MACRO MODELS – DEVELOPING THE BIGGER PICTURE

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1 Introduction

Macro models, as the name suggests, cover large catchments or drainage areas. Historically, these large models were frequently of a very coarse resolution, due primarily to limitations with modelling software relating to the number of nodes that could be represented within a single model. In a similar fashion, computer processing technology was not adequate to create very high resolution models over large areas. Despite these limitations, numerous successful studies have been carried out where low resolution sewer models have been developed as a planning tool for very large catchment areas, often on the full city scale.

The last five years has seen a rapid advancement in both computer processing technology and hydraulic modelling software, especially with the development of InfoWorks and its ability to operate with much larger databases. The emphasis today in sewer modelling studies is much more focused on limiting the amount of simplification to hydraulic models, and drainage area models frequently contain all public sewer manholes, even where the sewers are of small diameter. As a result, the majority of DAP models developed are considerably detailed, and are more representative of Type III models in relation to the number of nodes, rather than the base requirement Type II.

With river scale UPM studies or coastal bathing beach studies, there can be the requirement to combine a number of DAP models so that the cumulative effect of intermittent and continuous discharges from a number of catchments can be assessed. This has led to the development of a new type of macro model, which is based on a combination of DAP models. These macro models not only cover a large catchment area, but also are highly detailed containing a large number of nodes. The benefits of being able to analyse the performance of large sewer systems in such detail is obvious, given the reduction in predictive accuracy of highly simplified models. This is especially the case around CSOs, which through water quality issues are frequently the main driver for developing these large catchment models.

This paper will use the Meadowhead catchment as a case study, which involved the development of a 14,000 node macro model, covering ten individual towns and numerous villages. The paper will identify the technical issues and procedures that were raised in developing this macro model, through the combination of individually verified DAP models, and should be treated as a possible user guide for future studies. Combining various DAP models from a number of different sources, is not a straightforward process and without careful attention there are a number of factors can cause previously verified DAP models to form an unverified macro model.

2 The Catchment

In 2002, Scottish Water (SW) commissioned WS Atkins Consultants (Atkins) to construct a macro model for the Meadowhead WWTW catchment, based on all the available existing hydraulic sewer models. The main driver for constructing such a model was to assess the compliance of the bathing beaches along the Firth of Clyde from Irvine Bay to Ayr Bay with the Bathing Waters Directive, with specific attention to the various intermittent CSO discharges, and the continuous discharges from the Meadowhead WWTW. However, despite there being over 150 overflow locations within this drainage area, there is considerable uncertainty as to whether periods of non-compliance on the bathing beaches are due to discharges from the sewer system or due to 'other', possibly more natural, inputs from the River Irvine.

The Meadowhead catchment is situated approximately 35km south west of Glasgow, and comprises of the towns of Annick Water, Ayr, Barassie, Irvine, Kilmarnock, Prestwick and Troon, and the villages of Crosshouse, Knockenteiber, Dundonald, Springside, Dreghorn, Darvel, Newmilns, Hurlford, Galston, Mossblown, Tarbolton, Monkton, Symington, Drybridge and Gatehead (see Figure 1). The catchment covers an area of approximately 62km^2 and lies within the range of 0m to 150m above mean sea level. The total catchment population is 190,000 people. The major watercourses within the catchment are Annick River, River Lugton, River Garnock, River Ayr, and River Irvine.

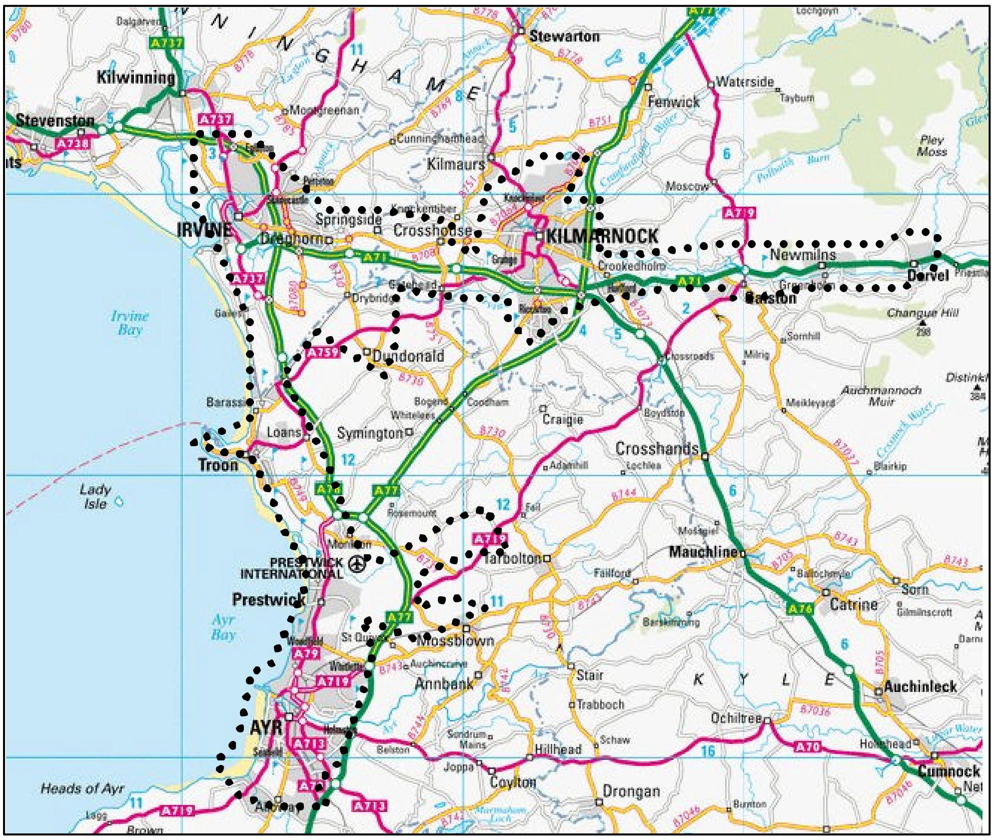

Figure 1 – Drainage Catchment Boundary

The catchment is predominantly combined, and historically, the majority of the catchments discharged directly to the sea with only preliminary treatment. This included the inland town of Kilmarnock, and adjacent villages, which discharge towards the coast via the Irvine Valley Trunk Sewer (IVS). The Meadowhead WWTW was constructed at the lower end of the IVS in the 1980's to provide preliminary treatment for approximately 6m^3/s. In addition, flow from many of the coastal towns (Ayr, Prestwick, Troon, and Irvine) was diverted, via large terminal pumping stations, to the Meadowhead WWTW. In 2001, a PFI scheme was constructed at Meadowhead WWTW to provide secondary treatment for 2.147m^3/s of the flow entering Meadowhead WWTW. All flow from Meadowhead WWTW, whether it has full secondary treatment or only primary treatment, is discharged to sea via the Gailes PS.

There are no hydraulic overflows at the Meadowhead WWTW; however there are overflows at all the terminal PSs, and numerous CSOs in the gravity system associated with the IVS. It is the potential cumulative effect of these CSO discharges, and any treated flows, on the water quality (in terms of Faecal Coliforms) at the various bathing beaches along the Ayrshire Coast. In order to carry out a thorough investigation of the impact of these discharges, an integrated modelling methodology was developed whereby a detailed sewer model would be utilised to determine the spill volumes from the CSOs, a bespoke river model (developed by Hyder Consultants Ltd) would be utilised to convey these flows to the coast where appropriate. Finally, a 3-D marine model (developed by Babtie Group) is to be used to assess the dispersion and impact of these discharges and pollutants on the bathing beaches. This paper will focus only on the development of the first step of the process, which is the sewer macro model. No attention will be paid to the river or marine models, as this stage of the process is still ongoing.

3 Base Sewer Models

As part of the SW DAP process, verified hydraulic sewer models were available for all catchments within the Meadowhead drainage area except Ayr and Troon. A rough cut unverified planning Phase model and an eight year old verified Wallrus model were available for Troon and Ayr respectively. Due to time constraints, it was necessary to utilise these models, though DAP studies are currently ongoing for these catchments. The revised models will be included within the macro model when completed. Table 1 details the various base models utilised within the macro model.

Model	Model Status	No. of Nodes	Population	Source
Annick Water	Verified DAP	1,695	17,719	Hyder
Ayr	Wallrus	1,362	34,722	SW
Dundonald	Verified DAP	285	2,359	Ewan
Irvine	Verified DAP	851	22,748	Hyder
Kilmarnock and Upper Irvine	Verified DAP	5,250	62,121	Atkins
Lower Irvine	Verified DAP	1,309	6,716	Atkins
Prestwick	Verified DAP	2,155	25,110	Atkins
Springside and Dreghorn	Verified DAP	175	2,830	Ewan
Troon	Planning Phase	849	15,303	Ewan
Total	**-**	**13,931**	**189,628**	

Table 1 - Base Models used to construct Macro Model

4 Construction and Testing of the Macro Model

All DAP models had been verified against a suitable number of flow monitors, and further flow survey and verification of the macro model could not be justified at this stage. A procedure was developed for combining the models to ensure the verification status of a DAP models was not compromised during the construction of the macro model. This involved simulating the model at frequent intervals during the combing process and checking that the predicted flows and depths for a specific storm did not change. This checking procedure was considered vital to eliminate human error, due to the large amounts of data that were being copied, deleted and pasted between the models.

Model Review

Following the initial model retrieval from the various consultants, a review was carried out for each model to briefly assess its suitability and to identify any outstanding issues that future users of the macro model should be aware of. This final point may seem rather un-important, but a frequent failing of 'second' users of a model following handover from another source is the failure to identify limitations within that model. Second users frequently ignore these warnings and blindly use a model, assuming it is adequate in all areas. Other than the Ayr and Troon models not being of the required standard, the review highlight significant variations in infiltration and permeable response within the Irvine and Prestwick catchments during summer and winter periods. The review concluded that initially the macro model would be based on the summer conditions, as the study is primarily concerned with the performance of the system during the bathing season. However, it was noted that should the model be used to assess year round conditions, then the winter scenarios in these catchments would require incorporating into the macro model.

Parameter Conflicts

The review highlighted conflicts within the different models between various model parameters. For example, LUD 1 may utilise the standard Wallingford runoff surfaces in one model, but various fixed and New UK surfaces in another model. Similarly, individual runoff surface ID's represented different New UK or Wallingford surfaces in different models. As a result, if the models had simply been amalgamated, these conflicts would have seriously affected the performance of the model. This issue is frequently overlooked when models from different sources are combined, often causing the accuracy of a model to be compromised when combined to another model with conflicting parameters.

In order to prevent conflicts, a project specific coding system was developed for each catchment and new LUD and runoff surface codes were allocated to each of the models prior to any combining process. A similar re-allocation of profiles was also required for wastewater and trade profiles, as wwg profile 1 was used in all models, but in each case represented a catchment specific diurnal profile and wastewater consumption rate. Table 2 highlights a detailed example of conflicting LUD and runoff surfaces between the Prestwick, Irvine and Kilmarnock catchments. From this it is clear to see that LUD 1 consistently utilises the standard Wallingford surfaces 10, 20, 21 (which had not been altered from the default). However, the runoff surface 3 used for LUD 50-53 between Kilmarnock and Prestwick varies in each case, and all runoff surfaces for LUD 50 vary when the Irvine model is considered.

LUD	Model	Runoff Surface 1	Runoff Surface 2	Runoff Surface 3
1	Kilmarnock	10	20	21
1	Prestwick	10	20	21
1	Irvine	10	20	21
50	Kilmarnock	1	2	19
50	Prestwick	1	2	14
50	Irvine	40	45	50
51	Kilmarnock	1	2	18
51	Prestwick	1	2	15
52	Kilmarnock	1	2	17
52	Prestwick	1	2	16
53	Kilmarnock	1	2	16
53	Prestwick	1	2	17

Table 2 - Example of LUD conflicts

In order to prevent such conflicts, all LUD, runoff surface, wastewater profile and trade profile parameters were re-allocated based on a catchment specific framework. These are highlighted in Table 3.

Catchment	Wastewater Profile	Trade Profile	LUD Profile	Runoff Surface IDs
Annick	1	1 – 4	46, 47	*, 46 - 48
Ayr	11 – 14	-	1 - 4	*
Dundonald	21	21	80 - 82	80 – 82
Irvine	31 – 35	30 – 35	85	85 – 87
Kilmarnock	41, 42	41, 42	30 - 45	*, 30 – 43
Lower Irvine	51, 52	51	50 - 56	*, 50 – 58
Prestwick	61, 62	61 – 63	60 - 67	*, 60 – 73
Springside	71	71, 72	76	76 – 78
Troon	81	-	90	90 - 92

Table 3 - Parameter Re-allocation

The simulation parameters within each model were also reviewed, as differences between these would also affect the model simulations when all models are combined. All simulation parameters were found to be identical, except in the case of Annick Water, where Minimum Base Flow Depth and Base Flow Factor parameters were found to be marginally different. The effect of standardising these was investigated and found to be insignificant.

Following this review, all models were amended to prevent the parameter conflicts. All default flags within each model were also amended to a fixed flag, so as to ‘freeze’ the original default set value. This was carried out to prevent conflicts between the various default parameters (e.g. roughness or flood type) within each model. By changing the flagging system, all previous default values would be carried through into the final combined model.

Model Combining

All nodes, links and subcatchments from each of the models were pasted into the same database, and the models connected as necessary. This involved either connecting gravity sewers to the IVS (from catchments such as Kilmarnock, Dundonald, Springside or Lower Irvine), or connecting the pumped links (from coastal catchments directly to the collection chamber at Meadowhead WWTW). The WWTW was included in this model, as it was not included in any of the individual DAP models, and there were a small number of local industrial flows located close to the Meadowhead WWTW.

Model Testing

During the model combining process, check simulations with the 1 year 60 minute design storm were carried out to assess the performance along key links. Any changes in the predicted flows or depths between the various stages of the model development would indicate some form of change to the model status, which should be investigated. Unless there is a hydraulic influence from adjacent catchments, these test simulations should indicate no change in the flow characteristics of the model, and are thus an ideal tool to identify potential errors in the combining process. These simulations were carried out at four stages for comparison:

1. Original stand-alone DAP models before any amendments were carried out, to establish base line verified model performance.

2. Stand-alone models following identification and amendment of all parameter conflicts and default flags. This simulation was carried out to ensure parameter re-allocation process had not altered the verification status of the models.

3. Following the initial pasting of all models to the same database, but before linking of the models. At this stage the models all drain to their original individual outfalls, and this check was carried out to ensure all aspects of the model were correctly copied and pasted to the macro model database.

4. Following the linking of the individual models to the IVS or Meadowhead WWTW. This simulation would identify any areas where model performance significantly changes due to the influence of adjacent catchments.

As a further check to ensure the performance of the individual models had not been significantly affected, flood volumes at each node were plotted between the original individual models and the final combined macro model. Obviously, where flood volumes were not the same, a change in the model performance had occurred.

Figure 2 shows an example of the model testing procedure, highlighting how the main flows from Prestwick did not changed during the development of the macro model. This was generally the case in all catchments. In the case of Lower Irvine, the flows were predicted to significantly increase (Figure 3). This however, was expected as the main outlet link in this catchment forms part of the IVS, thus the original model did not include the flows from Kilmarnock, Upper Towns and Dundonald, which now occurs within the combined model. Figures 4 and 5 are examples of how flood volumes and inflow to nodes were used to check that model performance had not been significantly changed during the combining process. Following the successful testing process, the macro model is now available for use to assess the spill characteristics of all the CSOs in the catchment.

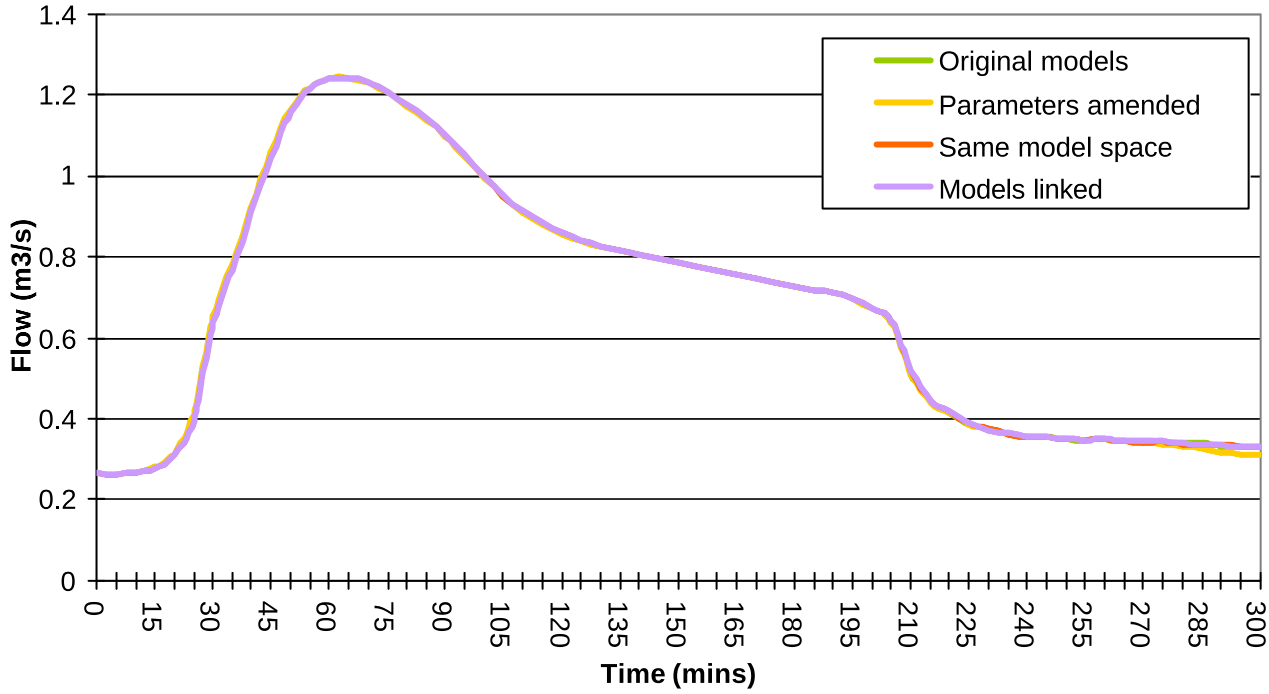

Figure 2 Prestwick Flows

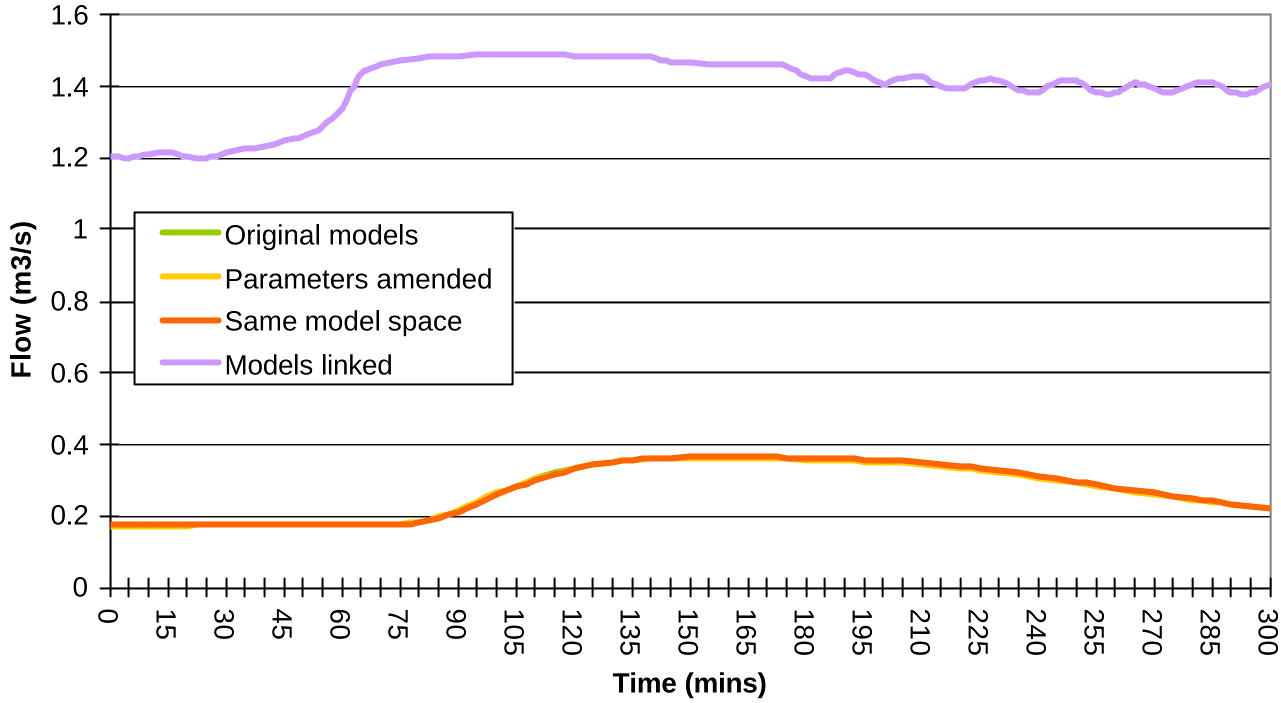

Figure 3 Lower Irvine Flows

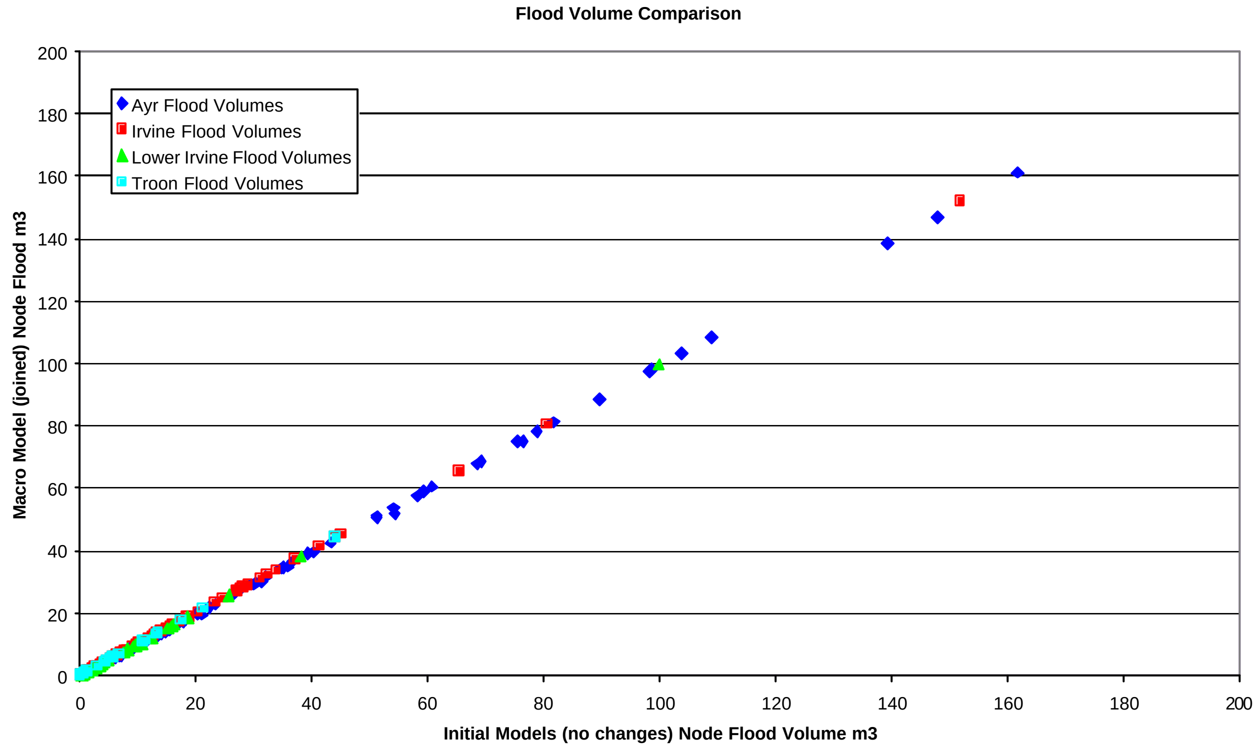

Figure 4 Flood Volume Check

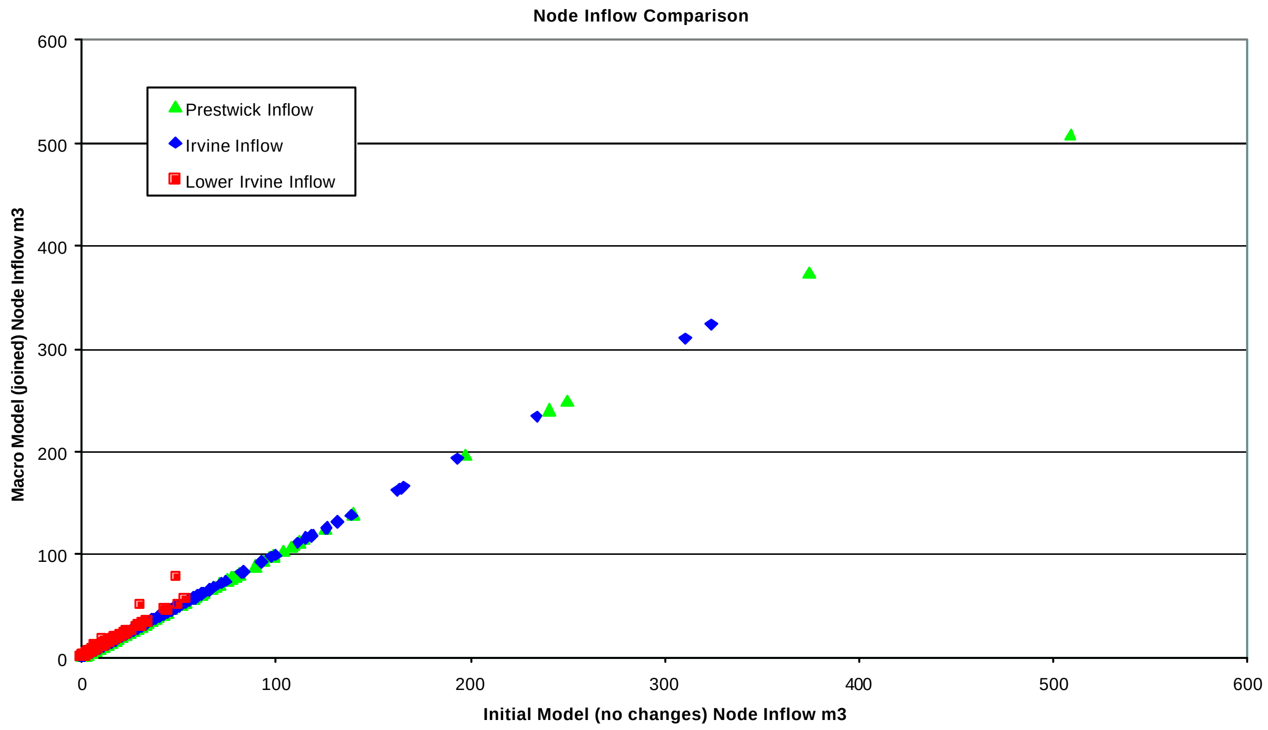

Figure 5 Node Inflow Check

5 Choice of Rainfall

A further consideration in using macro models, which is frequently ignored, is the choice of rainfall. The current analysis of the performance of the system is still ongoing, as a consequence no results have been made available from the model. However, the choice of rainfall to use in the analysis was a complex process, and many of the issues considered would apply to other macro models.

The main issue to consider when choosing appropriate rainfall to simulate with a macro model is spatial variability. In catchments such as Meadowhead, storms may take a number of hours to move across the modelled catchment, and rainfall is also highly likely to occur in sporadic and scattered patterns. Simply applying a single design or stochastic profile simultaneously across the whole of the catchment would generally be inappropriate for an extensive drainage catchment. As compliance with bathing beach regulations, during the bathing season, is the main driver for this study, time series rather than design rainfall was chosen to simulate with the model. The following options were considered as sources of the time series rainfall data:

- Generate a historic series based on long term daily data available at three Met Office sites within the catchment. This was discounted as the data was only available in daily format, and would not be detailed enough to determine storm characteristics or disaggregate in StormPAC.

- Generate a stochastic series based on the long term daily rainfall data available from the three Met Office sites within the catchment. This method was discounted as the spatial resolution of the sites was not considered adequate to determine any spatial variability, and concerns that StormPAC would not be able to generate stochastic series for the three sites that would correspond to each other, and allow them to be simulated together.

- Radar Rainfall Data was considered but discounted on the basis of cost and availability in the Meadowhead area.

- The utilisation of high temporal resolution rainfall data from the various DAP flow surveys was considered, but this was discounted for two main reasons. Firstly, the flow surveys were generally carried out over ten week periods, which is not an adequate length of time, and secondly, the flow surveys were carried out at different times and so data is not available for the whole catchment at the same time.

- Obtain SEPA rainfall data from nine SEPA sites in the catchment. This data is available for event gauges, which record the depth of rainfall every 15 minutes. Whilst this results in short high intensity periods of rainfall being averaged out over 15 minutes, it was considered suitable to use as an initial analysis tool. The nine sites offered an improved representation of the spatial variability within the catchment. The main limitation with this rainfall is that it is only available for the 2001 and 2002 bathing seasons. However, this rainfall data was chosen to assess the performance of the model in the first instance, due to its relatively high spatial resolution, but also so that the initial results could be utilised with the marine model to predict the extent of bathing beach compliance. These predictions can then be compared to SEPA observations and act as a form of model verification.

The model was updated to include rainfall profiles representing the available rain gauges, based on the Theissenn polygon method. No consideration was given to topographical factors in allocating rainfall profiles to the model due to the lack of any further data. This, though, may be an important consideration. The model is currently being analysed with the SEPA rainfall data for the 2001 and 2002 bathing seasons.

6 Conclusions

Many of the water quality and bathing beach problems currently being addressed by engineers and hydraulic modellers require extensive and highly detailed models so that the cumulative effect of intermittent and continuous discharges from a number of individual catchments can be assessed simultaneously. As a result highly detailed macro models are required to be constructed to analyse issues such as bathing beach and river water quality failures.

The use of macro models is not a new concept as they have been in existence for a number of years now, being used as a tool for planning drainage strategies and determining Real Time Control regimes. However, there is a general realisation industry wide, that whilst the historic macro models were coarse and served a purpose, they were limited by the simulation duration times and software restrictions in place at the time. With the advancements made to both computer processing speeds and the available software packages these limitations are no longer an issue.

With the intensified focus on the improvement of the water quality of water courses and bathing beaches it is evident that given the reduction in predictive accuracy, highly simplified models are no longer suitable for analysing large systems in the detail required. This is especially the case around CSOs, which through water quality issues are frequently the main driver for developing large catchment models.

It is highlighted that one of the most important processes of constructing a macro model is identification of model limitations so that they can be packaged as part of the model user documentation. This should ensure that future users of the model will be made fully aware of any limitations of the model.

This study has highlighted that modern macro models have the potential to be significantly larger and infinitely more detailed than their predecessors. Modern macro models are likely to comprise a number of verified DAP models. As a result, the process of constructing the macro model is complex, and frequent checking procedures should be undertaken to ensure that the original verification status of the verified models is not compromised. Consideration should also be given to the rainfall used when simulating a macro model, as spatial variability, and rainfall data availability are likely to be important issues.

7 Considerations for Further Work

From carrying out this study it is highlighted that there are a number of steps and checks which are required to be undertaken in order to successfully construct a macro model. As no documentation is currently available on this process, a set of procedures and check lists would provide useful guidance in undertaking this type of activity.

The effect of spatial and temporal varying rainfall on large catchments, with highly detailed modelled sewer coverage is largely unknown. Testing the sensitivity of macro models with detailed spatially varying rainfall patterns would provide useful guidance on the level of detail of rainfall data required to accurately simulate large catchment models with ‘real’ rainfall data. Factors such as topography, altitude, distance from coast and location may be required to be taken into account whenever modelling investigations are carried out with spatially varying rainfall.

8 References

The Wallingford Procedure for Europe (2000) Best Practice Guide to Urban Drainage Modelling

9 Acknowledgements

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