catchments and the Partick Interceptor, which drains areas like Partick, Whiteinch Hyndland and Scotstoun. These two interceptors drain adjacent to the River Clyde, entering the Partick Pumping Station at a low level (around -1.1mAD). From here flows are lifted into the high level (approx 8.5mAD) Great Western Outfall Sewer from where they gravitate for 10.5km to the Dalmuir WWTW inlet works.

The Clydebank Interceptor Sewer collects the flow from the Yoker, Knightswood, Duntocher and Clydebank catchments. This interceptor sewer is very flat, draining roughly at sea level from east to west adjacent to the River Clyde. It eventually discharge flows into a low-level pumping station at the Dalmuir WWTW inlet works from where flows are lifted to join up with the flows from the Great Western Outfall Sewer and the Glasgow Sewer No. 1.

The Glasgow Sewer No. 1 receives flows from Clydebank North, Drumchapel, Acre, Kilmardinny, Bearsden, Summerston and Milton-Dalmuir. One of the main inflows into the Glasgow Sewer No. 1 is from the Kelvin Valley Sewer, which joins with the Glasgow Sewer No. 1 near the John Paul Academy in Acre. The Kelvin Valley Sewer was constructed during the past decade and collects the sewage flows from all the outlying towns to the north of Glasgow. Numerous flow control structures eg Stormkings, Hydrobrakes and siphons underneath the River Kelvin, exist along the Kelvin Valley Sewer.

For practical reasons due to the size of the Dalmuir catchment, the study was divided into eight sections.

Figure 2.2 shows the boundary of the eight sections and the layout of the main sewerage system.

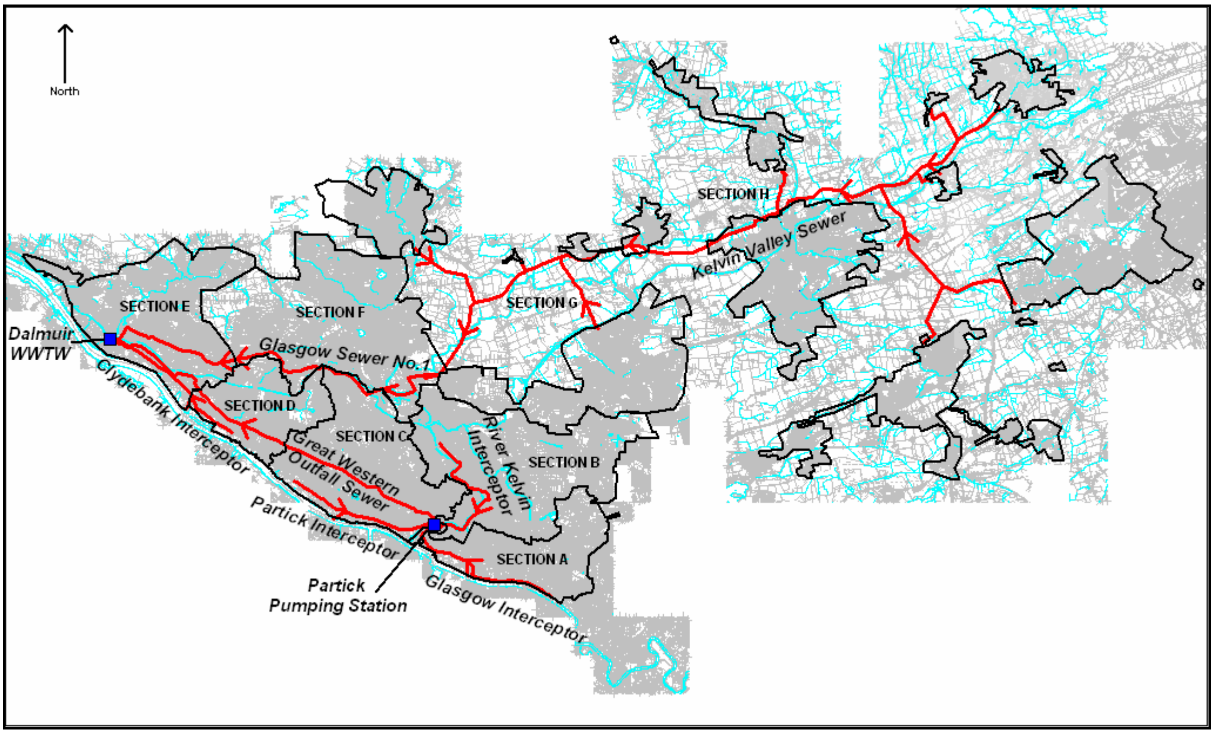

Figure 2.2 – Dalmuir Main Sewerage System and Modelled Sections

3. Data Collection

As part of the Dalmuir Drainage Area Plan Phase 2, an extensive data collection exercise was undertaken. This data collection exercise comprised of manhole surveys, ancillary surveys including all CSOs, bifurcations and pumping stations, structural surveys consisting of standard and specialised CCTV, Impermeable Area Surveys and flow surveys consisting of short-term and long-term flow surveys.

Due to the size of the Dalmuir catchment each of abovementioned data collections were done section by section. This ensured that when the data was collected for each section, this could then be feed as soon possible into the model built process. Since many of the surveys were located within difficult survey locations eg the Glasgow City Centre, traffic sensitive roads and tidal influenced areas, careful planning and close liaison between the various contractors, Scottish Water, the Glasgow City Council, the East Dunbartonshire Council and the West Dunbartonshire Council were required.

- Manhole Surveys

The Dalmuir catchment comprises of roughly 50,000 manholes. A scoping study was done to identify the manholes to be surveyed, to ensure that the surveys are the most beneficial and cost-effective for the study. A dedicated data collection team was involved to ensure good quality data were collected by the various contractors. Since these contractors had various levels of experience a strict audit system were used to check the quality of the data. Just over 3000 manhole surveys were attempted, with an overall success rate of 62.9%.

The Sighthill / Pinkston Road area in Section A required an innovative method of obtaining manhole and connectivity data. No man-entry could be carried out due to the very high levels of Hydrogen Sulphide in this area caus ed by an abandoned chemical factory in this vicinity. Hydrogen Sulphide levels are a major problem in this area with levels up to ten times more than those triggering a gas alarm. To obtain correct connectivity, approximate depths and pipe sizes, surveys were carried out from the surface, in conjunction with a CCTV contractor using a CCTV camera attached to a rope.

- Ancillary Surveys

Numerous ancillary structures are located within the Dalmuir catchment. Many of these ancillaries are key structures in terms of directing flows around the catchment, thereby influencing flooding and spill from CSOs. To ensure that these key structures are correctly incorporated in the Dalmuir model, many of them were surveyed with the modeller being in attendance. The modeller guided the contractors to ensure all important data was collected. For example, at numerous CSOs along the River Clyde flap valves were found to be seized closed, opened or somewhere in between. With the modeller present at the surveys, it ensured that the modeller could guide the survey team in obtaining the correct “opening” size of the flap valve. This could then be fed into the model to create the correct tidal inflows into the system for verification purposes. The Partick Pumping Station was another key ancillary that was surveyed using a combined 6-man survey team from EGP and a survey contractor. To correctly model the pass-forward flows from the pumping station, it was very important to survey the penstocks into the wet well. These penstocks are Real-Time Controlled (RTC) with the opening height being controlled by the level in the wet wells and the depth within the receiving sewer. The surveyed penstock opening height could then be related back to the RTC %opening to create the inflows into the pumping station.

Overall 83 CSOs and 191 bifurcations were attempted to be surveyed, with a survey success rate of respectively 90.2% and 78.5%.

- Flow Surveys

A comprehensive flow monitoring exercise, comprising of short -term and long-term flow surveys was done as part of the Dalmuir DAP.

The long-term flow survey comprised of 13 ADS flow monitors, 1 depth monitor within the Dalmuir WWTW, 16 rain gauges, 3 tidal monitors and the logging of the RTC Operations at the Partick Pumping Station. The locations of the long-term flow survey are shown in Figure 3.1. The long-term flow survey formed a framework of fixed, high quality data points into which the short term flow surveys were fitted. In addition very useful long-term information in terms of annual rainfall, storm movement, infiltration levels and tidal levels were gathered. This information assisted in understanding the catchment behaviour over longer periods and its influence on the sewerage system.

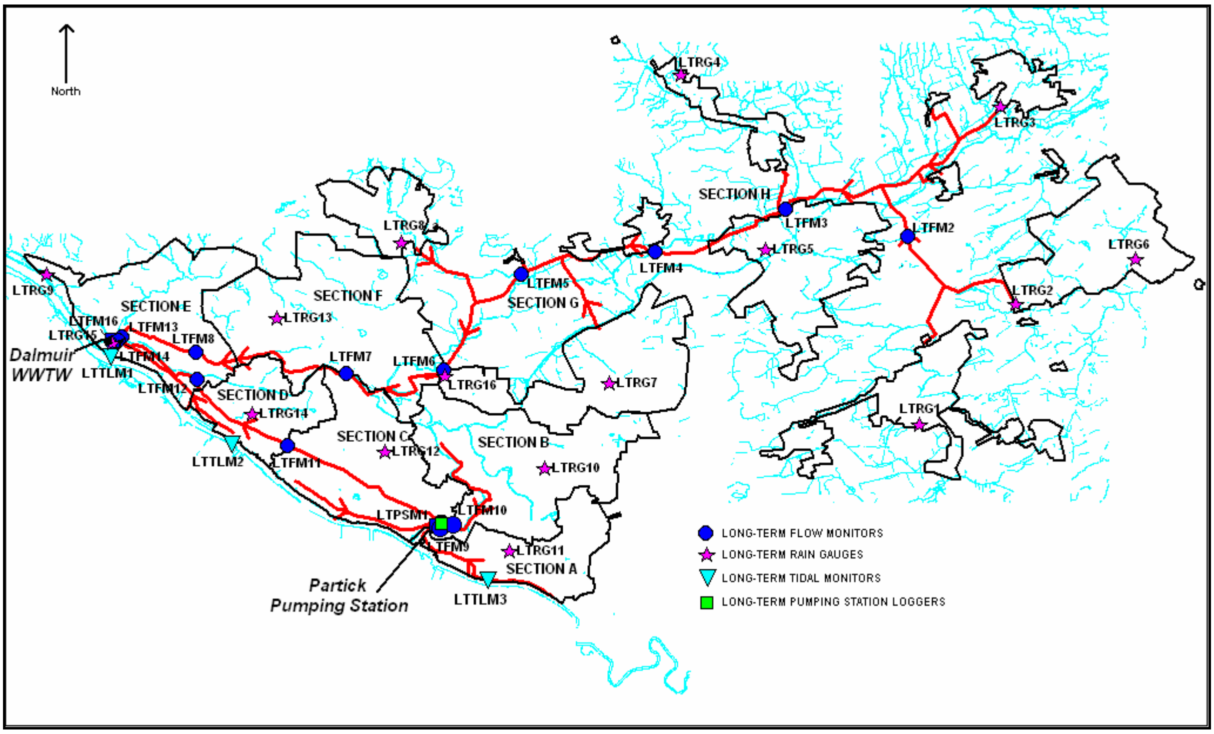

Figure 3.1 – Long-Term Flow Survey for the Dalmuir DAP

The short-term flow surveys were completed section by section and consisted of flow monitors, rain gauges and pump loggers. Details of these surveys can be found in Table 3.3.

Section	Number of flow monitors	Number of depth monitors	Number of rain gauges	Number of pump loggers
A	55	1	7	0
B	69	0	12	0
C	50	1	10	0
D	43	5	4	0
E	49	6	10	5
F	60	0	10	4
G	29	0	10	0
H	0	0	0	0
Total	**355**	**13**	**63**	**9**

Table 3.3 – Short-term flow surveys

- Structural CCTV Surveys

An extensive CCTV data collection and assessment process has been completed as part of the Dalmuir DAP. This process started with the identification of all critical grade A and B sewers in the catchment. Any existing CCTV footage was then assessed in terms of age and grading. If applicable some of these existing CCTV footage sewer lengths were rescheduled for survey.

Two types of CCTV surveys were done as part of the Dalmuir DAP. These were respectively standard CCTV survey work for the normal sewers and specialised CCTV survey work using a pan-and-tilt camera for the main sewers/interceptors.

Overall 316km of sewers were scheduled for CCTV survey with a success rate of 57.7% achieved. The lengths of sewers surveyed were then assessed in accordance with the “Sewerage Rehabilitation Manual”.

4. Modelling and Verification

One of the potential biggest problems of building and verifying such a large model is to ensure that the different modellers building and verifying each of the sections work according to a standardised procedure. The Dalmuir DAP’s procedures were compiled at the start of the project and standardised the model build process eg merging and pruning, wastewater and trade profiles and landuses. This resulted in the size of the model and the number of files being kept to a practical level.

The model and verification process were completed section by section. The model build process started from Section A and Section H, working gradually downstream towards Section E and the Dalmuir WWTW. After the model build process each of these sections were verified against their short-term flow survey and the relevant long-term flow survey monitors.

Since Section H comprises of previously verified DAP models draining along the Kelvin Valley Sewer, no short-term flow survey was done for this section. The model build process for this section comprised of combining all of the individual DAP models into a single model. Since all of the individual DAPs were done by different modellers using different model build procedures, it were very important to ensure that the combined model performs similarly to the individual models. For example landuses and runoff surfaces need to have the same characteristics in the combined model as in the individual model to ensure similar subcatchment responses are created. To ensure that the combined model performed similarly to the individual DAPs, all of the verification events for the individual DAPs were re-run on the combined model. This proved to be a very useful exercise and highlighted potential problems in the combined Section H model. To verify the final combined Section H model, the long-term flow survey was used to test the system along the Kelvin Valley Sewer. Figure 4.1 shows details of the individual DAPs within Section H and the long-term flow monitors used to verify this Section.

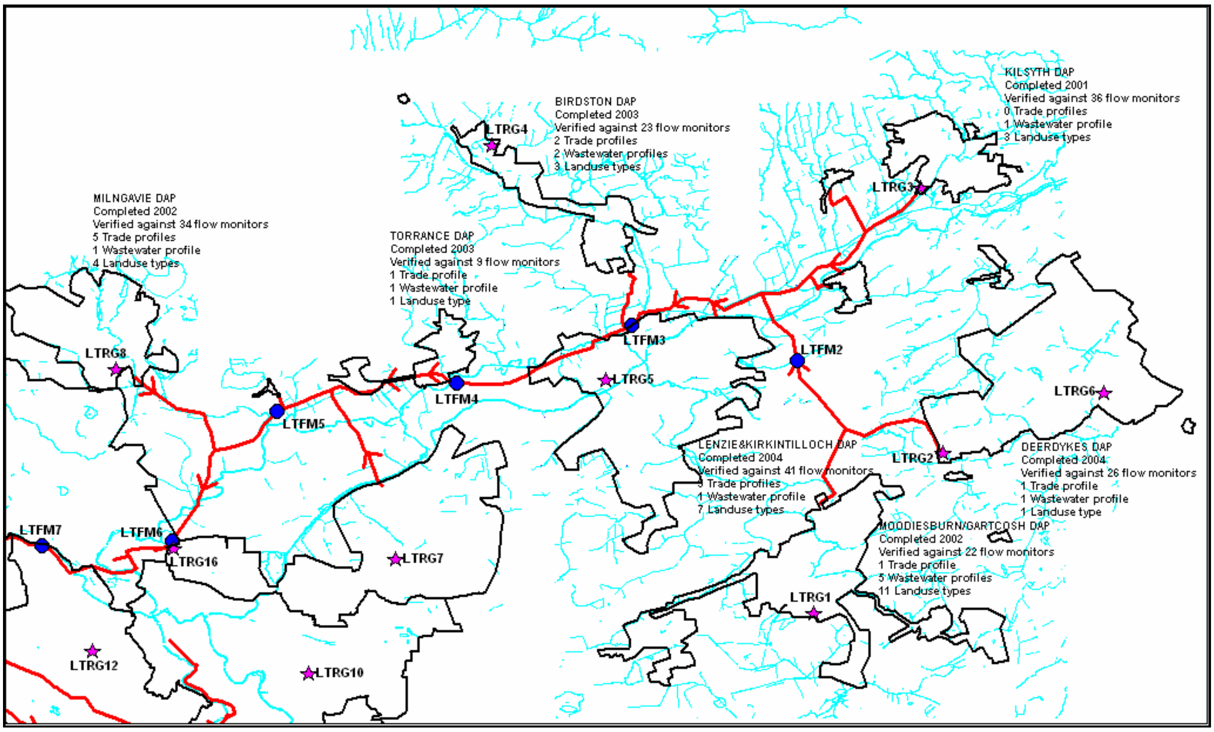

Figure 4.1 –Section H Individual DAP models

During the verification process quite a few unique aspects of the Dalmuir catchment were discovered that has a large influence on the sewerage system. Some of the more interesting discoveries were as follow:

- Impact of trade. During the verification process, it was realised that in certain parts of the catchment, trade has a massive influence on the sewerage system. In a few cases special methods were used to model this large impact. A good example is the trade profile created specifically for the Glasgow City Centre, which shows large activity between 22:00 and 02:00 in the evening when all the bars and the nightclubs are at their busiest. Another good example is a distillery in Section B with a consented discharge of 3404m^3/day. Quite a few short-term flow monitors were installed downstream of this distillery and indicated clearly the massive influence of the distillery processes on the sewerage system. After talks with the process engineer at the distillery, the processes were more accurately modelled using a dummy pumping station.

- Tidal influence. During the short-term flow surveys it was noticed that the River Clyde has a massive tidal influence on the sewerage system. Large tidal inflows occur into the system through some of the CSO's seized flap valves. This of course could result in flooding due to lack of capacity in the sewers and very large saline concentrations at the Dalmuir WWTW. In Figure 4.2 flow survey data from Section E is graphed showing clearly the large impact of the tide on the system.

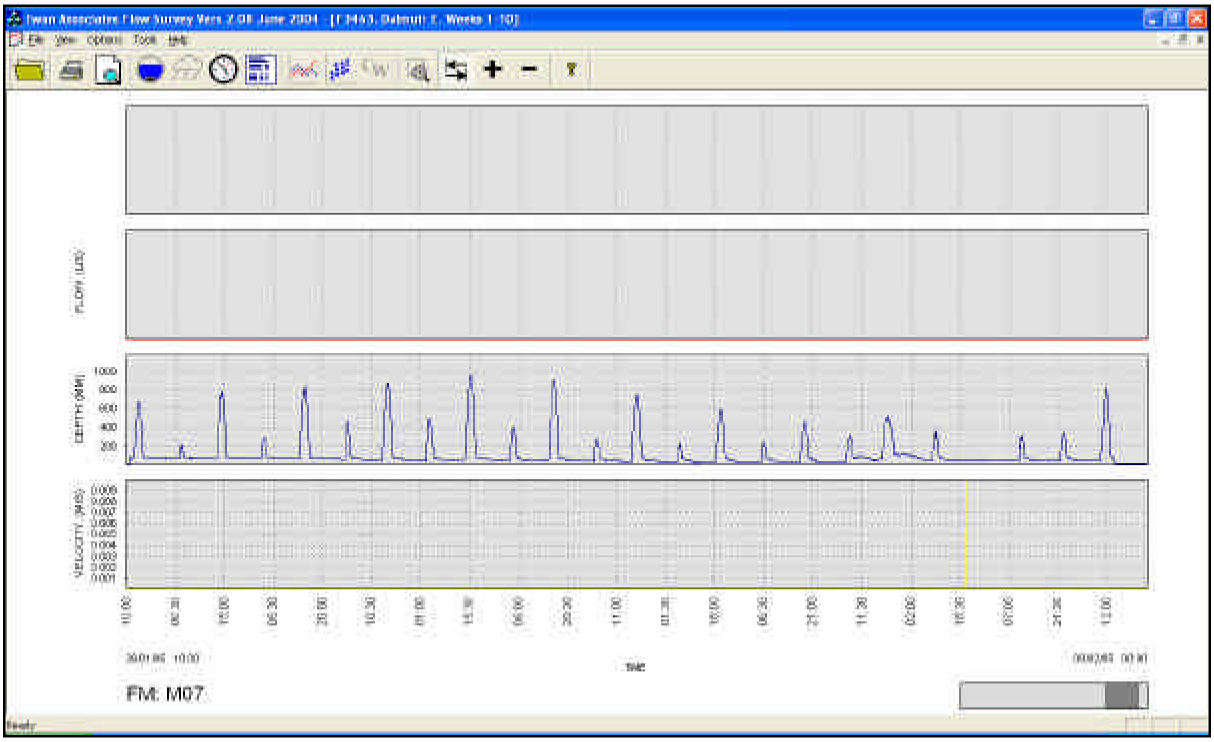

Figure 4.2 –Evidence of Tidal Inflows into the Dalmuir Sewerage Network

- Interaction with culverted watercourses. As part of the development of Glasgow, many of the traditional burns were culverted. In quite a few cases interaction between the culverted burns and the sewerage system were noticed with spills occurring in both directions. A good example of this is the culverted Moledinar burn, which has numerous points of interaction with the sewerage system. To get an indication of the interaction at one of these points, an ultrasonic depth monitor was installed in the burn as part of the short-term flow survey for Section A. Figure 4.3 shows a photo of the culverted watercourse, including the weir that control flow to the sewerage system and data from the depth monitor showing spill into the sewerage system.

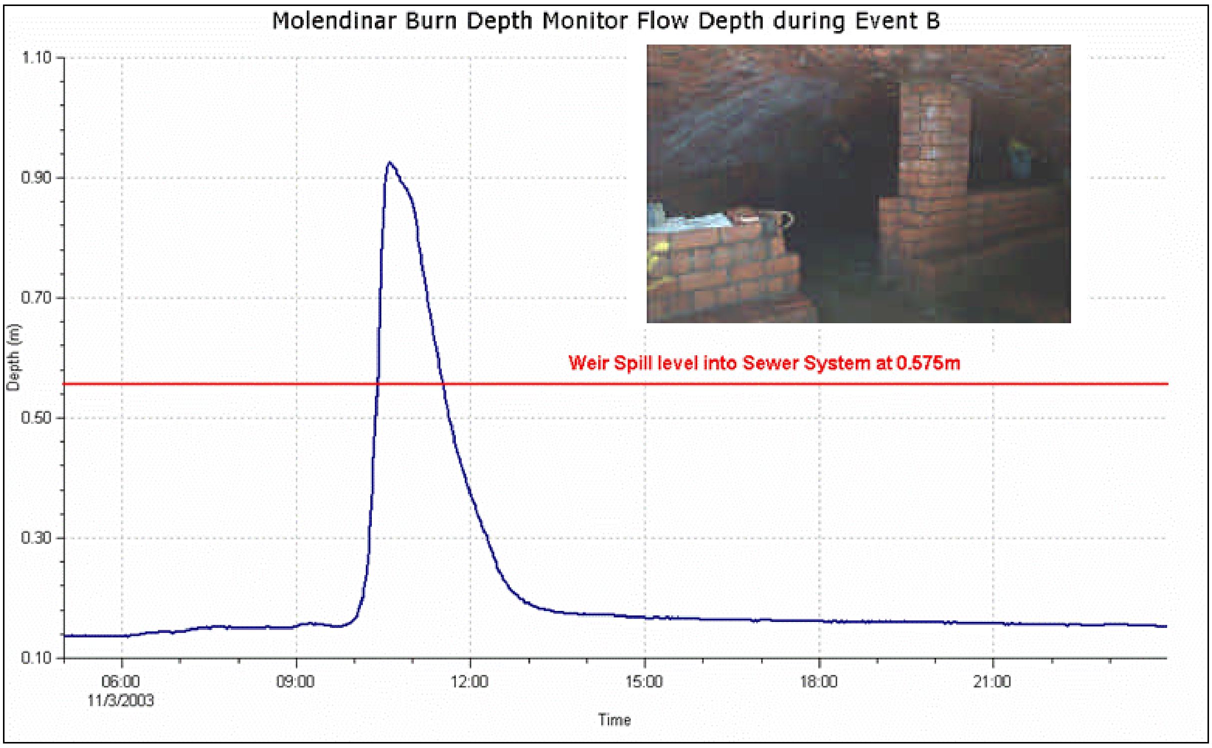

Figure 4.3 –Interaction of the Moledinar Burn with the Sewerage Network

After each of the eight individual sections was verified against their respective short-term flow survey, they were combined into a single global model. During this process an extensive exercise was done to remove all overlapping areas, include all missing areas and ensuring all parameters eg landuses and wastewater profiles were correctly applied in the global model. This global model was then tested against the long-term flow survey to ensure that the global model perform accurately over the whole of the flow survey period.

During the verification of each of the individual sections, it was noticed certain parts of the sewerage system are influenced by workings in different parts of the catchment. For example the flows into the Partick Pumping Station are heavily influenced by the workings at the pumping station. Since the penstock openings are controlled by the level of the wet wells and the level within the receiving sewer, final verification upstream of the Partick pumping station could only be achieved after each of Sections A, B and C were verified. To ensure a suitable level of verification was achieved at these sections influenced by workings at different parts of the catchment, the global Dalmuir model was then tested using the short-term flow survey and the relevant long-term flow survey points.

A crucial aspect of such a large DAP, is to provide a comprehensive model to deal with all hydraulic and pollution issues within the catchment, whilst limiting the model size for practical purposes in respect of usability / simulation times. To this end, the level of detail is high in driver areas, ancillaries, flow monitors and along main interceptors, whereas in less important areas, the model has been simplified to a much greater extent. The global model statistics can be viewed in Table 4.2.

Model	Nodes (nr)	Total CA (Ha)	Total Popn (nr)	PS (nr)	CSO (nr)	Bif'n (nr)	Landuses (nr)	W'water profiles (nr)	Trade profiles (nr)
Dalmuir Global	20051	8954	450,558	49	180	625	51	15	23

Table 4.2 – Global Model Statistics

5. System Performance Assessment Process

An essential part of the Dalmuir Phase 2 study, is the identification of deficiencies within the Dalmuir sewerage network. The system performance assessment process comprised out of the identification of the following deficiencies:

- Hydraulic deficiencies

FEH generated design storms were used to obtain the hydraulic deficiencies within the Dalmuir catchment. These hydraulic deficiencies were compared with historical flooding locations. Any unconfirmed flooding locations were investigated further either through site visits or through local catchment knowledge gathered during the study.

- Environmental deficiencies

The performance of each of the CSOs within the Dalmuir catchment was assessed in terms of spill settings, Formula A settings and spill frequency. The CSO spill frequency and its annual spill volumes were assessed by simulating a typical year's rainfall data as discussed below.

- Structural deficiencies

The structural data gathered as part of the Dalmuir DAP were used to identify all structural deficiencies within the catchment. This process was done in accordance with the "Sewerage Rehabilitation Manual".

- Operational deficiencies

Information gathered during the Dalmuir DAP was used to identify all operational deficiencies within the catchment. Sources of these deficiencies included SW Operations and the various data collection exercises.

- Other deficiencies

During the model build and verification process, it became clear that certain other types of deficiencies exist that don't fall in any of the above categories. These deficiencies were reported separately. Examples include the interaction of the sewerage system with watercourses and the tidal inflows into the system.

The long-term flow survey completed as part of the Dalmuir DAP proved to be a very useful tool for assisting in the system assessment process for such a large and complex catchment. Some of the more interesting ways in which the long-term flow survey assisted in the assessment process, were as follow:

- Calculation of design NAPIs

The two and a half year's rainfall data gather from the Dalmuir DAP long-term flow survey were simulated though the model. From this the annual variation in NAPI could be calculated. Based on this information realistic values of NAPI were obtained for used in the assessment process.

- CSO spill frequency assessments

A detailed analysis of the usability of the long-term rain gauge data for the CSO spill frequency assessment was done. This data for each of the rain gauges were compared to their respective SAAR values to eliminate rain gauges which annual rainfall totals don't match well with their recommended SAAR value. The suitable rain gauges were then compared with available historic daily rainfall totals and with the stochastically dataset created as part of the Glasgow Strategic Drainage Plan. An example of this rainfall depth threshold comparison for some of the long-term rain gauges can be seen in Figure 5.1.

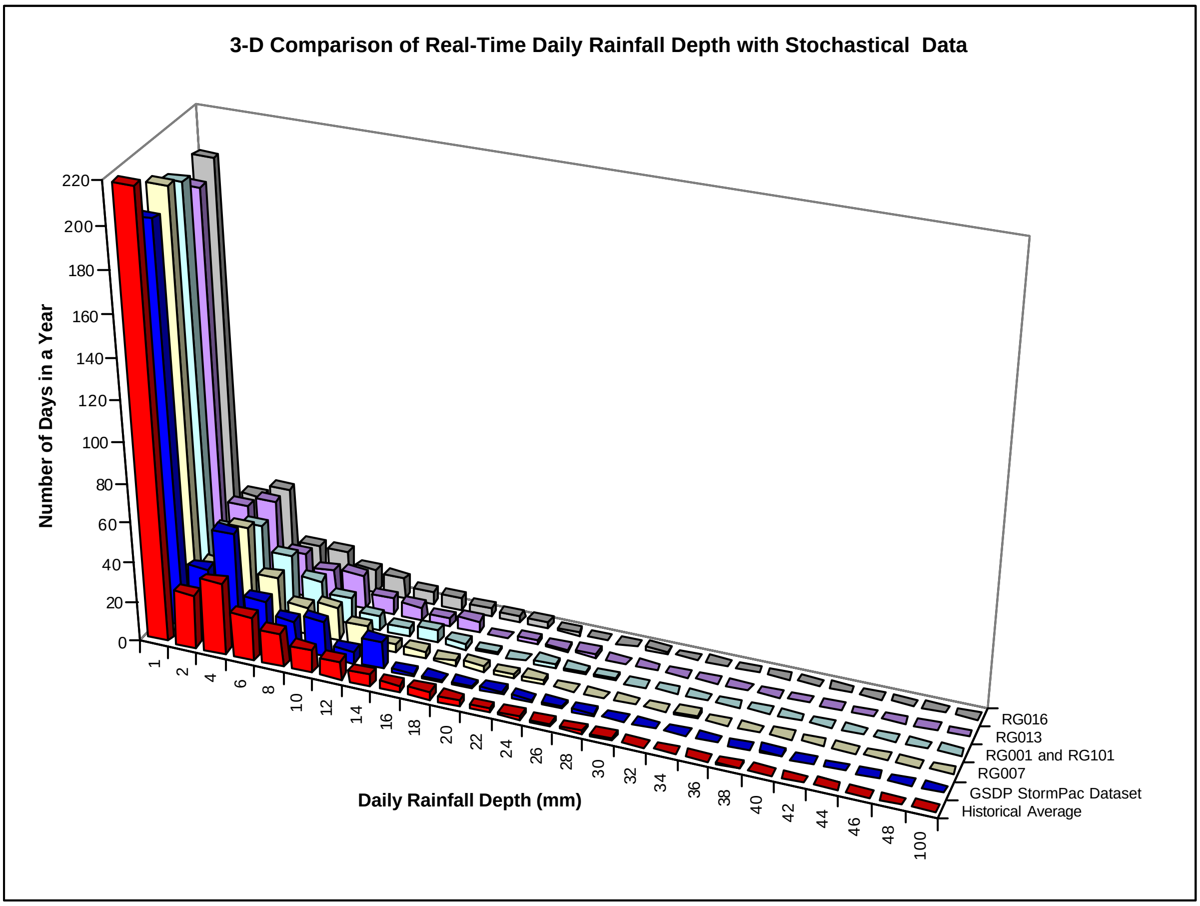

Figure 5.1 – Example of a Daily Rainfall Depth Threshold Analysis

This analysis of the long-term rainfall data indicated that the data collected during 2004 were of a "typical" year for 10 of the rain gauges and would therefore be suitable for the CSO spill frequency assessment. Some of the advantages of using the long-term flow survey data for the spill frequency assessment are as follow:

- Actual two-minute rainfall data are used. If this data compared well with a "typical" year it is more appropriate to use actual data instead of stochastically created data.
- By using various rain gauges distributed over the whole of the catchment, an allowance for spatial variation can be made. This is especially important for such a large catchment.
- NAPIs and the change in catchment wetness can be modelled more correctly using actual rainfall data.

- <u>Storm movement and spatial variation</u>

An assessment of storm movement and spatial variation through the Dalmuir catchment was made by simulating the long-term rainfall data through the model. All daily rainfall totals more than 5mm were used in this assessment.

- <u>Infiltration</u>

Infiltration is a major source of flows into the Dalmuir WWTW. It is believed that up to 60% of the dry weather flow is the result of infiltration. A detailed infiltration assessment was carried out using the long-term flow survey data and the infiltration rates used during the verification of the individual sections or DAPs. A dimensionless factor showing the annual variation of infiltration was calculated using key long-term flow monitors (refer to Figure 5.2). Since each of the sections and individual DAPs were verified during different times of the year, this dimensionless factor could be used to scale baseflows up or down to reflect summer or winter conditions.

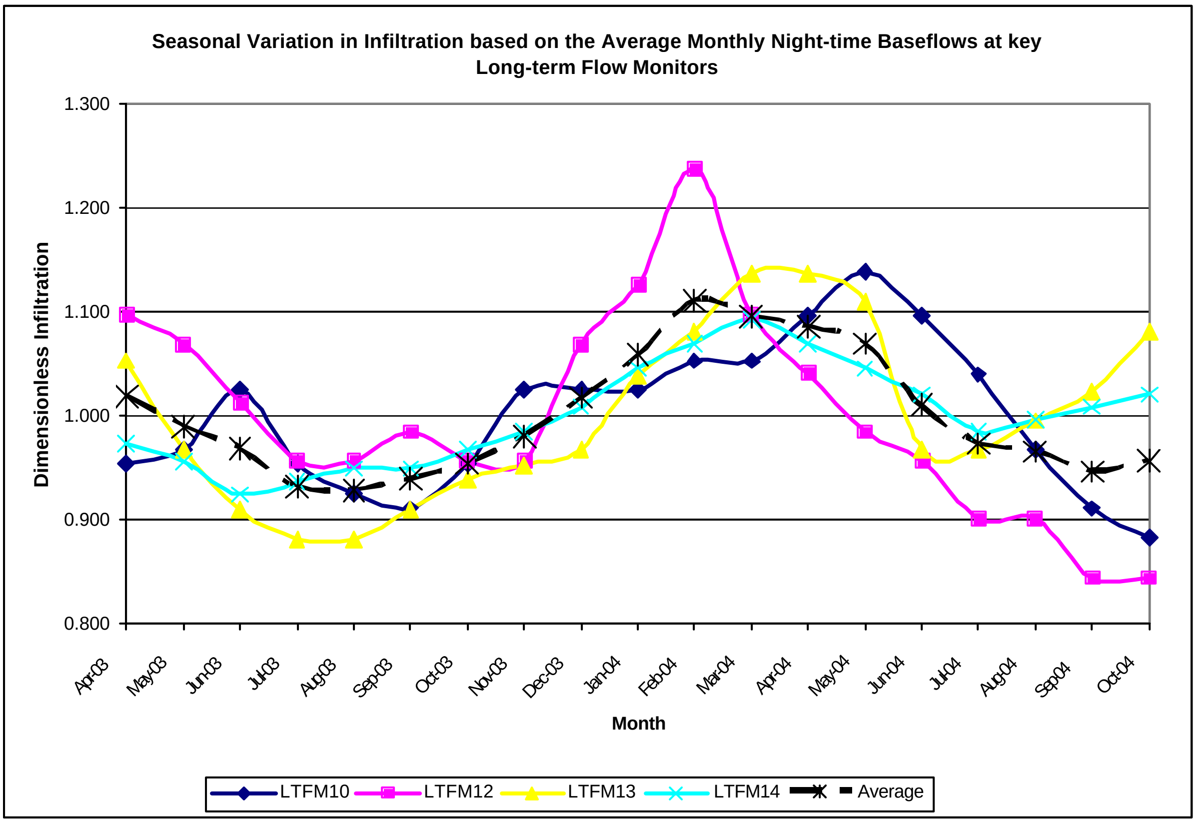

Figure 5.2 – Graph of the Annual Variation in Baseflows

- Typical flow conditions along main sewers

The long-term flow monitor data were assessed in terms of "typical" flow conditions within the main sewers, thereby obtaining flow rates that are achieved 95% of the time. These flows were then used to assess parts of smaller, local sewerage systems within the Dalmuir catchment which are influenced by the downstream flows within the main sewers. This was necessary since a small sewerage system connecting quite far down the system into the main sewers, would not be necessary tested correctly using the typical smaller duration design storms since inappropriate downstream flows conditions could exist.

6. Conclusion and Recommendations

Being part of such a large and complex DAP, highlighted some important facts. These were as follow:

- If a large data collection exercise is planned, it is useful to have pro-active control of the data collection aspects. It is efficient to have a dedicated data collection team which can ensure close liaison with the different parties, strict quality control and the timely delivery of data. Such a pro-active control will decrease the risk of data collection problems having an impact on the delivery of the project.
- It is important to ensure potential data collection problems are highlighted beforehand. If data collection will be difficult due to certain aspects eg traffic and pedestrian control in the City Centre

or tidal impact on the sewerage system, it is worthwhile to do extra preparation for these surveys. This will ensure maximum delivery of data in a timely fashion.

- When a large model, comprising of different sections being done by different modellers, is planned, it is useful to have model build and verification procedures. This will assist the different modellers in building the models and ensure that the different sections are compatible with each other.
- The long-term flow survey proved to be a very useful source of information for understanding the catchment behaviour over a longer term. Key aspects in the performance of any sewerage system eg infiltration levels and storm movement, can then be assessed to understand the catchment much better.
- When doing such a large DAP over a long period, it is very important to ensure that all of the knowledge gathered by all of the different parties is not lost. Good reporting and sharing of knowledge are key instruments to ensure knowledge is not lost.

7. References

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8. Acknowledgement

Ewan Goup Plc would like to thank Scottish Water for allowing the use of the project and its results in the preparation of this paper.