Prestwick model cast study: the benefits of using separate winter and summer models

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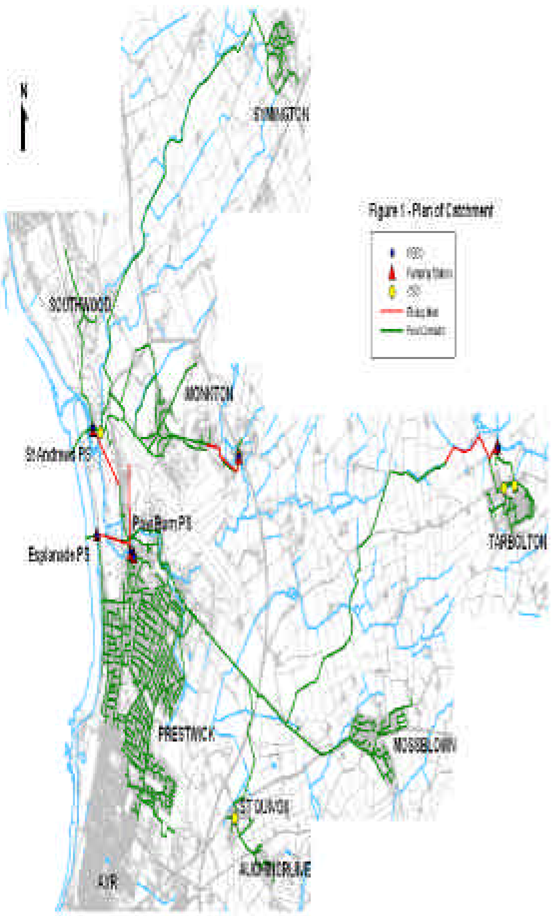
1 Introduction

WS Atkins Water (WSA) were commissioned by West of Scotland Water (WoSW) to carry out the Prestwick Drainage Area Study (DAS) in September 2000. Prestwick was undertaken as a priority phase 1 catchment within the West of Scotland Water's larger Drainage area Planning programme because of Bathing Beach Directive Issues (EEC Directive 76/160EEC 1976) The Prestwick Bathing Beach was one of the original 23 designated as such by the Scottish executive in 1987. There are currently a total of 60 designated bathing Beaches in Scotland that must comply by June 1st 2003. Failure to comply by that date will result in fines of £67,000 per day that will be applied retrospectively. Prestwick is considered 'at risk' with a number of bacteriological failures over the last ten years at the 'mandatory' criteria. Preswick also has a number of recorded flooding incidents that require investigation. The Prestwick catchment is located on the west coast of Scotland immediately to the north of Ayr and to the south of Troon. The Prestwick drainage area contains the following subcatchments, and these are highlighted on Figure 1.

- Prestwick Town.
- Symington, Monkton and Southwood to the north.
- Tarbolton, Mossblown, St Quivox and Auchincruive to the east.

These all drain, by gravity or pumped flow, to the Pow Burn PS in Prestwick town. This terminal PS discharges to the Meadowhead WWTW at Irvine to the north.



A total of 14 overflows (CSOs and PSEOs) exist within the catchment, though four can be considered more important due to the fact they discharge directly into coastal bathing waters, or into receiving waters that due to their close proximity to the coast, have an effect on the water quality of the bathing waters. These four key overflows include the Esplanade PSEO, St Andrews PSEO, St Andrews Caravan Park CSO and the Pow Burn PSEO / CSO. As a result the Prestwick DAS was focussed on providing a modelling tool suitable for assessing spill performance at these, and other, overflows.

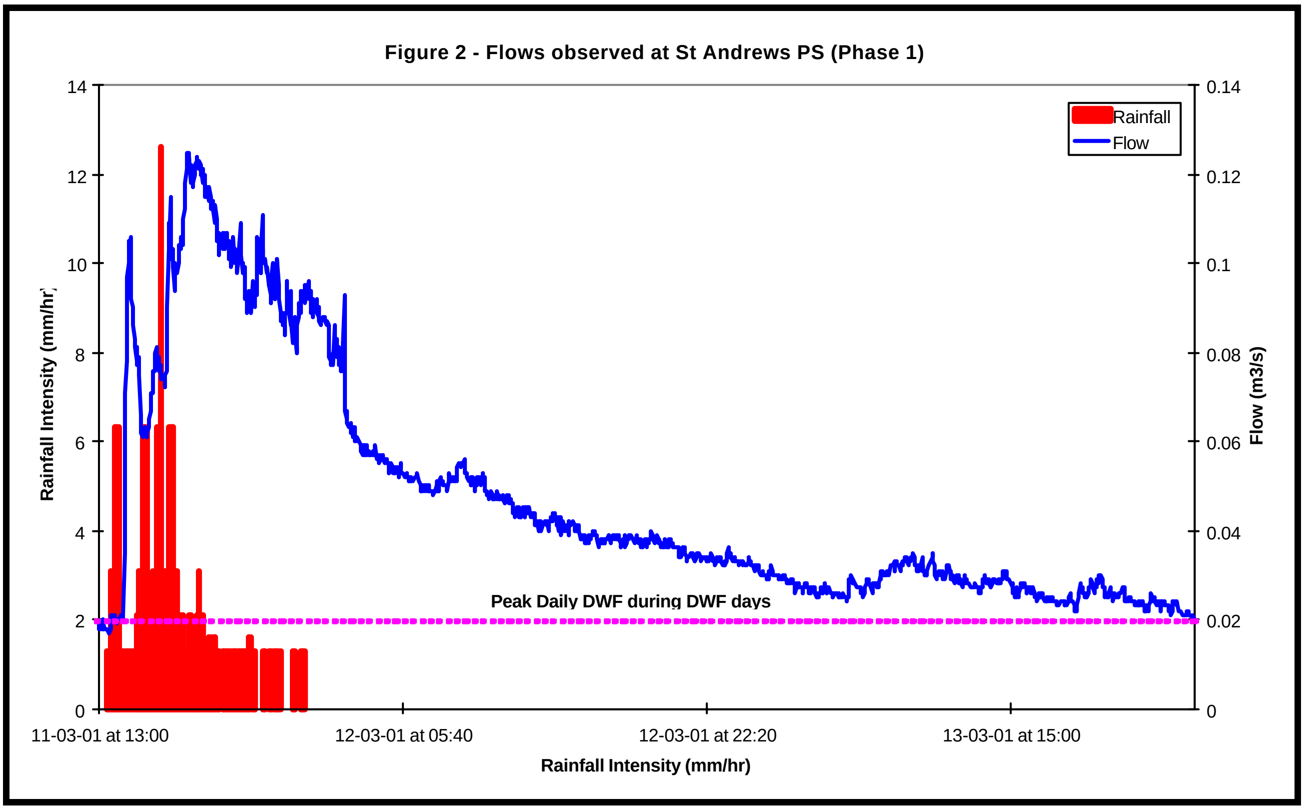
There is strong evidence throughout the West of Scotland area, from long term flow recording at treatment works and other shorter term flow surveys, that illustrates the potential variation in catchment response throughout a typical year. We have traditionally lacked the opportunity or focus to investigate these effects relying instead on conservative allowances or more often snap shot verifications based on the short term flow survey that can be as short as a 6 week period. Prestwick with its longer term flow survey offered an excellent opportunity to not only understand and model seasonal variations in catchment response but to demonstrate the importance of such considerations when tackling seasonal issues such as bathing beaches. Preswick will require of the order of £1.5m investment to meet the derived intermittent discharge criteria of three CSO spills in a bathing season. There are opportunities therefore for better understanding and better Engineering solutions.

2 Flow Survey

For a number of reasons, the flow survey for the DAS was carried out in two phases. The ‘Phase 1’ flow survey consisted of 18 flow monitors and five raingauges located throughout Symington, Monkton and Southwood, and terminating at the St Andrews PS. The flow survey was installed March 2001, and flows were monitored for a total of 16 weeks. A ‘Phase 2’ flow survey was subsequently installed throughout the rest of Prestwick in May 2001, and flows were monitored for a period of nine weeks. In total, 39 flow monitors and 15 raingauges were installed throughout the catchment. Five flow monitors (and raingauges) remained in the St Andrews area to allow flows from the now verified northern catchments to be assessed. Not only was it essential to measure the inputs from the St Andrews PS to Prestwick for verification purposes, but it was anticipated that this would also provide a useful comparison of infiltration levels between the winter / spring (Phase 1) and summer (Phase 2) conditions

3 Evidence of Rainfall Responsive Infiltration and Slow Response Runoff

During the Phase 1 St Andrews flow survey and verification stage, it became evident from the measured data that there was a significant amount of slow response pervious runoff or rainfall responsive infiltration flow. This was clearly observed at the downstream flow monitor located at the St Andrews PS, through which all the flow from Symington and Monkton passes. This is clearly highlighted in Figure 2.



The typical peak DWF during the verification DWF days was observed to be approximately 20l/s. It is clear to see from Figure 2 that following the rainfall event there is significant inflow into the system a considerable time after the event has passed, resulting in a prolonged recession limb on the hydrograph . The 'normal' peak DWF level is only reached after two days. During the final 24 hours of the presented data it is possible to see a DWF profile, however this appears to be 'shifted' upwards by approximately 15 l/s. The trunk sewers from both Symington and Monkton pass through 5.5km of rural land, and a delayed response causing the apparent rainfall responsive baseflows observed may be due to two possible mechanisms:

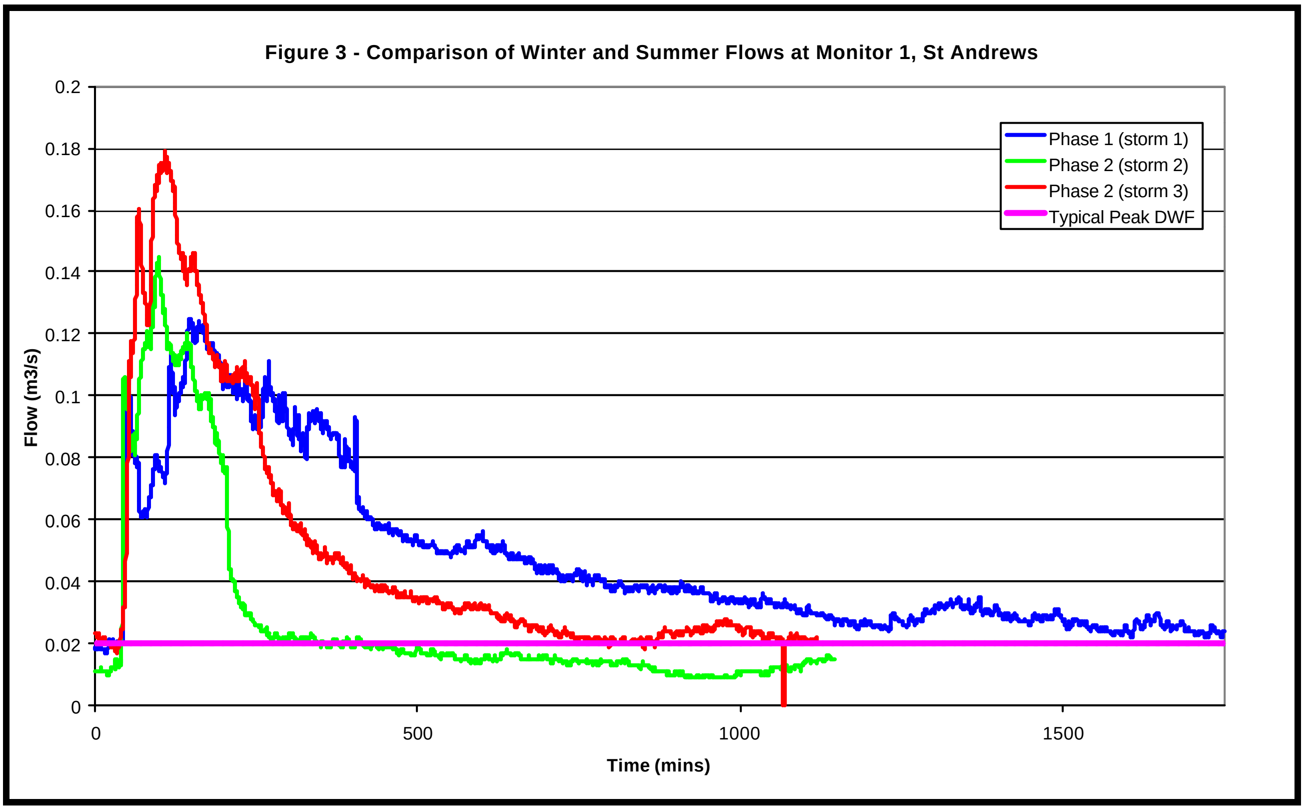
- Slow response runoff – The generation of runoff from fields and other similar pervious surfaces. Immediate runoff is not observed, as the initial rainfall has to wet and saturate the soil before any runoff is generated. Much of the runoff may be generated in fields a large distance from the point of entry (gully on a track) to the sewer system, and may therefore have a significant time of entry to the sewer.

- Land / field drains connected to sewer – these may add flow directly to the sewer system, but at a reduced rate.

- Rainfall responsive infiltration – This is the increase in infiltration into the sewer system associated with an increased saturation of the soil, due to a rainfall event. A delayed response to the sewer system may be observed due to the slow travel time of flow through porous media such as soil.

Due to the lack of detailed field data, it is impossible in this case to proportion the delayed runoff observed into either slow response runoff or rainfall responsive infiltration. It is likely, though, that all these processes are operating in tandem along the trunk sewer from Symington and Monkton to St Andrews PS.

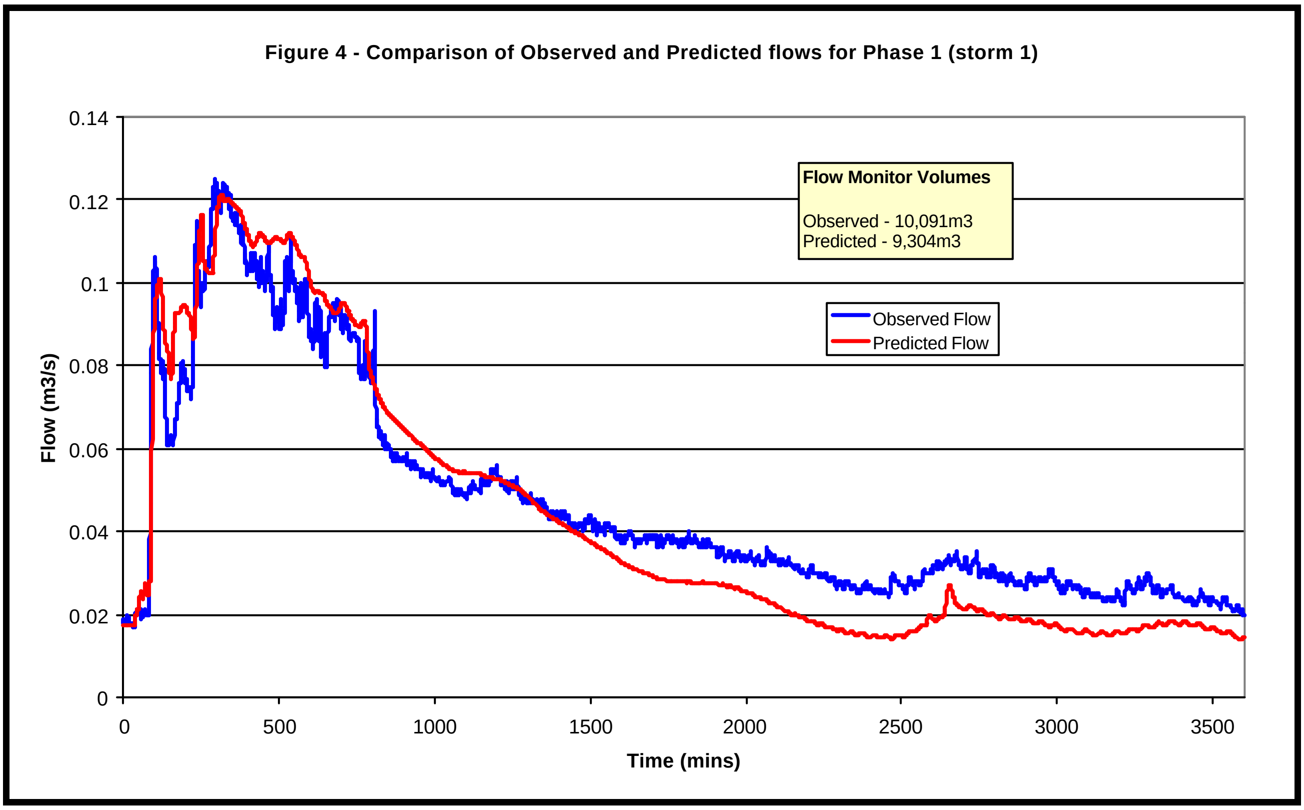
During the Phase 2 verification it became evident that the processes that caused the observed slow response runoff during the winter / spring (Phase 1) period do not occur to such a large extent during the summer (Phase 2) in the St Andrews catchment. The recession limb of the summer flows was observed to be much steeper than the winter flows and the flow response appeared to be more 'flashy' with the total measured flow volumes much smaller. This is well highlighted in Figure 3, which shows the difference in recession between a verification event from Phase 1 and a verification event from Phase 2. It can be clearly seen that the summer event returns to a condition similar to DWF much quicker than the winter event.



4 Verification of Model(s)

During the verification of the Phase 1 model, the New UK runoff model was utilised to account for these delayed inflows and additional area, utilising new pervious runoff surfaces, was introduced to the model. This slow response runoff area was modelled as having a delayed routing coefficient to represent the two possible mechanisms that may be adding flows to the system after the rainfall event has passed, though no attempt was made to quantify the relative amount of each. In total, nearly 300 hectares of slow response area were added to model to represent runoff or rainfall responsive infiltration from the fields surrounding Symington and Monkton, and the fields though which the Symington trunk sewer passes. It is interesting to note, however, that due to the low routing coefficient used to represent these surfaces, 10 hectares of pervious area equates to a peak runoff of approximately 1 l/s.

The addition of this pervious area throughout the St Andrews catchment resulted in a good verification of the model in this area. Figure 4 shows the observed and predicted flows at the most downstream monitor at St Andrews PS. It should also be highlighted that pump logger data at the St Andrews PS also indicated significant volumes of flow, confirming the accuracy of the data measured at this key flow monitor.

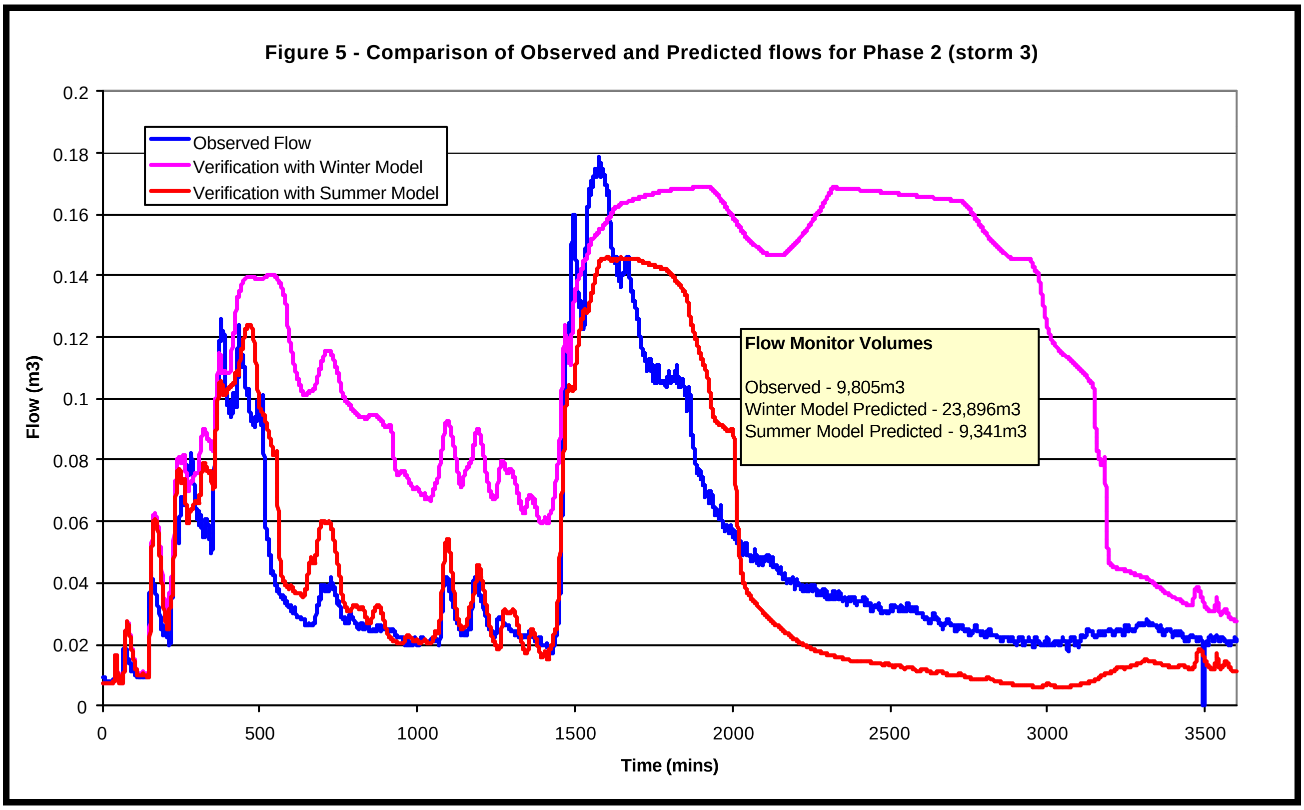


However, when the same model was simulated with the summer rainfall, the model significantly over predicted flows in the St Andrews catchment. This was attributed to the large amounts of slow response area added as part of the winter verification. Despite the Phase 2 verification events having markedly reduced API30 values (due to the summer antecedent conditions) the model significantly over predicted flow in the catchment for the Phase 2 events. Test simulations were carried out with further reduced API30 values, and the model continued to significantly over predict flows. This indicated that whilst the New UK runoff model was applicable for modelling the slow response runoff, or representing rainfall responsive infiltration for the winter condition, it was not applicable for the summer condition. This is shown in Figure 5.

The implications of this are the possibility of over designed improvement schemes, and thus uneconomic capital schemes. As a result, it was agreed with WoSW that the best approach to overcome this obvious seasonal effect with regard rainfall responsive infiltration / slow response runoff would be to utilise two models with one representing the winter condition, and the second representing the summer condition. The main difference between the winter and summer models being the amount of additional contributing pervious area representing the surrounding fields. In effect, 95% of the additional New UK runoff area added to verify the Phase 1 model was removed to verify the Phase 2 model. Following the removal of the additional slow response area, and 5l/s of infiltration, the Phase 2 summer model predictions matched those observed during the flow survey.

The use of this methodology requires an acceptance that pervious runoff processes operate quite differently across the seasons. For example, in the winter the soils may readily saturate due to cool conditions and higher groundwater levels. This increases the possibility of both slow response runoff from pervious surfaces and rainfall responsive infiltration. In contrast, in the summer months the higher temperatures and low groundwater levels, lead to the soil being less likely to saturate and thus less likely to produce runoff or promote infiltration. Soil water is perhaps more likely to infiltrate deep into the ground and thus not be available as an inflow into the sewer system. This is even more likely should the soil crack due to drying, as this would increase the soils infiltration capacity and thus convey more flow to deep lying stores. This argument counters the notion that in the summer pervious area acts as an impermeable surface, due to soils being ‘baked’. Similarly, changing amounts of vegetation through the seasons may affect the pervious runoff or infiltration capacity of the soil. Rainfall may be more suspect to higher evapotranspiration in the summer due to more dense vegetation (prevents direct contact with soil, and increases surface area for evaporation) and higher plant productivity (utilises more water through photosynthesis).

There are many variables at play that will influence the runoff characteristics of the catchment and it would be too simplistic to reduce this to a winter / summer difference. For example, a wet summer period may produce runoff characteristics similar to the winter conditions. However, very clear differences have been observed and this is the key point to note as it has significant ramifications for system performance analyses and design approaches.

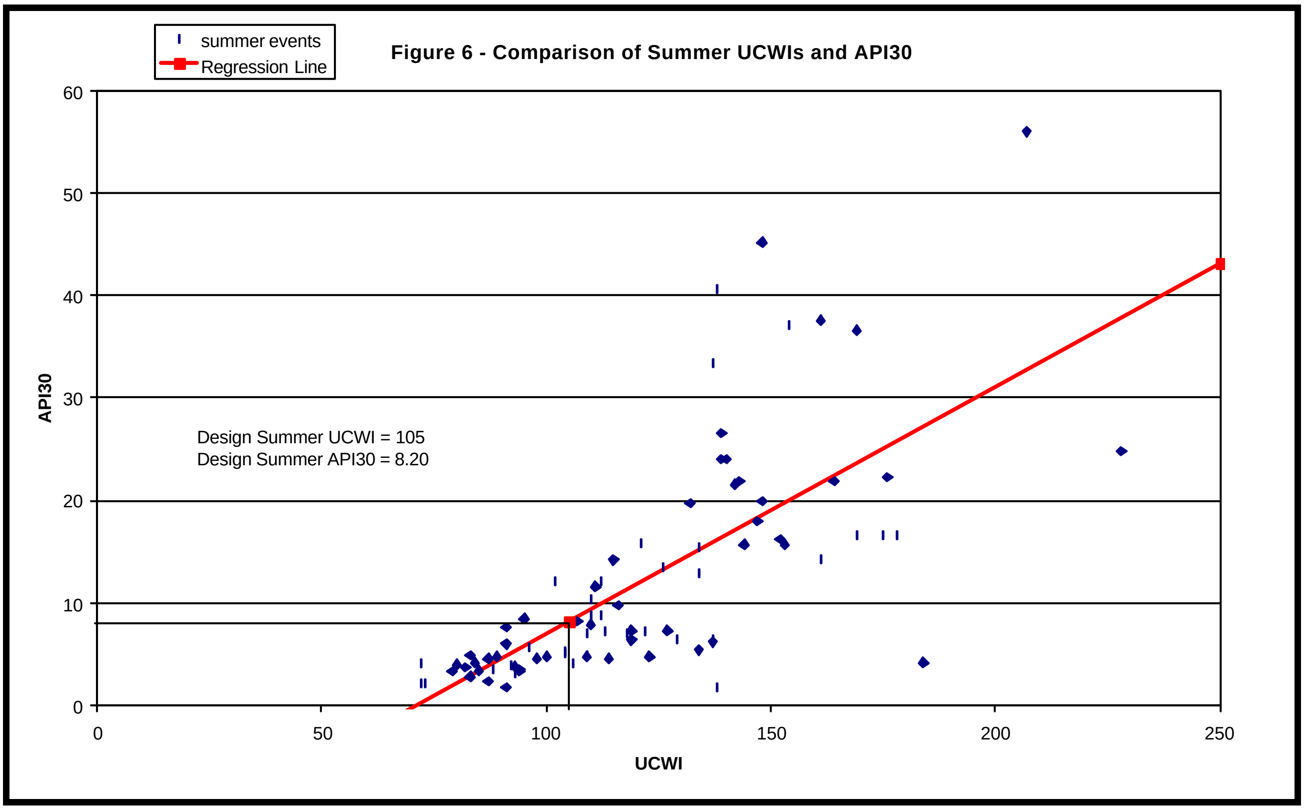


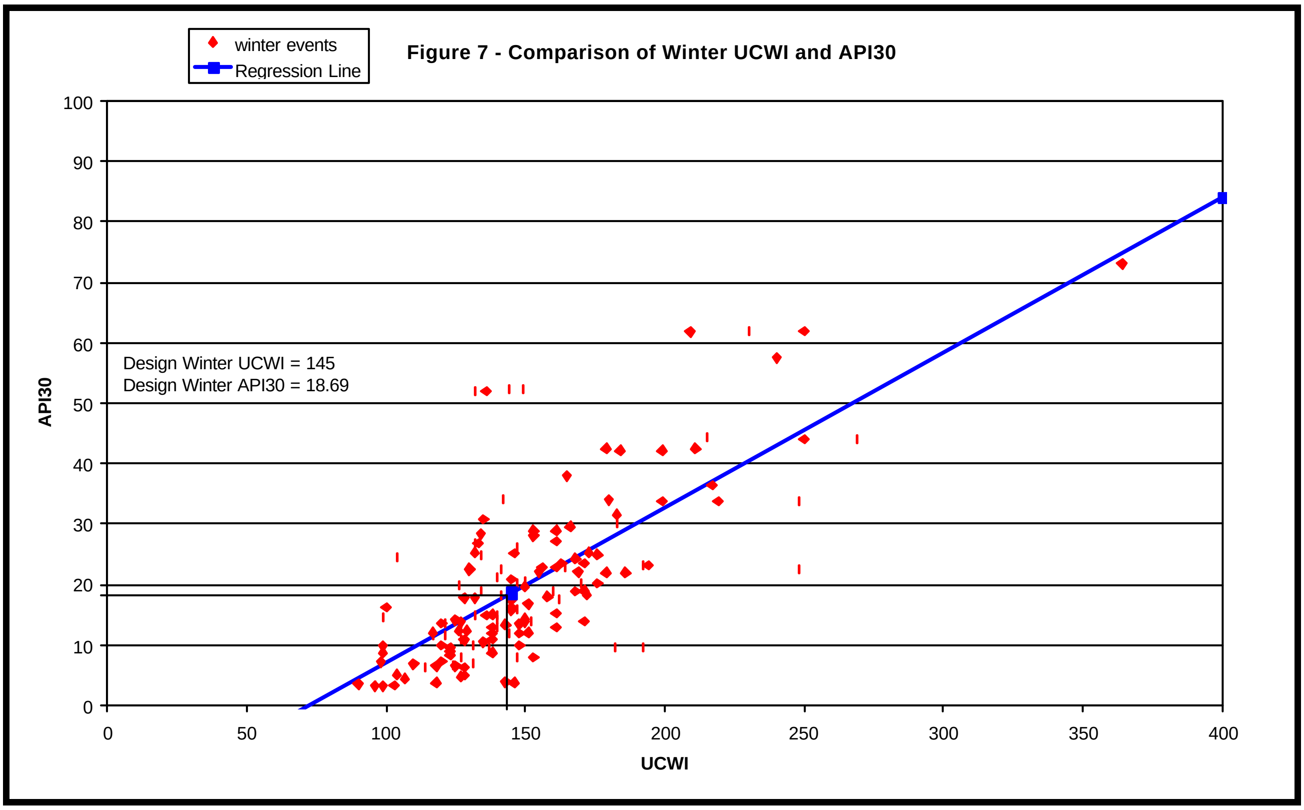
5 Design Criteria

Whilst this approach utilises different and winter summer models, the study has identified distinct seasonal trends relating to baseflows after a storm event. The extended flow survey has allowed a distinct comparison to be made between both the summer and winter condition. In many studies, flow surveys are isolated to a six or seven week period, and as a result do not measure any changes in the sewer response relating to the seasons. This obviously has important implications on the use of the model after design. For example, a model based on only a summer flow survey may not replicate the high winter base flows, and thus improvement schemes (especially storage) may be under designed. In contrast, a model developed only on a winter flow survey may tend to oversize the required improvement schemes, due to the dominance of the higher winter baseflows.

As this approach relies on the use of two models (winter and summer), a number of important issues need to be addressed for design. Firstly, should design simulations be carried out on the winter or summer model? The choice of this obviously depends on the catchment drivers. For example, flooding schemes should perhaps be developed on the worst case scenario (i.e. the winter model). In contrast, CSO spill frequencies can be assessed on either model. In the case of Prestwick, improvement schemes to address the required 3 spills per bathing season criteria were developed on the summer model. Alternatively, where improvement schemes were developed for the requirement of 10 spills per year, a combination of the winter and summer models was used, with the bathing season rainfall events simulated with the summer model and the remaining events from an annual series simulated with the winter model. It is acknowledged that this is an ‘all or nothing’ approach, as no consideration is paid to storms that are in spring or autumn. For example, should a storm in late April or early October be simulated with the summer or winter model? Similarly, this approach would not account for a wet summer, where infiltration and baseflows may persist at higher levels more akin to the winter condition. In this case, should spill frequencies be assessed using both models and take an average? As is highlighted, the choice of model is not simple, and different seasonal scenarios would require different base models. Whilst, it is not practical to create numerous base models to represent different seasonal phases, using a summer and a winter model does allow an assessment to be made of possible best and worst case scenarios and allow sensitivity analyses to be carried out.

Secondly, as the New UK runoff model has been utilised, the issue as to what design API_{30} values to use should be addressed. Many studies have not utilised the New UK runoff approach due to lack of clear guidance on the required design parameters. For the Prestwick case, a winter and summer design API_{30} value was estimated by correlating the calculated API_{30} and UCWI value from the stochastic time series of rainfall used in the hydraulic analysis of the catchment. This correlation (highlighted in figures 6 and 7) was not ideal, but provided a useful indication of any trends in the API_{30} values throughout the year. The design UCWI (from the Wallingford Procedure) was used to produce a design API_{30} value based on this correlation. Figures 6a and 6b show these correlations used for the summer and winter condition.





It is interesting to note that the original Wallingford Procedure calculated design UCWI values as a function of the median UCWI for a number of storms at a number of locations. In order to validate the sensibility of the design API_{30} value obtained by this approach, the summer median and winter median API_{30} value was also calculated. These were calculated as 7.25 and 16.8 respectively, which is similar to those obtained by the correlation method. The exact methodology by which to determine the design API_{30} value is not the focus of this paper. However, it is important to highlight that there are ways of calculating a design API_{30} value, which are no less accurate than the methodology used to calculate the design UCWI values in the Wallingford Procedure. It is anticipated that there will be the results of a number of studies relating to design API_{30} values presented later this year.

6 Conclusions

A number of general conclusions can be drawn from the methodology utilised in the Prestwick DAS. Many of these conclusions are directly transferable to other studies and these include:

- Are ‘one size fits all’ models always applicable? Catchments where significantly different inflow process dominate between seasons may require models for different seasons. It may not always be possible to calibrate a single runoff model to represent both the winter and summer condition.

- Seasonal effects should be assessed, or at least considered, at the start of a project.

- Where it is considered that seasonality may cause different processes to operate, then long term data is required to accurately understand the catchment characteristics. This may be in the form of long term flow surveys, or CCTV surveys carried out in both the winter and summer. Long term flow surveys may be required for a number of years, rather than the traditional 3-4 months.

- Long term flow data from the catchment STW should be used in every study to help define seasonal processes. This should, where available, provide an initial insight into infiltration trends over the year, and significant variations in hydrograph recession over the year.

- This approach allows a more accurate risk assessment to be carried out in relation to improvement scheme design, particularly in the case of storage. Do we use the worst case winter model (with its larger capital cost scheme), or the smaller summer model schemes? This is obviously a choice for the water company or authority, depending on its own policies, but now a choice can be assessed based on more detailed model predictions.

- And finally, how confident are you in sewerage storage schemes that you recently completed or are currently designing?