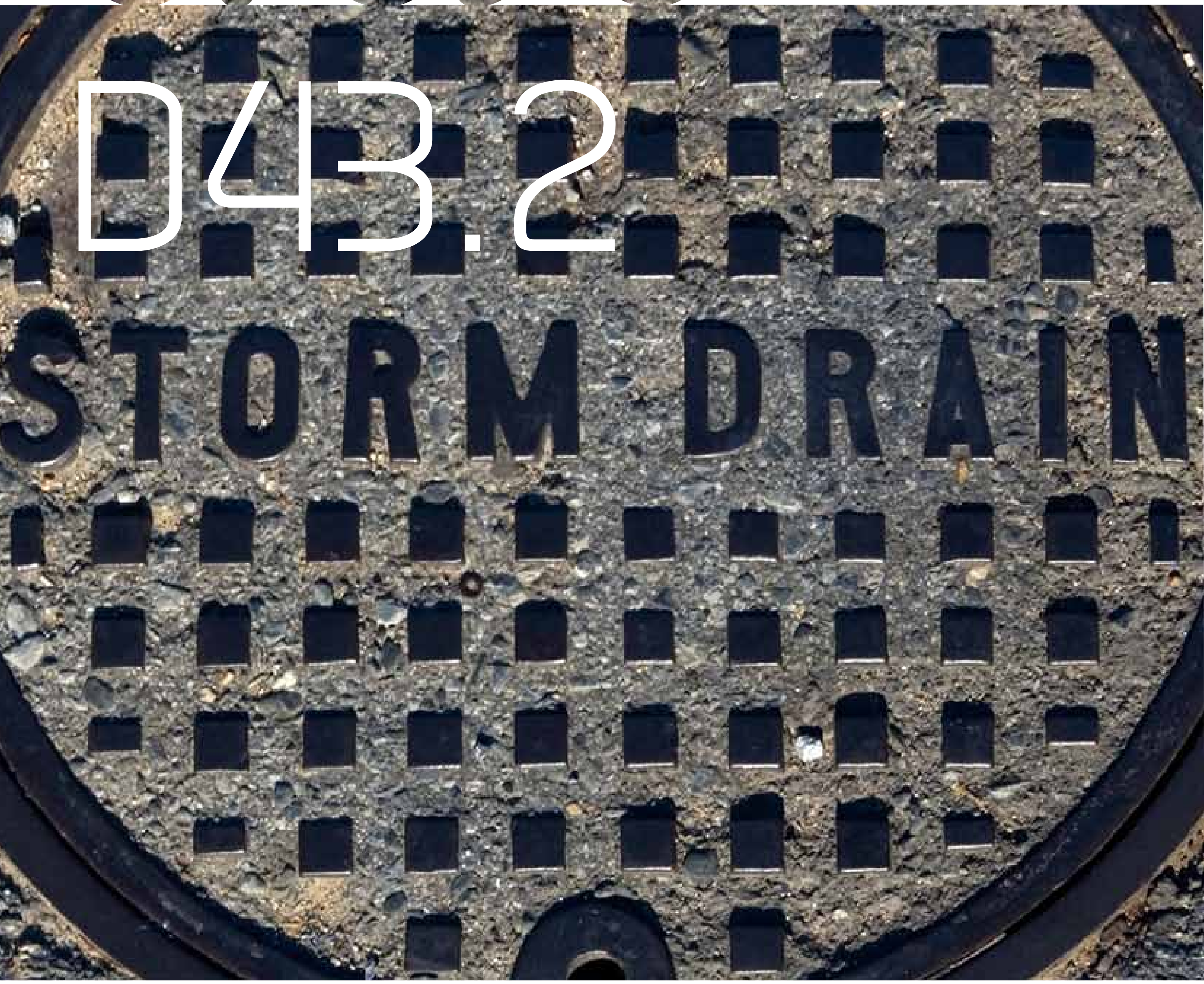
ADAPT
A Drainage Analysis Planning Tool

LEONORE BOELEE
RICHARD KELLAGHER

trust

D43.2



TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

ADAPT-A Drainage Analysis Planning Tool

Authors

Leonore Boelee BSc, MSc

Richard Kellagher BSc, MSc, MCIWEM, MICE, CEng,

Final Version for Distribution

January 2015

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265122.

TABLE OF CONTENTS

Summary 7

1. Introduction 8

2. The ADAPT model 10

2.1. ADAPT - Risk based methodology 11

2.1.1. Methodology description 11
2.1.2. Running the Risk based methodology 14
2.1.3. Analysis of risk based methodology results 14

2.2. ADAPT - Level of services methodology 16
2.3. ADAPT model parameter settings 18

2.3.1. Settings for the Genetic Algorithm 18
2.3.2. Objectives and constraints 20
2.3.3. Initial solutions 26

2.4. System state improvement options 27

2.4.1. Disconnections 28
2.4.2. SuDS 28
2.4.3. Storage Tanks and Orifices 29
2.4.4. Pipes 32

2.5. Costs 33

2.5.1. Asset modification cost 33
2.5.2. Target improvement and other boundary costs 35

3. Running ADAPT 38

3.1. Run times 38
3.2. Results 38
3.3. Processed ADAPT results 39

4. Creating the InfoWorks mdel of Hoffselva 42

4.1. Importing the model from Mike Urban 42

4.1.1. Hydraulic model parameters 42

4.2. Combined Sewer Overflows (CSOs) 43
4.3. Hydrology and runoff modelling 45
4.4. Dry weather flows 46

5. Model verification 47

5.1. Verification data 47

5.2. Verification results...48
5.3. Areas for model improvement...49

6. ADAPT application on the pilot catchment of Hoffselva, Oslo...51

6.1. Performance expectations...51
6.2. Model preparation...52
6.3. ADAPT results...55

6.3.1. Option 1 - Storage tanks to control CSO spills to 3 times a year...55
6.3.2. Option 1A - Storage tanks to control CSO spills to 3 times a year and the Lake CSO to 1 spill a year...63
6.3.3. Option 2 – Pipe upsizing to control CSO spills to 3 times a year...63
6.3.4. Options 3, 4 and 5...65

7. Conclusionas and recommendations...66

References...67

Appendices...68

A. - A Technical summary of ADAPT...68
B - The verification of the Infoworks model...69
C - Modifications of the CSOs in the model...75

LIST OF FIGURES

Figure 1. An overview of ADAPT 8

Figure 2. The Hoffselva pilot catchment 9

Figure 3. The ADAPT tool 12

Figure 4. Number of system states for drainage analysis considering blockage and collapse (Dti SAM (HR Wallingford)) 13

Figure 5. Attribution of damage to system network nodes (SR700 Risk based integrated flood management of drainage assets R1_0, HR Wallingford 2009) 16

Figure 6. Schematic overview of ADAPT setup 17

Figure 7. Network Optimisation in ADAPT 19

Figure 8. Level of Service Analysis in ADAPT 22

Figure 9. Boundary points in ADAPT 24

Figure 10. Improvement points 25

Figure 11. Providing initial solutions into ADAPT 26

Figure 12. ADAPT variables – storage nodes 31

Figure 13. ADAPT variables – pipes 32

Figure 14. ADAPT – asset modification costs 34

Figure 15. ADAPT – Improvement and Boundary costs 37

Figure 16. ADAPT output summary file for each set of runs for one generation 39

Figure 17. Convergence towards a minimum cost solution 40

Figure 18. The use of a multi-objective optimisation – boundary costs trade off against asset improvement costs 41

Figure 19. Location of raingauges used for verification of the model: Blindern within the catchment, and Shell 2km outside the catchment 47

Figure 20. Modelled flow hydrographs showing impervious surface flows (green), impervious + pervious surface flows (red) and impervious, pervious and infiltration flows (blue) 49

Figure 21. The Hoffselva pilot catchment showing potential locations of storage tanks (blue) and CSOs (pink) 56

Figure 22. Long section through storage tank with associated orifice and weir and downstream CSO. 57

Figure 23. Results of optimisation for preventing CSO spills to the 0.3 year return period event.....60

Figure 24. Overview of all pipe groups.....64

Figure 25. Overview of selected pipe groups.....65

LIST OF TABLES

Table 1. Optimisation variables used for the Hoffselva catchment.......................................20

Table 2. Maximum, minimum and step size of storage nodes and orifice flow rates for the 0.33 return period event.......................................30

Table 3. Costs in the Hoffselva catchment.......................................35

Table 4. Overview of costs for the Hoffselva catchment.......................................36

Table 5. CSO links in the Hoffselva InfoWorks CS model.......................................43

Table 6. Other outflow links in the Hoffselva Infoworks CS model.......................................45

Table 7. CSO spill volume (m3).......................................53

Table 8. Solution details rank 1 (Chromosome 11500).......................................59

Table 9. Solution details rank 2 (Chromosome 11885).......................................61

Table 10. Solution details rank 13 (Chromosome 11920).......................................62

SUMMARY

HR Wallingford are a partner in the EU funded TRUST project. They are involved in Work package 4.3 Wastewater and stormwater systems, to produce a model and report on a system sustainability analysis and potential for improvements for stormwater systems as Deliverable 4.3.2.

This report is deliverable 4.3.2. It details the development of the tool ADAPT (A Drainage Analysis and Planning Tool). The objective of the tool is to evaluate the improvement requirements to a stormwater system in order to achieve a sustainable performance in serving the community with minimal impact on the environment. The tool is based on the use of optimisation of a range of possible options to achieve a stated set of performance criteria. Improvements to the drainage system can be effected by either making changes to the network assets (pipes and storage tanks), and removal or modification of the runoff from paved surfaces.

The tool has been applied to the small steep catchment of Hoffselva in Oslo. The catchment has problems associated with both flooding (58 known basement locations) and pollution in the two small watercourses from 21 overflows from the combined sewer system. An Infoworks CS model has been built (10km2 and 2200 pipes) and verified, before being used to analyse the system behaviour and evaluate options for meeting performance requirements.

The results demonstrate how the performance requirements might be achieved and confirms the capabilities and effectiveness of the tool.

The deliverable is complete in as much as it demonstrates the tool exists and works. However development is on-going and this deliverable will be updated at the end of the project.

The report is detailed in two parts in the main section; the development of ADAPT, and then its application in analysing the pilot study area. This is followed by appendices which provide supporting information.

1. INTRODUCTION

HR Wallingford has been working as part of the TRUST (Transitions to the Urban Water Services of Tomorrow) consortium on the topic of Wastewater and storm water disposal (collection, drainage, treatment, discharge) in urban water systems (WP4.3). For this purpose the ADAPT tool (A Drainage Analysis Planning Tool) has been developed. ADAPT is a optimisation tool that runs a genetic algorithm which is able to explore a wide range of potential drainage solutions to identify those which are optimal based on user defined costs and benefit functions. The Hoffselva catchment in Oslo has been used to test the tool.

The Hoffselva urban drainage model covers a district approximately 10km2 in extent in Oslo, Norway. It has been modelled using Mike Urban in two parts; one by DHI and the other by the city of Oslo. These models were then combined to provide a single model of the system. The simplified model converted to InfoWorks CS comprises approximately 2200 links and nodes, four pumps and 26 outfalls (17 CSOs, 4 pump station emergency overflows and 5 distribution weirs). The network comprises a combined systems in the southern portion with separate foul and storm systems in the northern portions of the model, reflecting the more recent urban development being in the north with the construction of the separate systems. DHI (2011) should be referred to for more detailed discussion of the Mike Urban model build and calibration. The Hoffselva model was successfully transformed from Mike Urban to InfoWorks CS. Verification of the model was carried out using the flow survey data which was collected for verifying the Mike Urban model.

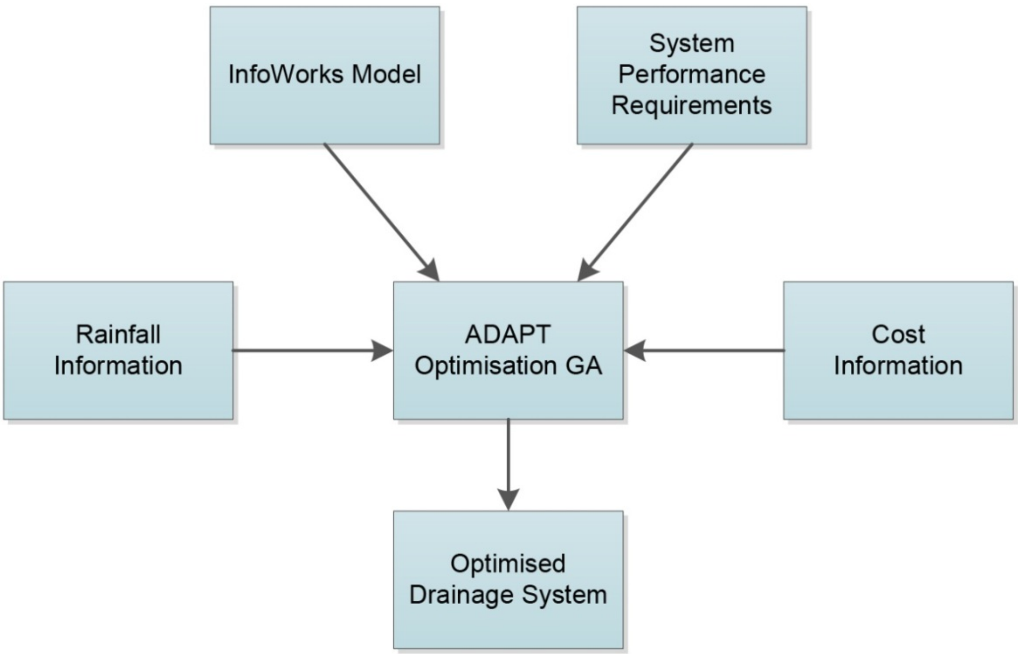


Figure 1. An overview of ADAPT

ADAPT provides the capability to carry out multi-objective optimisation which analyses possible interventions of sewerage asset changes and to find optimal solutions at a minimum cost. In the Hoffselva catchment several scenarios of network improvements have been tested with the objective of reducing the number and volume of spills from most of the 21 CSOs. In addition solutions to address problems associated with 58 known basement flooding locations have been explored. Solutions have explored the use of both attenuation storage systems as well as increasing pipe sizes at strategic locations. The assessment of the beneficial impact of reducing runoff from paved surfaces using SuDS techniques is not included in this report, but is to be explored before the end of the TRUST project.

This report first gives an overview of the capabilities of ADAPT, and then details how it is used for the Hoffselva catchment. The Hoffselva catchment is described and details of the need for improvement along with the modelling of the network is then discussed. This is followed by detailing of the options development, issues in running the ADAPT tool and the outcomes of the analysis.

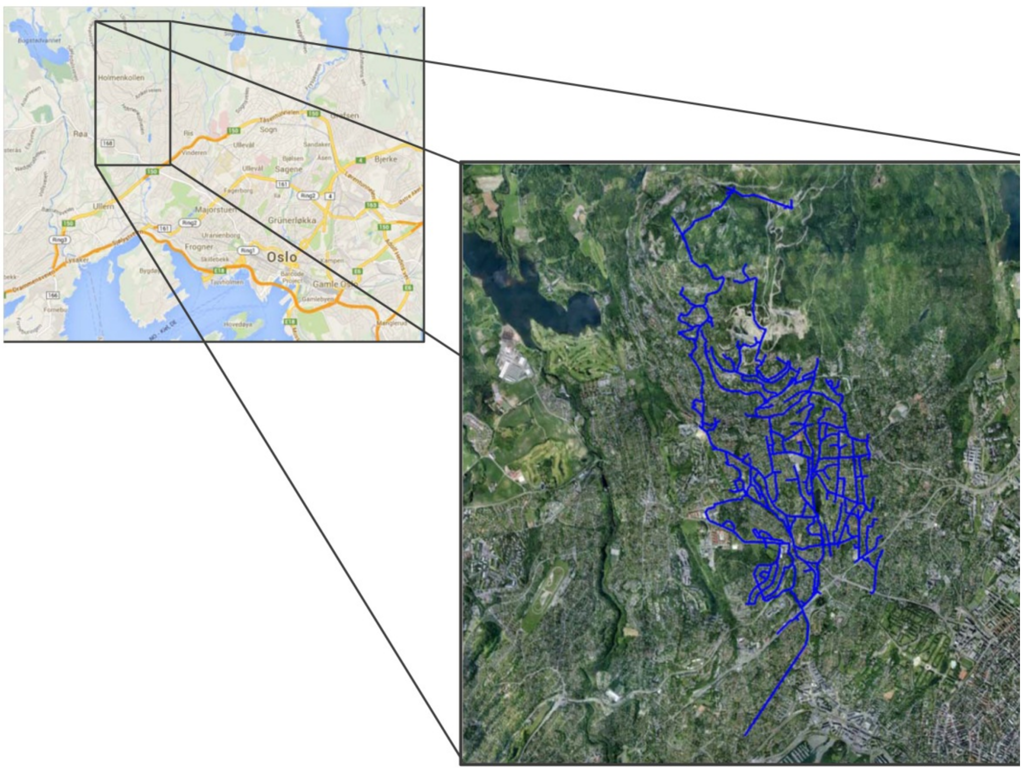


Figure 2. The Hoffselva pilot catchment

2. THE ADAPT MODEL

ADAPT is a multi-objective optimising tool which undertakes the development of solutions which meet specified criteria by modifying the network assets or modifying the runoff characteristics for a minimum cost. The tool interacts with InfoWorks CS (IWCS) through the COM-interface to consider multiple possibilities of changes to the system (which are defined by the user), to converge on an optimal arrangement which meets the performance criteria, assuming a solution can be found. It has been developed as a tool to aid the engineer recognising that there are many factors which cannot be quantified in the tool such as buildability of options. Therefore control is ceded to the engineer in allowing the tool to be constrained by the range of possible development changes which can be considered.

A governing principle applies to the application of ADAPT whichever of the various approaches available is used; which is that any solution proposed cannot make the performance at any other point in the network worse than the baseline system state. This is defined as making any point of flooding worse for any given event, and can be extended to include points where surcharge cannot be increased either.

There are two principal methods of approach for using ADAPT. These are:

- A risk based method, and
- A level of service method.

The risk based method is outlined briefly in section 2.1. This method has not been used for the pilot study primarily due to data availability and the system criteria which was set by the drainage infrastructure owners of the Hoffselva catchment. The level of service approach is then described in more detail in section 2.2.

The scope of ADAPT is aimed at providing three main outputs:

- Solution(s) which achieve the minimum cost for the capital cost of construction;
- An evaluation of the Whole Life Cost (WLC) of schemes (still in development);
- The order of construction of schemes with multiple interventions (still to be tested).

This report only explores the capital costs of schemes for the Hoffselva catchment, but this will be extended to look at operating costs in due course.

Although capital costs tend to dominate scheme selections in drainage systems, WLC analysis is normally considered for any design of a system. This is particularly relevant where running costs of systems are important, such as manning requirements or the energy used in a WwWT downstream. This is particularly appropriate for ADAPT when solutions involve paved runoff removal, in that the return for investing in such solutions will be gained over many years from reduced energy consumption as well as many other potential benefits of SuDS schemes.

Scheme implementation can be difficult to schedule. If they are built in in the wrong order, parts of the network may get worse even though they might address a specific problem. This is particularly relevant when pipe sizes are increased. As budgets for any proposed improvement may preclude solutions being implemented at one time due cost or practicality, improvements may be needed to be spaced out over a number of years. The tool has been developed to carry out a second stage optimisation to maximise the benefits of transitioning the system to its future state as well as try and prevent any solution making the current situation worse at any location as a result of any works. In practice, certain solutions may not be able to meet this criterion and therefore this analysis is critical in confirming that a proposed set of changes to the system are viable.

A complete description of all aspects of the ADAPT tool will be provided later in Appendix A of this report.

2.1. ADAPT - Risk based methodology

2.1.1. Methodology description

The risk based approach incorporated into ADAPT is based on an assessment of damage costs and finding the most cost effective solution in reducing these costs. Damage costs are estimated on the basis of calculating Estimated Annual Damage (EAD). EAD can be calculated for flood or environmental or other measure "damage costs" such as societal impact. There are two common elements to being able to calculate EAD and these are:

- Calculation of damage for a full spectrum of rainfall events and other relevant loading conditions (system failure, river or tidal water levels, etc.);
- Information to be able to assess damage costs.

Calculation of EAD requires the damage impact due to all possible rainfall events to be established. The annualised damage cost is then calculated by taking into account the frequency of each event. Thus very rare events (say 1:1000 years) although likely to have a considerable impact, happens so rarely that its contribution to EAD may be very small. In practice for most drainage systems in cities it is often events in the region of 10 to 50 years which contribute most to the value of EAD.

Information that is needed to be able to calculate damage costs is considerable. These are:

- Property values (and other values associated with other damage measures such as water bodies) data set such as the UK National Receptor Dataset (NRD) which can be used to calculate damage;
- Topographic information to enable the prediction of flooding of a receptor using flood routing models;

- A model with 2D finite volume flood routing model to predict the water flows and levels at receptor points.

Figure 3 shows all the components of the ADAPT tool and highlights those elements which are specifically needed to enable a risk based approach to be carried out.

In many cases there is insufficient information available for a risk based study as one or more of these elements may not exist. However even if they do exist and a consequence / risk based approach is possible, the computational time needed for running all the relevant events (Time series or Design storms) to calculate EAD, and the additional modelling of flood routing or environmental impact modelling, adds considerably to the effort required. Therefore optimisation analysis based on EAD is likely to be based on associating damage costs to flooding at manholes.

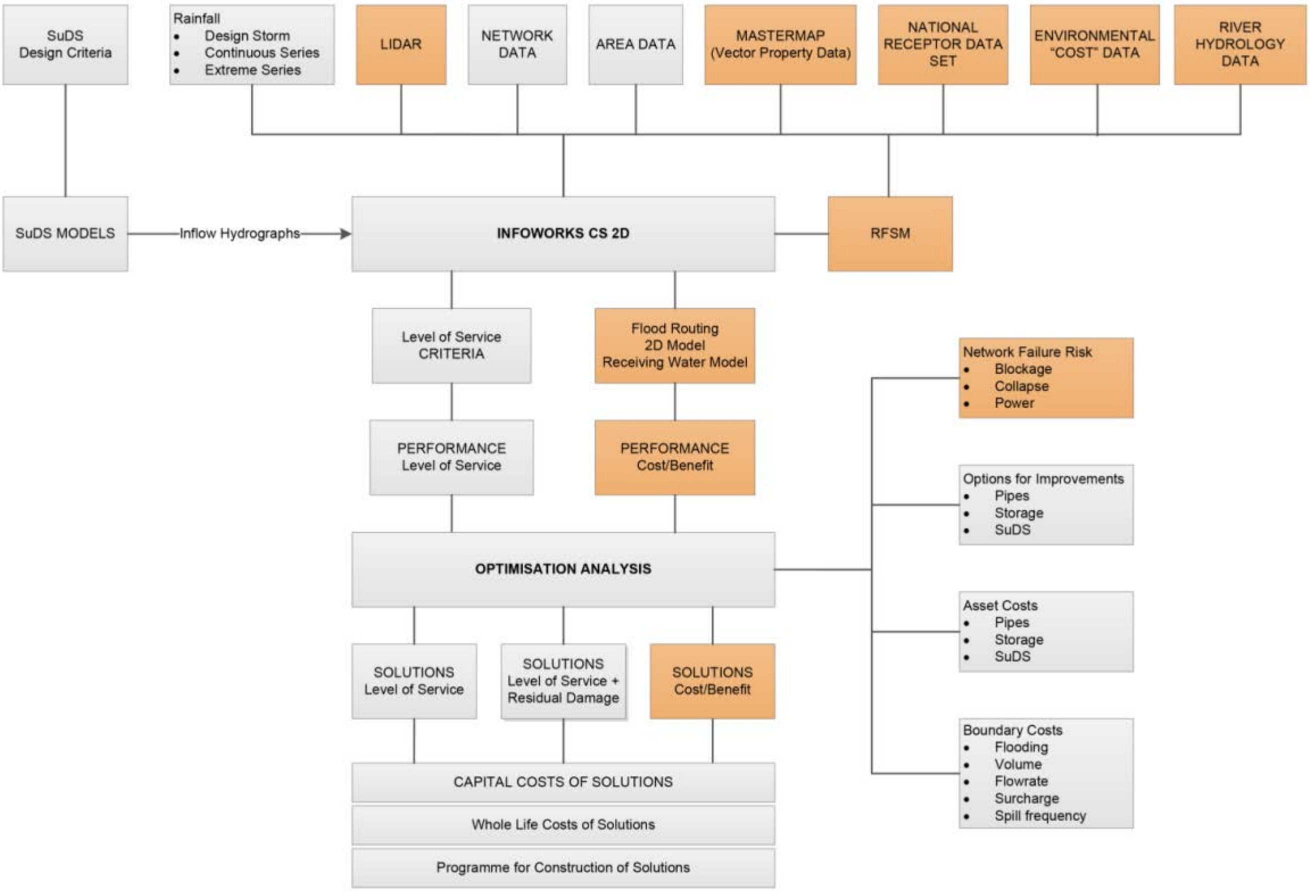


Figure 3. The ADAPT tool

There is one final aspect to mention with regards to carrying out a risk based analysis of a drainage system. The original development of the ADAPT tool enabled EAD to include the risks associated with failures in the system. The obvious ones for drainage networks are blockage and collapse of pipes as well as pumps failing. There are also other risk elements such as joint probability of downstream hydraulic constraints and potential failures of embankments and so on.

The inclusion of these failure elements is possible as there are algorithms for assessing the likelihood of these conditions effectively creating many other possible system states to analyse. However the calculation of any given system is possible theoretically (as convergence to a value of EAD can be achieved long before all system states are analysed), but to go on to assess many hundred alternative solution systems which includes these potential failure system states to find optimum solutions is not feasible based on current technology. It is therefore unlikely that studies will include failure modes in applying ADAPT to find solutions, but it is still of considerable value in being able to analyse a catchment for risk associated with potential system failures. In this case it is important to be able to attribute EAD costs to each of the categories as the impact of the normal performance of the system (no failures) is likely to dominate the predicted damage costs. Figure 4 illustrates the very large number of rainfall events and dry periods and alternative system states which theoretically need to be assessed for potential damage. The number of potential system states is directly a function of the number of links in the model as each link has a probability related to a pipe that blocks or collapses.

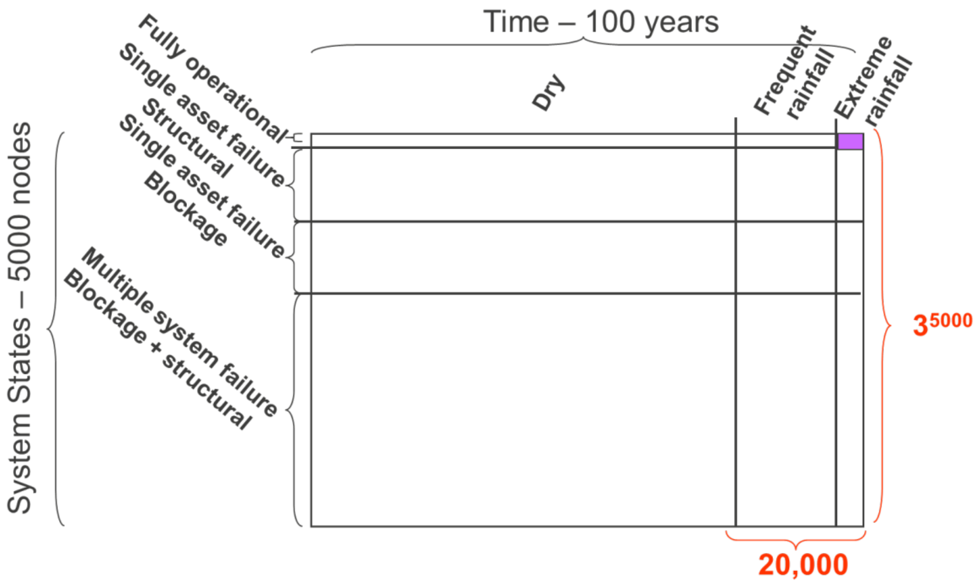


Figure 4. Number of system states for drainage analysis considering blockage and collapse (Dti SAM (HR Wallingford))

2.1.2. Running the Risk based methodology

When carrying out the risk based method, it is necessary, in theory, to run all possible events. In practice a reduced set of runs can be used as long as convergence to an accurate assessment of EAD is arrived at. For example a time series of rainfall for a 100 year data set might have around 300 events in that period when flooding from a network could possibly occur, and probably 5000 or more events which might cause spills from overflows. Preparation of the data set could therefore screen out the less relevant events and sampling be made on the selected events. It is quite likely that random sampling or running the selected events in date order would result in convergence long before all events are run. ADAPT can recognise this point by being given it a maximum range of change in EAD over a number of events or period of time.

Two further alternative rainfall methods are also possible to limit the number of events needed to obtain convergence. These are either to use a matrix of design storms for an appropriate range of frequency and duration, or the simplest of all approaches which is to use a Chicago hyetograph so that durations are all nested in the one event. Thus around 6 return periods from 5 to 100 years with 5 or 6 durations ranging from 30 minutes to 12 hours (depending on the subcatchment runoff characteristics) would result in around 30 events, and the Chicago hyetograph method would only require the 6 return period events making a significant reduction in computational demand.

It is important to decide what cost is to be measured. The analysis may focus on flooding at a specific location, or it may consider the flood damage for the whole catchment. It should be noted that flooding at different points in the catchment will have very different characteristics. EAD may be seen to have converged, but this might be dominated by the result from one particular area of the model, and convergence may not have been achieved at other locations.

2.1.3. Analysis of risk based methodology results

The risk based approach effectively presumes that there will always be an EAD cost, as there is always bound to be a "damage" cost for a certain severity of event. Thus the results are always going to be in the form of a pareto front with a trade-off between EAD reduction and cost of the possible solutions. There are several ways in which decisions can be made. These are:

- A minimum Cost – Benefit ratio,
- The maximum Cost – Benefit ratio,
- The maximum Benefit available for a given budget.

There is no one solution which is the best one. The Cost – Benefit ratio used by the UK government for funding flood schemes is stated as being 8:1 (the Benefit is 8 times the cost of the scheme, though this is not just a measurement of physical damage cost). This ratio could be justified with any figure down to 1:1 below which point expenditure will be greater than the benefit gained. The maximum Cost Benefit ratio is a simple and single point solution, but it may result in a relatively arbitrary level of improvement which may not sufficiently address the problem. Finally, the budget limit is quite a practical way of assessing the appropriate solution as there is usually a limitation on the budget available.

By definition, the risk approach is not aiming to provide a specific level of service. However the problem with this is that there is an element of inequity to stakeholders in the philosophy of maximising the efficiency of cost and benefits. Areas of high value will obtain greater levels of protection than less valuable areas. It is therefore likely that a minimum level of service should also be considered. This is also possible to apply by carrying out an approach which uses two ranges of cost; a very high value of damage at the target locations for events which are incurred for events which are more frequent than the level of service required, but standard damage costs for events which are more extreme. Solutions will then be rejected where damage occurs at these target locations for events which are less than the level of service.

As the tool makes all the decisions as to possible solution system states to try, it is theoretically not important to attribute damage costs to the nodes from which the flood flows or spills originated. However it is quite useful to understand why the network is causing damage in certain receptor catchments. Flows causing damage in a subcatchment can come from multiple nodes, and one node can cause damage in more than one catchment. The RFSM tool used with ADAPT can track flows and therefore it can apportion and associate costs back to every node in the system. This is not necessarily possible if other flood routing models are used. This is a relatively simple task where time series rainfall is used or the Chicago hyetograph method is used. However where there are multiple durations used for design events, different nodes will have different critical durations which makes attribution very difficult. In this case the simplest approach is to use the duration which provides the maximum catchment damage cost and attribute these costs back to each contributing node. It should be noted that in using the different attributed costs back to each manhole, although it makes it much more efficient to assess the reduction in EAD, the solution will be an approximation of the most cost effective solution as the damage cost weighting between manholes is likely to change once the system state changes.

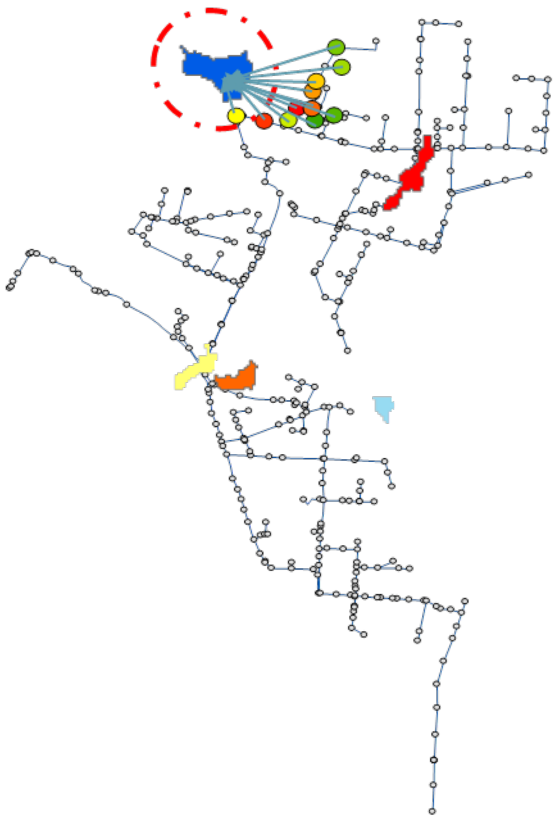


Figure 5. Attribution of damage to system network nodes (SR700 Risk based integrated flood management of drainage assets R1_0, HR Wallingford 2009)

The risk methodology is therefore a very powerful tool which enables expenditure on asset management to be targeted most effectively.

2.2. ADAPT - Level of services methodology

The level of service approach in ADAPT is the more traditional one of assessing the performance of the network itself rather than assessing the consequences of the failure of the network. This approach means that a traditional 1D verified model of the network can be used. Measures of level of service performance available in ADAPT are (currently) associated with frequency of occurrence of points of flooding at manholes, surcharge water level in manholes (basement flooding), and spill frequency (for overflows). Other measures could be added.

A schematic overview in greater detail for certain components of ADAPT is provide in Figure 6. The core of the tool interacts with the Infoworks CS model using a generic algorithm (GA) to modify the network to assess different possible system states for their cost (for implementing changes) and their compliance with meeting the performance criteria. The GA mutates and alters system state solutions each iteration to evolve toward better solutions and discard the more costly ones.

ADAPT requires an InfoWorks CS model and rainfall events to predict the performance of a network. In order to provide ADAPT with the required information to find appropriate solutions, it requires additional information (Figure 6) and this is detailed in the next sections of this report.

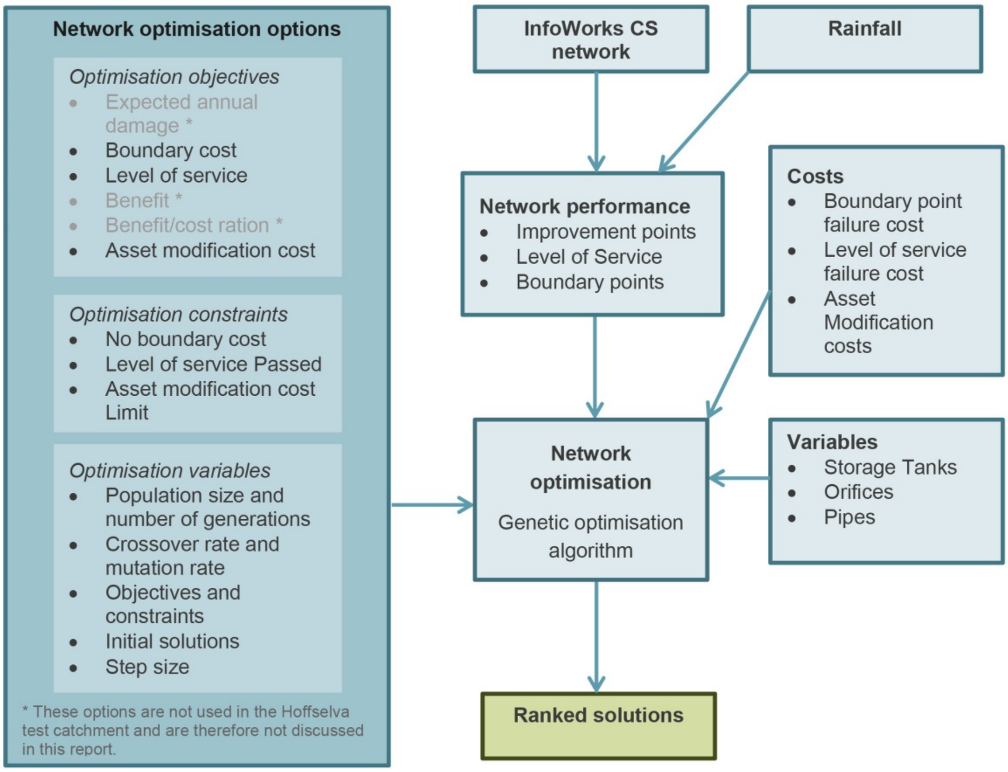


Figure 6. Schematic overview of ADAPT setup

2.3. ADAPT model parameter settings

2.3.1. Settings for the Genetic Algorithm

The network optimisation in ADAPT is based on a multi objective genetic algorithm called NSGA2. Parameter settings in the tool require values for the mutation and crossover rates, and the total population size. The population size is the number of different system states it considers each time it carries out an evaluation after each generation cycle. Typical values of these parameters are shown in Figure 7. A number of generations can be set from two to any value based on the number of generations that are likely to be needed. The programme can be interrupted, viewed and stopped at any time. To try and avoid selection of similar system state solution arrangements, the last 1000 solutions are remembered.

As it progresses through each generation it examines and ranks the best solutions and keeps half of them. It then creates new solutions for the remaining 50% of the population size to run using the best solutions from the previous generation.

To minimise the number of generations needed the modeller can provide one or more initial solutions, which may or may not satisfy all the constraints, and even though it is not an optimal solution, it will normally significantly reduce the computational time needed to find a good set of solutions.

The solutions it arrives at are tested for similarity to ensure against too much clustering around one outcome. This ensures a good spread of options from which the engineer can then progress to detailed evaluation of each option.

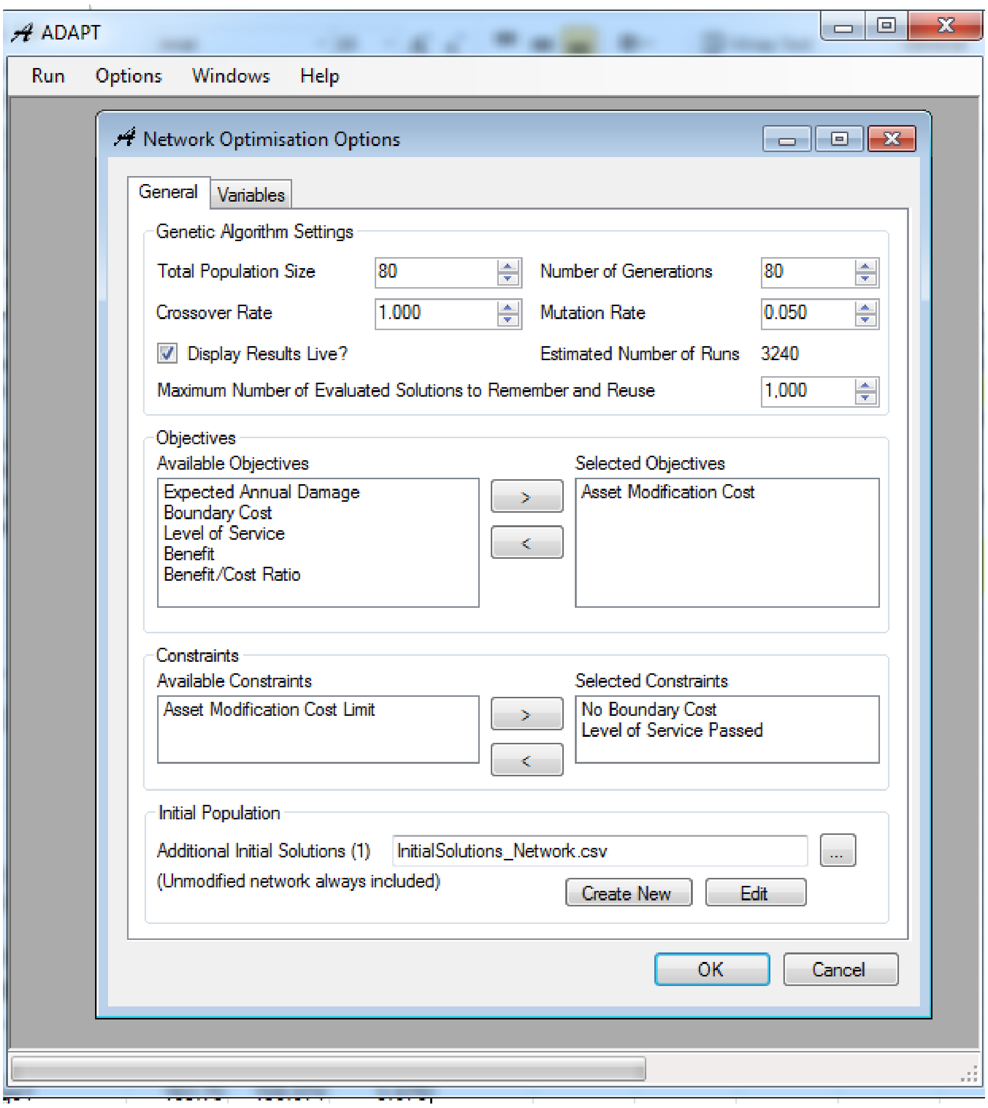


Figure 7. Network Optimisation in ADAPT

The GA parameter values used for the Hoffselva catchment are shown in Table 1.

Table 1. Optimisation variables used for the Hoffselva catchment

OPTIMISATION VARIABLE	
Population size	80
Number of Generations	80
Crossover rate	1.00
Mutation rate	0.05

2.3.2. Objectives and constraints

There are three principal elements in a model which is to be used to find an optimised solution. These are:

- The target points which require level of service compliance to be achieved;
- Boundary conditions set so that the performance of the proposed solutions at any location in the model that is not a target for improvement is not made any worse;
- The outfall and any other points which need to have a cost attributed to them for their change in performance to take account of the impact of any changes within or downstream of the model.

The last bullet moves the solution away from finding a minimum cost solution to a pareto front of multiple solutions traded off against additional costs incurred by the solution.

There are costs associated with each aspect. Thus a target CSO which is expected to not have a spill for a certain design event it will have a cost associated with the spill volume so its relative performance with another solution can be ranked if there is insufficient budget to achieve a solution which meets the performance criteria. Similarly the boundary condition of flooding or level of surcharge at a node may have been made worse and the additional volume or level is associated with a cost. These costs are set so high so as to ensure that these solutions are rejected in favour of solutions which do not fail the boundary criteria.

The outfall costs can be optional or set very low as there will be cases where the increase in discharge may not be considered to be an issue. However normally there is some impact on receiving waters or the WwTW so costs should normally be associated with any change in outflows. This could be positive or negative as a reduction in flow downstream might have significant benefits. The model has two methods for outfall costs; they are based on the change in volume difference passing through the outfalls and on the volume difference above a flow rate threshold. The decision on these costs is more important than the boundary condition costs, as these are effectively real costs associated with the downstream impact of the changed system. Where more than one event is applied (design storms or time series) the costs are cumulated. This is not particularly logical for use with one or more design storms (as the more storms used, the greater the outfall costs), but it fits well with the use of a continuous series. The benefit of reduced volumes is particularly relevant for WLC analysis in assessing benefits related to operating costs.

As it can be seen from Figure 7, these conditions are translated into the terms Objectives and Constraints. The Objective is the aspect which is to be optimised; when using level of service approach this will be minimisation of the asset costs with constraints that meet the target level of service for each location and also minimises constraint costs associated with boundary outfalls and other points in the system. A constraint cost is deemed to indicate a "failure".

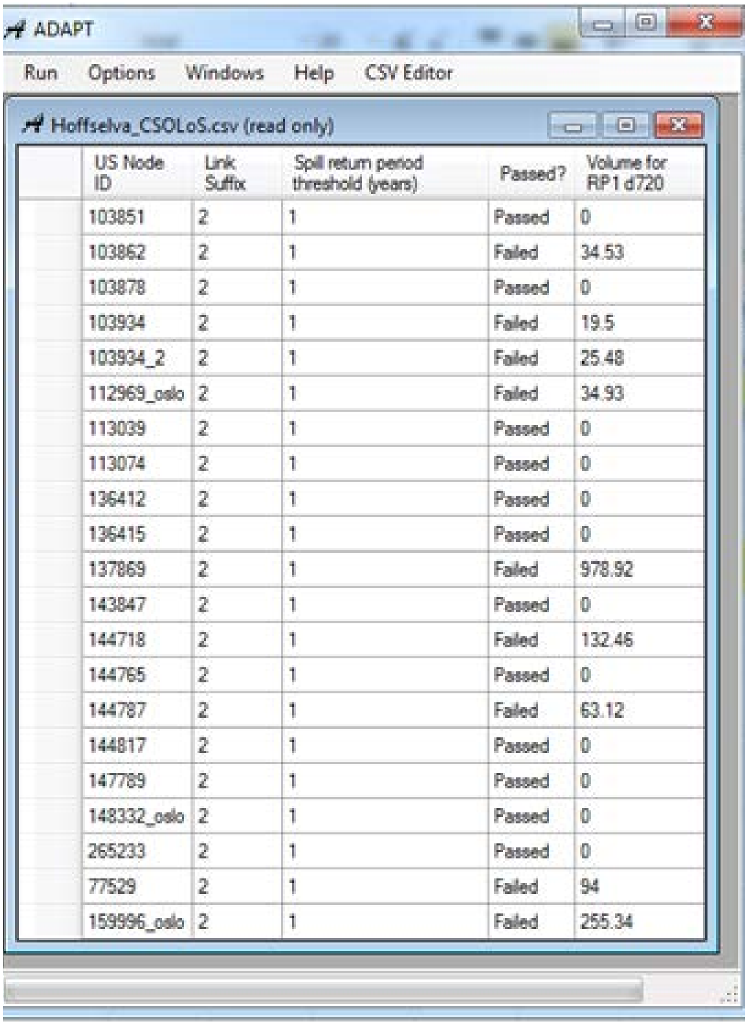
In the case of the Hoffselva catchment the objectives are:

- To minimise the asset costs to achieve performance on both CSO spill frequencies and prevention of flooding of basements,

The constraints are:

- Minimise Boundary Costs for flooding,
- Minimise Boundary Costs for surcharge of selected basement nodes,
- Minimise Boundary Costs at outfalls for volumes above a defined flow rate above a 2 year threshold,
- Minimise Boundary Costs on flow volume at each outfall (not applied),
- Level of service for target locations must be passed.

To find out whether or not a solution has passed the network performance requirements for the 'Level of Service Analysis' a check can be made to see if all the conditions have been met. An illustration is shown in Figure 8. This shows Pass or Fail, and also how much spill volume was generated.



US Node ID	Link Suffix	Spill return period threshold (years)	Passed?	Volume for RP1 d720
103851	2	1	Passed	0
103862	2	1	Failed	34.53
103878	2	1	Passed	0
103934	2	1	Failed	19.5
103934_2	2	1	Failed	25.48
112969_oslo	2	1	Failed	34.93
113039	2	1	Passed	0
113074	2	1	Passed	0
136412	2	1	Passed	0
136415	2	1	Passed	0
137869	2	1	Failed	978.92
143847	2	1	Passed	0
144718	2	1	Failed	132.46
144765	2	1	Passed	0
144787	2	1	Failed	63.12
144817	2	1	Passed	0
147789	2	1	Passed	0
148332_oslo	2	1	Passed	0
265233	2	1	Passed	0
77529	2	1	Failed	94
159996_oslo	2	1	Failed	255.34

Figure 8. Level of Service Analysis in ADAPT

Boundary points are the locations in the network where no negative change should be observed due to the network improvements. In order for ADAPT to be able to observe any changes it performs a baseline run which has had no changes made to the network. ADAPT then uses these results to compare with the runs of proposed solutions to check to see that there are no negative changes in the boundary points.

Effectively all nodes which can flood are boundary points so in the Hoffselva catchment there are 1547 locations in the network which need to be checked for additional flooding, whether they flood in the baseline condition or not. Figure 9 illustrates the tool interface on boundary points for ADAPT. If the network improvement system state results in additional flooding at any of these points a significant cost is assigned to it. This will cause ADAPT to rank this solution as a less desirable option. Solutions with no boundary costs incurred will therefore have a high ranking.

The boundary points that are taken into account in the Hoffselva catchment are:

Flooding points

The network improvements should not increase flooding compared to the base run for any flooding location.

Basement surcharge points

The network improvements should not increase surcharge water level in any nominated node above a specified level. This is not the same as setting a constraint of no-worsening as water levels could increase up to the specified level. If the water level is set lower than the existing system performance then effectively an improvement will need to be achieved to enable a system solution to “Pass”. In the case of Hoffselva, this is set as being a water level at 58 target node locations where surcharge greater than 0.9m is considered to cause basement flooding.

CSOs at outfalls

The network improvements should not increase the volume of water spilling from outfall and other non-target CSOs compared to the base run. A throttle and a weir is applied to all outfalls to generate outfall overflow volumes. In the case of Hoffselva there are six outfall CSOs with orifices set based on the pass forward flow rate for the 1 in 2 year event from the base model.

Outfalls

The total volume of runoff is measured at every outfall and additional runoff will result in additional cost if a cost is associated with this measurement. If CSO spills are reduced in the catchment upstream, an increase in total flow at outfalls will always result. In the case of this pilot study a cost associated with total flow to the system downstream has not been added as the impact on the drainage system and WwTW downstream has been stated as being small.

It is important to recognise that a CBA approach which uses boundary costs to develop a Pareto front means that thought must be put into the relative costs of the different boundary cost elements.

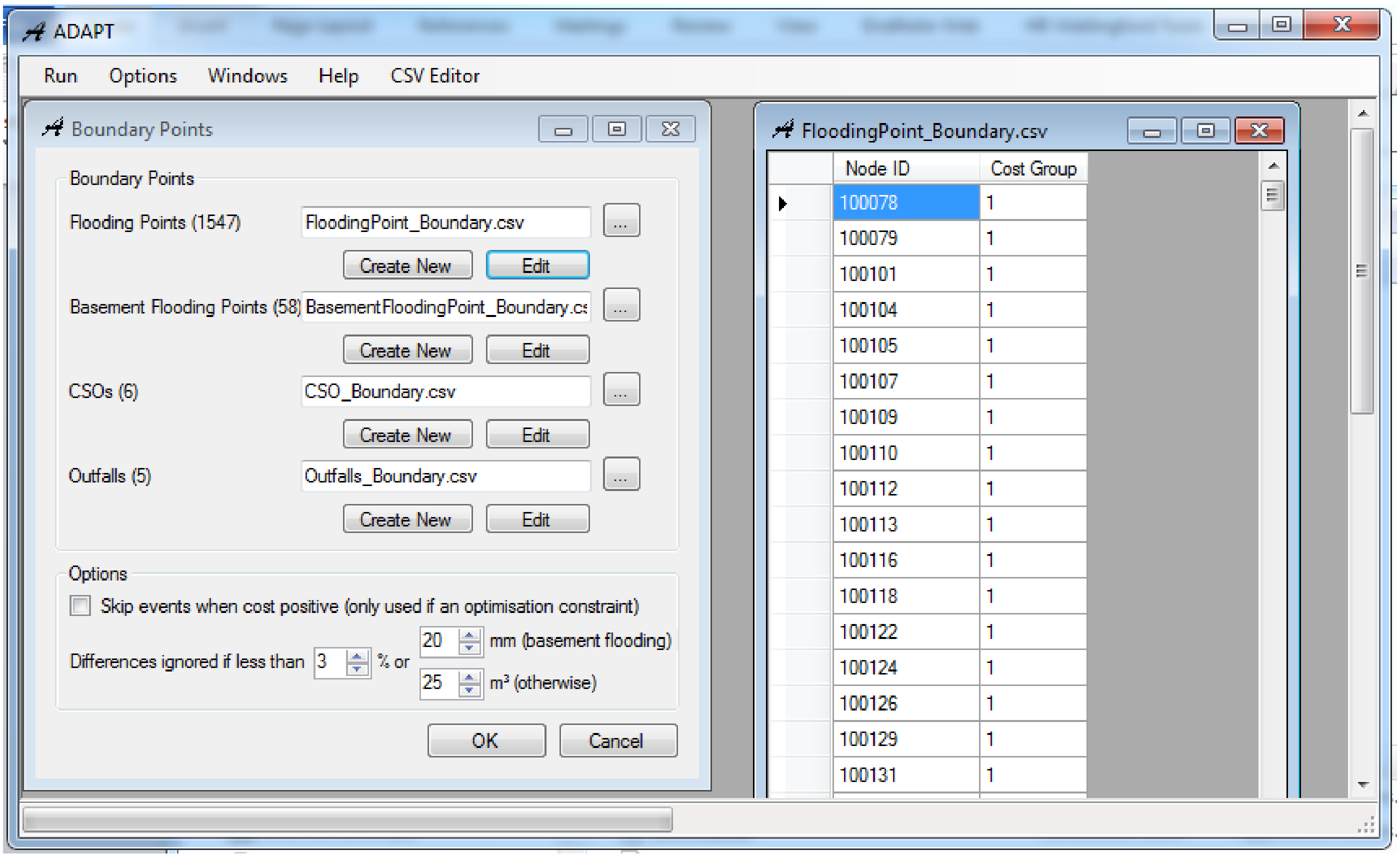


Figure 9. Boundary points in ADAPT

Improvement points or target points are the locations in the network where the level of service needs to be met. In the Hoffselva catchment 21 CSO spills were identified as improvement points. If a selected system state results in a CSO spill at a target CSO it will be classified as a failure and a cost will be associated for the spill volume. This will result in ADAPT giving the solution a low ranking. Note that where there is insufficient budget available to achieve the level of service criteria, then the cost for the spill volume at each target CSO must be based on the impact of the spill on the environment and a solution will be produced which minimises the cost associated with the spill volumes from the target CSOs for improvement as well as any other boundary costs incurred.

ADAPT has the option of using different criteria for different target location points or categories. Thus Basements can be set to comply with a 10 year event, a selection of CSOs could be given a higher performance requirement than others, and so on. Figure 10 shows the setup of improvement points in ADAPT.

Infoworks CS calculations can result in very small differences in water levels and flood volumes at points where no changes have been made. This is due to changes made elsewhere in the model (which should have no influence on the results at other locations, but which do result in differences. This is due to different time-steps being used in the computation for different runs. To cater for this, a small tolerance allowance is introduced into the water levels and flood volumes before costs are incurred for boundary constraints failures.

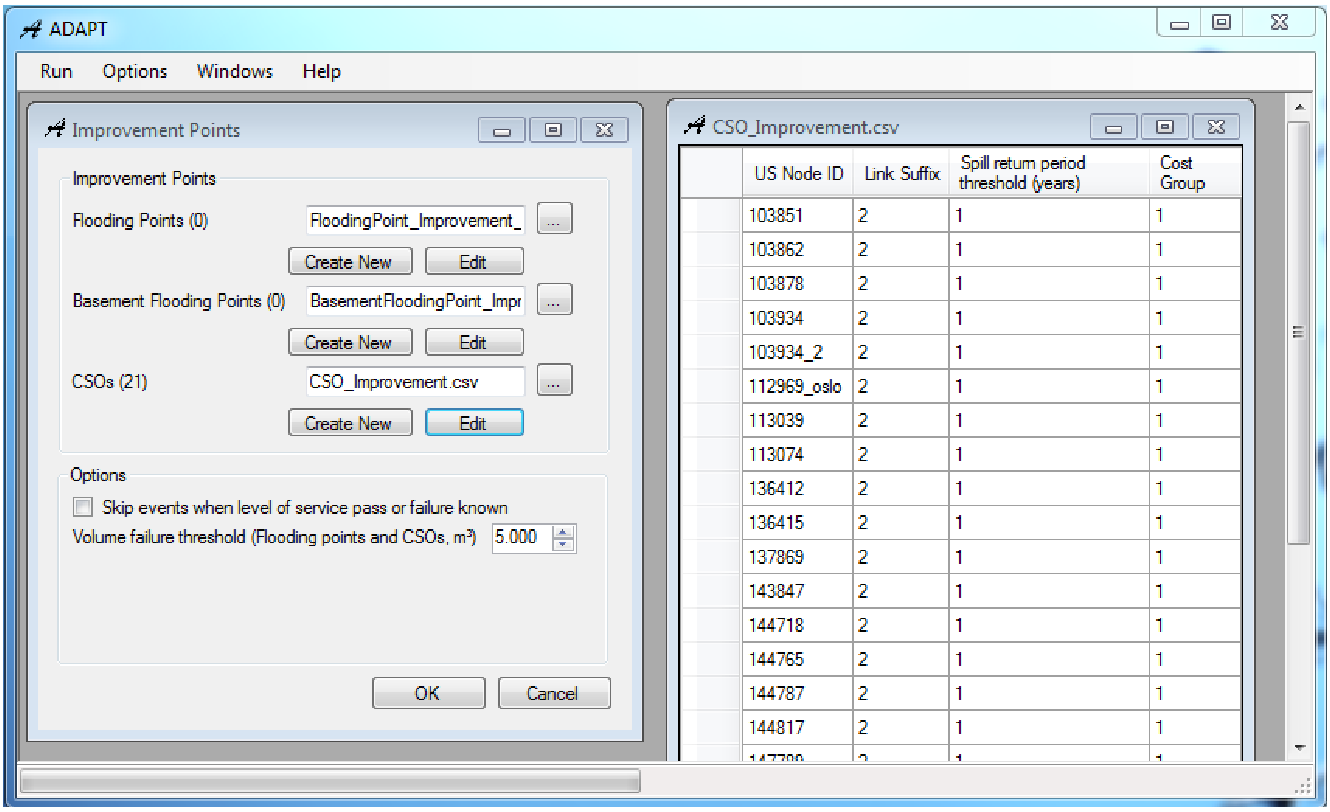


Figure 10. Improvement points

2.3.3. Initial solutions

Initial solutions can be used by the engineer to give ADAPT a starting point to minimise the number of generations needed.

ADAPT stops after it has reached the specified number of generations. The solutions that have been found might still be improving, and possibly the level of service constraint may not have been satisfied. One or more of the solutions established at the point at which the tool has been stopped can be used to continue running ADAPT. Figure 11 shows how initial solutions can be added to ADAPT. In this example one solution is shown, but multiple solutions can be provided.

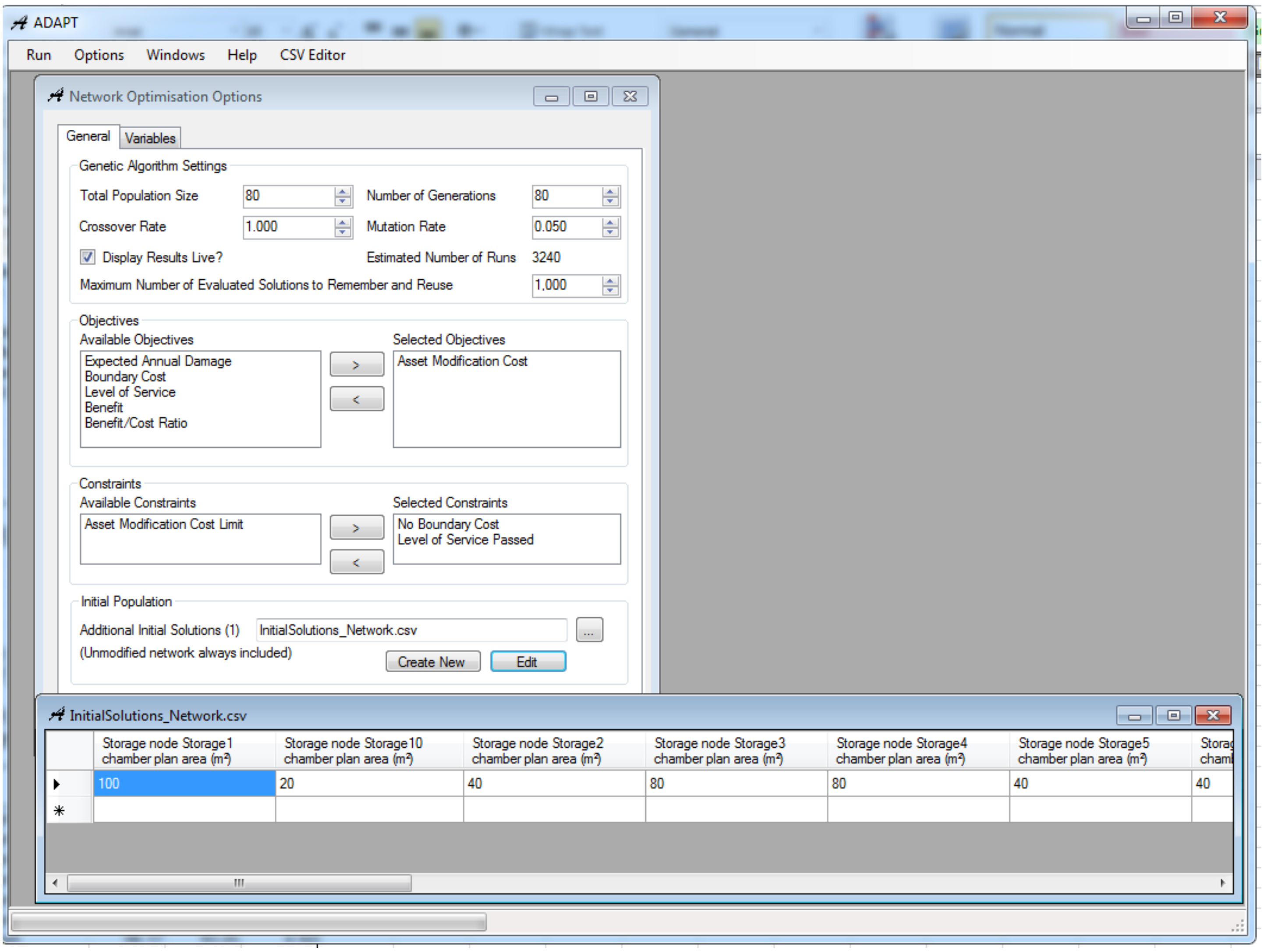


Figure 11. Providing initial solutions into ADAPT

2.4. System state improvement options

There are various ways in which ADAPT can find a solution to meet specified performance criteria. There are three ways in which the performance of a network can be improved. These are:

- Reduce flows;
- Attenuate flows;
- Provide greater conveyance capacity.

The safest approach is to reduce flow volumes as this is bound to result in no worsening at any point in the system, however this is not always possible to achieve and not necessarily the most cost effective approach.

The next most easily applied solution technique is the application of attenuation storage. This makes no difference to the performance of the network upstream of any storage provision and any part of the system downstream will have reduced flow rates. However flow volumes passing forwards from the network downstream will increase if CSO spill volumes are to be reduced.

The use of increasing pipe sizes is appropriate in relieving constraints in the system, but at the expense of increasing flow rates and flow volumes downstream with the risk of making the hydraulic conditions worse at points downstream of any intervention. The use of a pipe size increase generally means pipe sizes need to increase all the way downstream, or the inclusion of a tank to attenuation flows, or an increase in spills at a CSO downstream.

ADAPT applies this concept in the three main categories as follows:

- Disconnection points on a surface network (flow rate and volume reduction);
- The use of SuDS (runoff reduction and attenuation);
- Storage tanks and orifice controls (attenuation);
- Pipes (conveyance).

Optimisation can be performed using one or all of these various techniques. These are discussed in the following sections.

It is important to note that the network model must have all elements of the nodes and links and controls in the system. These can be modified by ADAPT in devising the optimum solution, but cannot be added during the analysis process. The only exception to this is that inflow hydrographs can be called up as and when they are needed. The use of inflow hydrographs are used when considering the application of SuDS elements.

2.4.1. Disconnections

In many catchments there are areas where separate systems have been built. In some instances the surface water system has been connected into the combined system downstream. It is possible that at this point or further upstream, that the surface water network can be disconnected and discharged to a watercourse. In some instances this might be just a simple matter of the cost of the construction of laying the sewer to a stream, but provision can be made to provide an attenuation storage system in conjunction with the disconnection to ensure the flow rate into the stream is limited to a maximum value to minimise morphological impact.

As all parts of the network must be in the model at the commencement of the analysis, this disconnection link and any control needs to be included in the model. Therefore these links need to be included as a nominal pipe of minimal size to allow initialisation of the model.

2.4.2. SuDS

There are a range of SuDS techniques; each of which provide different benefits. The SuDS components provided in ADAPT are:

- Infiltration / soakaway units;
- Rainwater harvesting;
- Attenuation basins / Permeable pavements;
- Ponds.

Infiltration systems are assumed to disconnect all the runoff up to a specific limit linked to a volume and the infiltration rate.

Rainwater harvesting systems are assumed to only be applied where they are designed as stormwater control systems. A specific retention volume is provided after which runoff is not restrained. Their representation will only be approximate as their performance is strongly dictated by antecedent conditions. Therefore any solution which is dependent on rainwater harvesting should be check subsequently using a continuous time series.

Attenuation basins are assumed to provide the same behaviour as attenuation tanks, but an initial runoff loss can be assumed.

Ponds are assumed to perform in exactly the same way as attenuation storage tanks.

The SuDS tools work on the basis of disconnection of paved area from one or more catchments. This area is run in the appropriate SuDS model and an inflow hydrograph is generated to include the resulting flow into the main model at the appropriate location. More than one type of SuDS model can be considered for disconnection of any paved area.

2.4.3. Storage Tanks and Orifices

On-line storage tanks and orifices are improvement asset options in ADAPT. Figure 12 shows the ADAPT interface for adding storage tank locations. Every storage tank has an associated weir for overtopping when it is full to pass flows forward. The normal outlet from the tank has an orifice. ADAPT explores the options of using different tank sizes and different orifice control rates.

The on-line tanks are modelled as storage nodes with an orifice based on limiting the flow rate. Until the storage node volume is modified by ADAPT in its options selection process, it will ensure that the size of the orifice is not modified. Flows will only be throttled once a storage tank is being considered as an option for variation. However this dependency can be removed if it is thought to be appropriate.

A maximum and minimum size range can be defined for any storage node. This allows the space in which ADAPT searches for solutions to be narrowed. A default maximum storage size is found by using the total volume of the design event being used. A step size is provided to the degree of resolution to maximise computational efficiency. This also applies to orifice sizes.

Off-line tanks have not been included (yet) into ADAPT. This is because an RTC element is needed to allow flows to pass back into the system based on downstream capacity, but as the pump rate is a potential variable this would require the RTC rule to also allow a variable flow rate. This effectively creates too many variables making it an inefficient component to optimise. However on-line tanks have their own problems in that the depth of storage available is often limited at most potential locations and care is needed not to create backwater problems immediately upstream of the tank location. This means that artificially small depths are used resulting in very large cross-sectional areas. The “chamber” element of the manhole is used to provide the storage. In practice this means that engineering input is needed to interpret the actual construction requirements of optimum solutions suggested by the tool.

In the Hoffselva catchment 10 storage nodes with orifices were introduced as variables. The maximum size of the storage nodes were set using the total inflow volume from the base line run. The minimum size of the storage node is set effectively to zero (the size of a manhole). The maximum orifice flow rate was set to the maximum flow rate in the link upstream of the storage node in the base line run. The minimum flow rate was set to 1 l/s. The values use in the Hoffselva catchment for the 0.33 return period event (3 spills a year) are shown in Table 2.

Table 2. Maximum, minimum and step size of storage nodes and orifice flow rates for the 0.33 return period event

LOCATION	MAXIMUM STORAGE NODE SIZE (M2)	MINIMUM STORAGE NODE SIZE (M2)	STEP SIZE STORAGE (M2)	MAXIMUM ORIFICE SIZE (M3/S)	MINIMUM ORIFICE SIZE (M3/S)	STEP SIZE ORIFICES (M3/S)
Storage1	1880	0	37	0.15	0.001	0.0029
Storage2	631	0	12	0.05	0.001	0.0009
Storage3	1097	0	21	0.12	0.001	0.0028
Storage4	4517	0	89	0.26	0.001	0.0052
Storage5	660	0	12	0.05	0.001	0.0010
Storage6	1795	0	35	0.15	0.001	0.0029
Storage7	7242	0	144	0.83	0.001	0.0166
Storage8	1765	0	34	0.11	0.001	0.0022
Storage9	1045	0	20	0.13	0.001	0.0026
Storage10	134	0	2	0.02	0.001	0.0003

Notes: Step size is based on a resolution of 50, this resolution can be chosen on the ADAPT network optimisation variables interface.

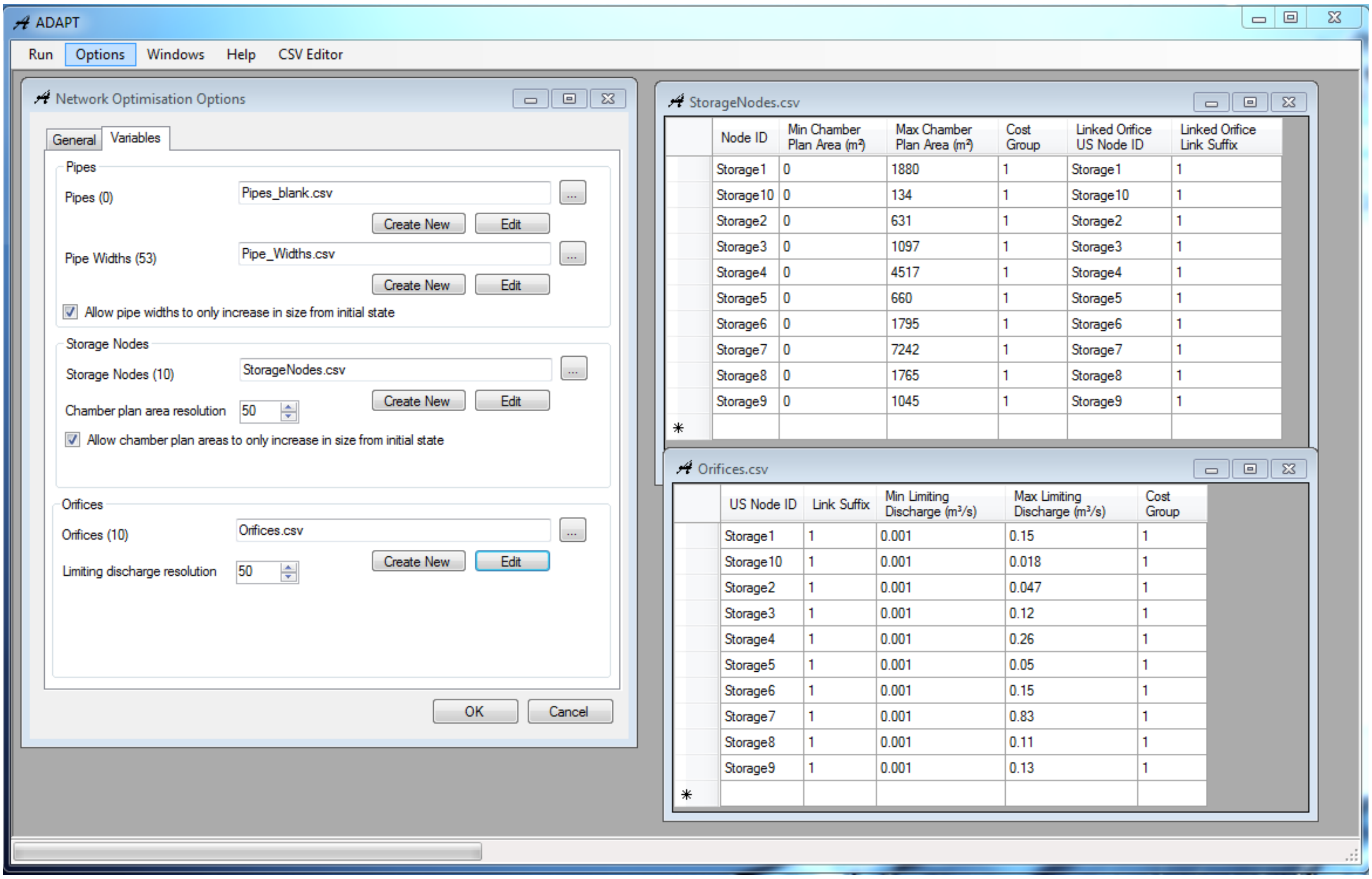


Figure 12. ADAPT variables – storage nodes

2.4.4. Pipes

Pipe sizes are often the same or very similar in size or capacity for many links in a branch. Changing one link then would normally require a change in the following links downstream. In addition the concept of a pipe size reduction from upstream to downstream is generally not considered to be good practice; at least for diameters below around 600mm. As a result the concept of pipe groups has been introduced so that where one pipe is changed all the pipes in the group are increased in size. ADAPT changes the pipe diameters using a library of pipe diameters. Figure 13 shows the ADAPT menu for pipe variables.

In the Hoffselva pilot when looking at using pipe size increases, 34 pipe groups were initially defined, and these were reduced by reselection once it was clear that viable solutions were being found that were not including using some of the groups.

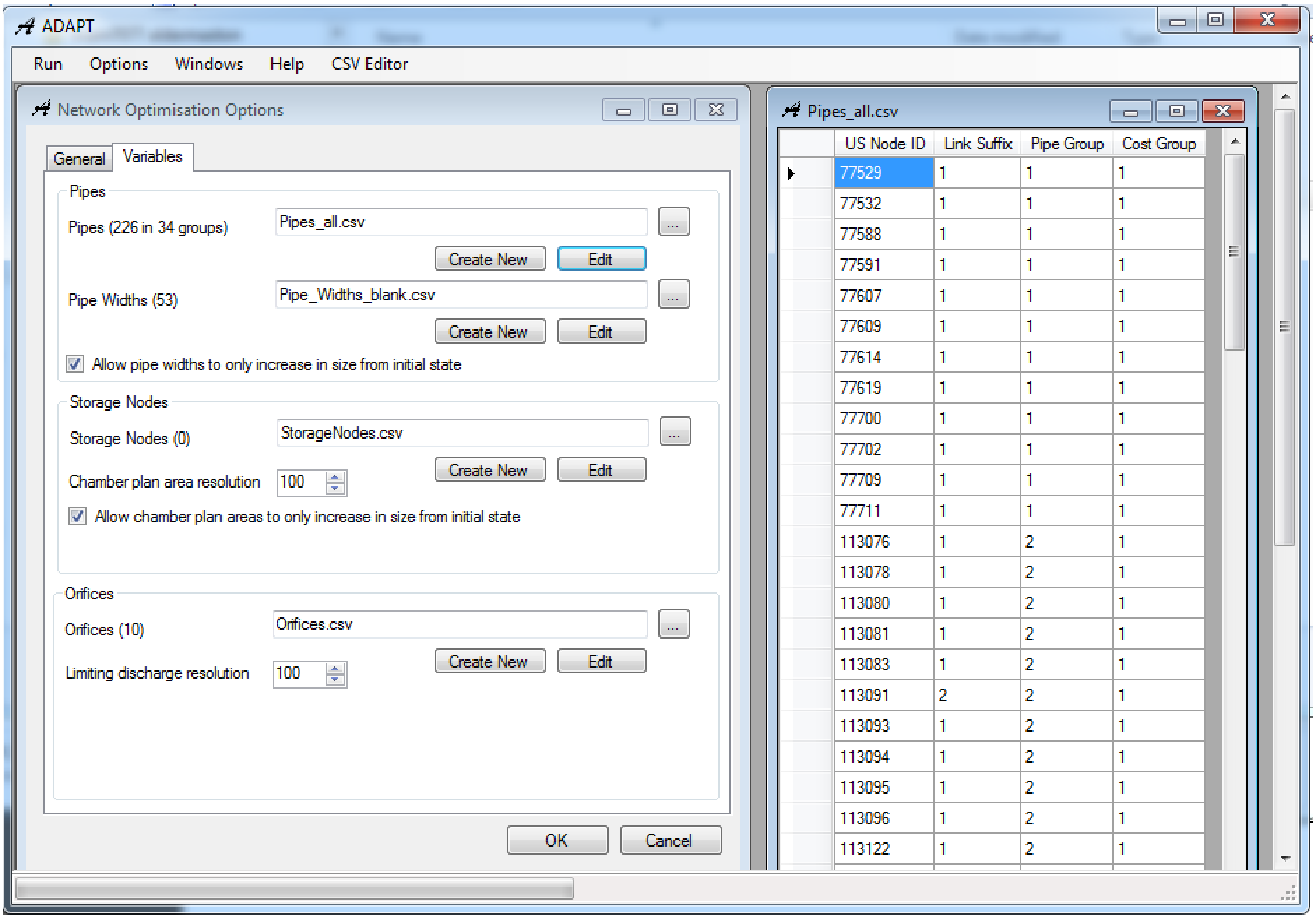


Figure 13. ADAPT variables – pipes

2.5. Costs

Costs are the mechanism by which the genetic optimisation algorithm arrives at the “best” set of solutions. There are two main types of cost in ADAPT:

- Asset modification cost; cost related to the proposed changes to the network;
- Boundary costs at all locations where system performance must be prevented from being reduced (which are therefore set high to ensure such solutions are rejected in preference to the costs associated with possible solutions);
- Boundary outfall costs associated with volumes above a flow rate, as well as total volumes of runoff;
- Target improvement point costs - penalty costs which are assigned when the criteria in the network performance requirements are not met (for instance spill volume costs when spill criteria cannot be complied with).

2.5.1. Asset modification cost

Cost related to the three variables (pipes, storage nodes and SuDS) can be defined in ADAPT. Multiple cost groups can be defined and linked to the variables. The different asset types can have unique or general costs associated with them. Figure 14 shows the ADAPT interface for asset modification costs.

Storage nodes and orifices each have the following costs, though orifices would normally have costs set to zero on the basis that they are part of the tank costs:

- Minimum cost for intervention – the minimum cost for construction to take place at a proposed asset change location;
- Tank - asset unit cost (by volume);
- Orifice - asset unit cost (by flow rate);

The pipes have the following costs:

- Minimum cost for intervention – the minimum cost for construction to take place at a proposed asset change location;
- Asset unit cost (by length) for each pipe size

The reason for having an intervention cost is to prevent lots of very small changes being proposed in the network which would be impractical to construct. The costs that have been used for Hoffselva are presented in Table 3.

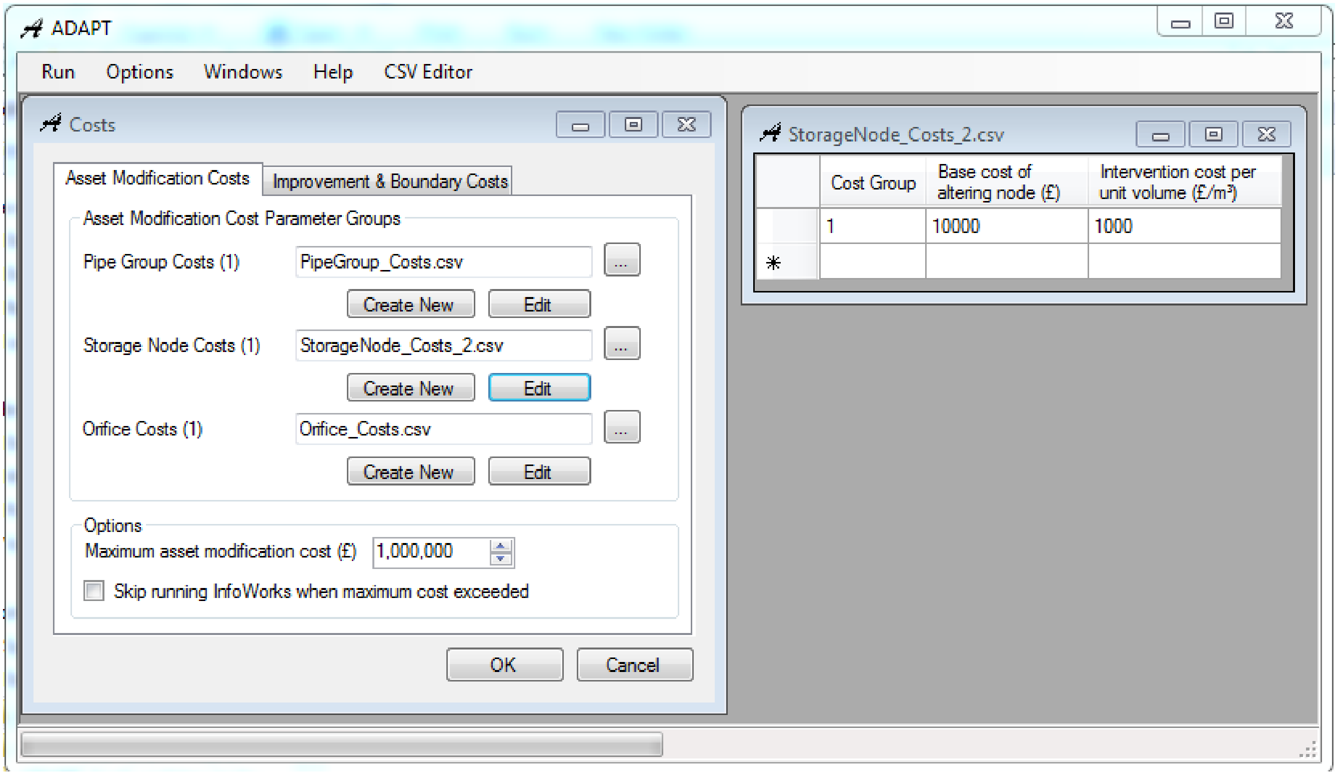


Figure 14. ADAPT – asset modification costs

Table 3. Costs in the Hoffselva catchment

VARIABLE	COST TYPE	COST
Storage nodes	Minimum cost for intervention	1,000,000 (kr)
	Asset cost per unit volume	10,000 (kr/m3)
Orifices	Asset cost of orifice	0 (kr)
Pipes	Minimum cost for intervention	1,000,000 (kr)
	Asset cost per unit length	150mm dia , 7500 – 4500mm dia 225,000 (kr)

Notes: No cost groups were used in the Hoffselva catchment

2.5.2. Target improvement and other boundary costs

Penalty costs are given when the criteria in the network performance (target and boundary points) are not met. Cost can be assigned to:

- Flooding at nodes
- Surcharge levels at nodes
- CSO spill volumes
- Outfall volume costs – volumes passing downstream, and volumes above a threshold passing downstream.

In the same way as for asset costs, costs have initial intervention costs and cost per unit flood volume or water depth or spill volume. If they are set as boundary points, costs are only incurred if the values increase compared to the system performance of the base model. If they are set as target improvements, then specific performance values can be allocated. A tolerance range is allowed before penalty costs are incurred as a model can return slightly different results at a location even when the system upstream of the point has not been changed.

Figure 15 shows the interface for improvement and boundary costs. Table .4 shows the improvement and boundary costs that have been assigned in the Hoffselva catchment.

Table 4. Overview of costs for the Hoffselva catchment

IMPROVEMENT AND BOUNDARY POINT COST PARAMETER GROUPS	TYPE OF COST	COST
Flooding points	Initial cost of flooding	10,000,000,000 (kr)
	Cost per unit additional volume	10,000,000,000 (kr/m3)
Basement point cost	Initial cost of flooding	10,000,000,000 (kr)
	Cost per unit depth	10,000,000,000 (kr/m)
CSO costs	Initial cost of a spill	10,000,000,000 (kr)
	Cost per unit additional volume	10,000,000,000 (kr/m3)
Outfall costs	Initial cost of a spill	0 (kr)
	Cost per unit additional volume of spill	0 (kr/m3)
	Cost per unit additional volume passing downstream	0 (kr/m3)

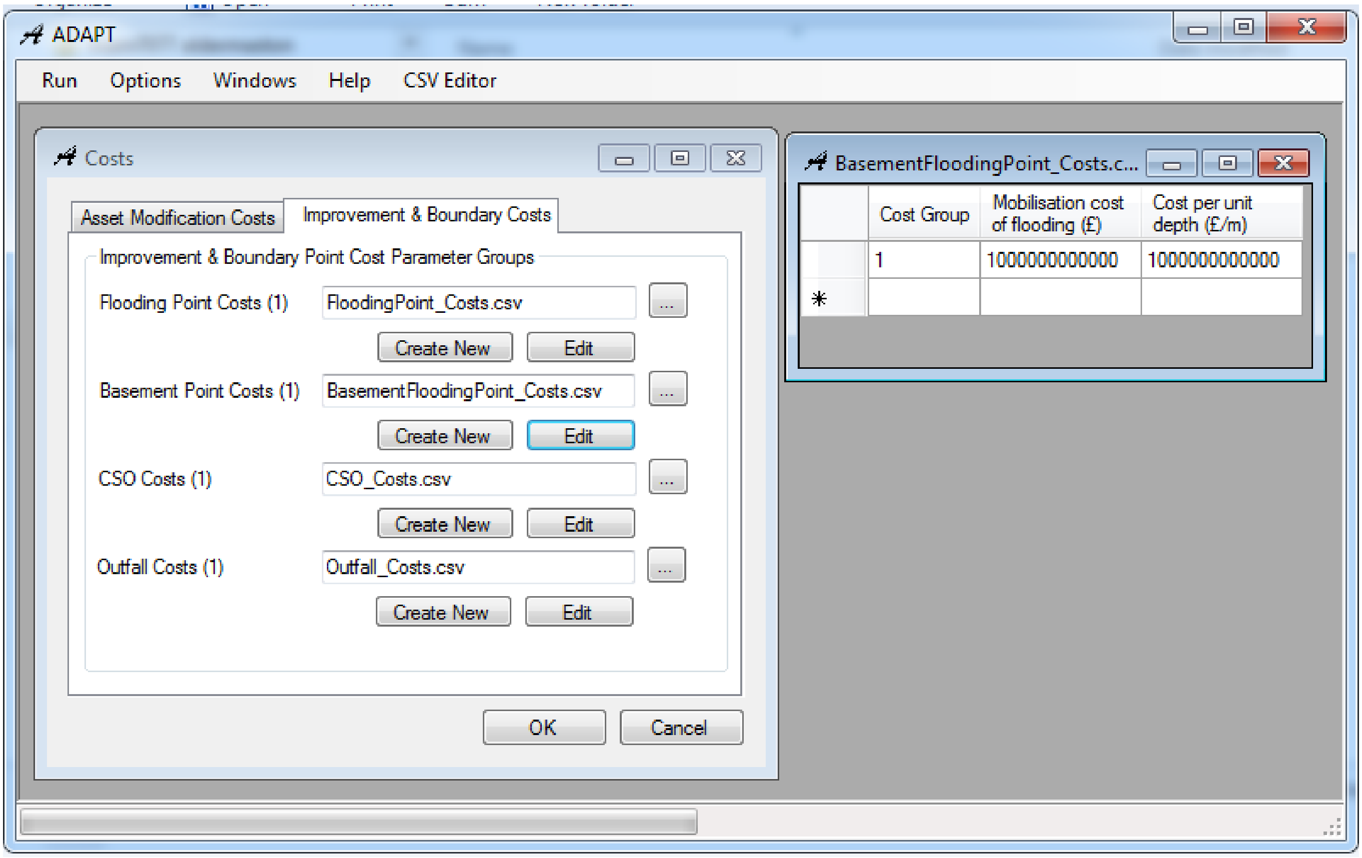


Figure 15. ADAPT – Improvement and Boundary costs

3. RUNNING ADAPT

3.1. Run times

The run time of ADAPT is linked to the runtime of the InfoWorks CS model and the number of times it is run. A 'chromosome' is a single run of network. One generation of the GA analysis consists of 80 chromosomes, 40 of which are the best solutions from the previous generation, which takes approximately 15 minutes to run in the case of Hoffselva. The total number of generations needed to find a set of compliant and optimum solutions is dependent on the number of variables that need to be chosen. When running the Hoffselva catchment with 20 variables (10 tanks and 10 orifices) it requires around 200 generations to find a good solution and this takes approximately 50 hours (2 days). In general the number of variables should be limited to 10 for efficient application of the tool, and any more than 20 requires very fast computing capability and / or small simulation models.

ADAPT can be stopped at any time to examine its results and restarted with one or more models with either the set of chromosome models or modified models.

ADAPT remembers all the possible solutions it has tried to ensure that it does not repeat certain system states of the same variable combinations. This can result in storage over-load and failure, so this record is normally limited to the last 1000 chromosomes; which at 80 chromosomes per generation is around 12 generations.

3.2. Results

ADAPT generates a output files for every generation containing details on all solutions (chromosomes). The files contain:

- Chromosome ID number;
- The variables used;
- Asset modification costs;
- Boundary costs;
- No Boundary cost (true of false);
- Level of service passed conditions;
- Level of service excess failing cost;
- Level of service excess surplus cost;
- Level of service passed (true of false);
- Rank.

Figure 16 shows an example output.

	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1	Storage nc	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Orifice Sto	Asset moc	Boundary	No Bounda	Level of se	LoS total e	LoS total e	Level of Se	Rank
2	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	834112	0	TRUE	21	0	0	TRUE	1
3	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.02	0.594	0.021	0.016	838923.8	0	TRUE	21	0	0	TRUE	2
4	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0231	0.019	0.594	0.0237	0.016	838923.8	0	TRUE	21	0	0	TRUE	2
5	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.0144	838923.8	0	TRUE	21	0	0	TRUE	2
6	24	0.035	0.0079	1 (original)	0.0171	1 (original)	0.0228	0.018	0.594	0.0237	0.016	838923.8	0	TRUE	21	0	0	TRUE	2
7	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	838923.8	0	TRUE	21	0	0	TRUE	2
8	26	0.035	0.0076	1 (original)	0.0144	1 (original)	0.0204	0.02	0.594	0.021	0.016	839539.8	0	TRUE	21	0	0	TRUE	3
9	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	842546.8	0	TRUE	21	0	0	TRUE	4
10	24	0.035	0.0079	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	842546.8	0	TRUE	21	0	0	TRUE	4
11	24	0.035	0.0079	1 (original)	0.0171	1 (original)	0.0204	0.018	0.594	0.0243	0.016	842546.8	0	TRUE	21	0	0	TRUE	4
12	24	0.035	0.0079	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	842546.8	0	TRUE	21	0	0	TRUE	4
13	24	0.035	0.0079	1 (original)	0.0144	1 (original)	0.0231	0.018	0.594	0.0237	0.016	842546.8	0	TRUE	21	0	0	TRUE	4
14	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.0144	842546.8	0	TRUE	21	0	0	TRUE	4
15	24	0.035	0.0068	1 (original)	0.0207	1 (original)	0.0204	0.018	0.594	0.0237	0.016	843501	0	TRUE	21	0	0	TRUE	6
16	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
17	24	0.035	0.0079	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
18	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
19	24	0.035	0.0075	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
20	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
21	24	0.035	0.0085	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.021	0.016	843639.8	0	TRUE	21	0	0	TRUE	7
22	26	0.035	0.0076	1 (original)	0.0144	1 (original)	0.0204	0.02	0.594	0.021	0.016	843731.8	0	TRUE	21	0	0	TRUE	8
23	26	0.035	0.0076	1 (original)	0.0144	1 (original)	0.0231	0.018	0.594	0.0237	0.016	843731.8	0	TRUE	21	0	0	TRUE	8
24	26	0.035	0.0076	1 (original)	0.0144	1 (original)	0.0204	0.02	0.594	0.0225	0.016	843731.8	0	TRUE	21	0	0	TRUE	8
25	26	0.035	0.0076	1 (original)	0.0144	1 (original)	0.0204	0.018	0.594	0.0237	0.016	843731.8	0	TRUE	21	0	0	TRUE	8

Figure 16. ADAPT output summary file for each set of runs for one generation

ADAPT has the option of saving the InfoWorks run results enabling the solutions to be analysed in the network. Care needs to be taken with longer runs due to the run results taking up a large amount of space and ADAPT will fail when networks get too large. ADAPT only saves the results of the last generation.

ADAPT has the option of generating more detailed results for to assist in analysing the solutions. Creating these files is optional. The files can contain network details and run results. In the case of Hoffselva a request was made to report on water levels in the basement nodes.

3.3. Processed ADAPT results

Due to the large quantity of results available after one ADAPT run, processing is required and this is best done by using macros or developing some code. This ensures both efficiency and flexibility. Although any of the outputs can be used for data analysis purposes, the main output of ADAPT is the movement of the object(s) toward an optimum as the generation progress. Figure 17 shows an example of this for a run with a single objective and Figure 18 shows an example of this for a run with multiple objectives (two objectives).

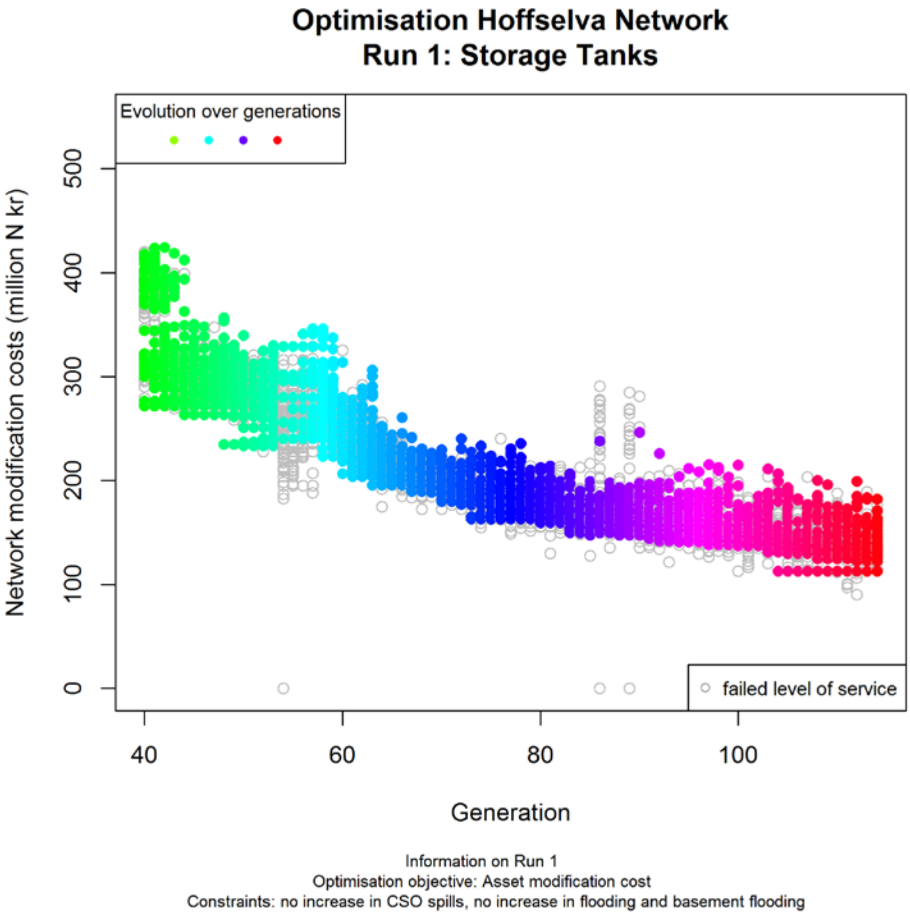


Figure 17. Convergence towards a minimum cost solution

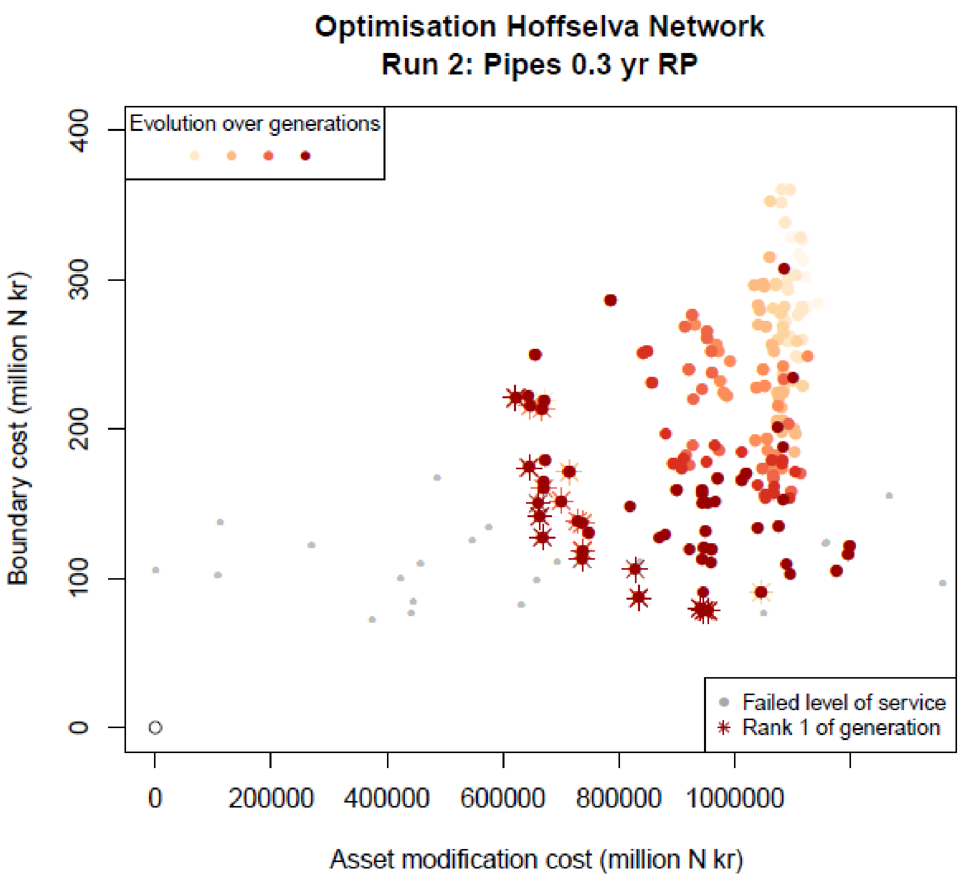


Figure 18. The use of a multi-objective optimisation – boundary costs trade off against asset improvement costs

The use of multi-objective analysis is generally used with a risk based approach, but it is also used for a level of service where appropriate. In a situation where the design criteria cannot be met (possibly due to excessive cost), the trade-off of penalty costs (say spill volume costs) against the asset solution costs is a useful output.

4. CREATING THE INFOWORKS MDEL OF HOFFSELVA

ADAPT is a tool based around the COM interface which is available in Infoworks CS. As the network data for Hoffselva was not available in digital format and because a calibrated Mike Urban model existed of the catchment, it was necessary to create the Infoworks model from the Mike Urban model. This chapter summarises this process and the verification carried out to show that the model is suitable for use for this study.

4.1. Importing the model from Mike Urban

The Mike Urban model required conversion into InfoWorks CS to carry out this pilot project. InfoWorks CS does not have the capability to import a model from Mike Urban directly, but it can import MOUSE model text files, which can be exported form the Mike Urban model. The MOUSE files consist of MPR summary files, a UND file which contains network information, and a HGF file which contains the subcatchment hydrology parameters. These MOUSE files contain the majority of information required by InfoWorks CS to produce a working model. However, some aspects of the models are not directly comparable and these required assumptions and recalibration to produce a suitable InfoWorks CS model. These include pump parameters, headloss coefficients and the runoff models. The key model parameters and any adjustments and assumptions made are detailed in the following sections.

4.1.1. Hydraulic model parameters

Hydraulic model parameters were imported completely without manual intervention, with the exception of pump data and headlosses.

Headlosses in Mike Urban are calculated at nodes whereas in InfoWorks they are calculated at links. They also make use of different formula for headloss. All MOUSE nodes used a type 2 outlet which is designed to approximate to a sharp edged transition from pipe to manhole and all nodes used this headloss model. This is imported to InfoWorks as the default headloss parameters of 'NORMAL' headloss with a coefficient of 1. These values have not been adjusted further in InfoWorks.

The pump data required head-discharge tables which appeared to be missing from the MOUSE files. Since the pumps are relatively small and operate on a small portion of the upper model they were approximated using fixed pump rates as specified by Oslo City Water and Sewerage Authority (VAV Vann- og avløpsetaten). Asset PA1624 consists of two pumps at 14 l/s and asset PA1642 consists of two pumps at 15 l/s.

Roughness values of 85 (Manning) were used throughout the Mike Urban model and this value was therefore used in the InfoWorks model rather than using Colebrook-White.

4.2. Combined Sewer Overflows (CSOs)

CSOs were imported successfully and have been cross checked with the CSOs reported in the verification report (DHI, 2011). Table 5 provides the CSOs' name together with the InfoWorks link ID which represents it. Note that the all CSOs are modelled as weirs except HO64_oslo which is modelled as a user defined head-discharge relationship.

Table 5. CSO links in the Hoffselva InfoWorks CS model

CSO NAME	INFOWORKS LINK REFERENCE
Ho4hi_oslo	148332_oslo.2
Ho6Ma	137869.2
Ho7Ma	143847.2
Ho8Ma	144817.2
Ho9Ma	144787.2
Ho10Ma	144765.2
Ho11Ma	103862.2
Ho12Ma	103851.2
Ho13Ma	103878.2
Ho14MA_230	103934_2.2
Ho14Ma_380	103934.2
Ho15Ma	113039.2

HO16Ma_oslo	112969_oslo.2
Ho18Ma	113074.2
Ho61	77529.2
Ho63Ma	144718.2
HO64_oslo	159996_oslo.2
Ho67_1	136415.2
Ho67_2	136412.2
Ho67_3	147789.2
Ho68	265233.2

Other model outflows

In addition to the CSOs, other locations exist at which water can leave the drainage model. These comprise transfers to other drainage systems as well as the main outfall from the Hoffselva model. Table 6 summarises these links.

Table 6. Other outflow links in the Hoffselva Infoworks CS model

INFOWORKS LINK REFERENCE	MODEL LINK	COMMENTS
138435_oslo.1	Conduit	Transfer
1_263_oslo.1	Conduit	Transfer
2_2_oslo.2	Conduit	Transfer, although it is in the centre of the system which makes it an unusual location for a transfer
Node_1.1	Conduit	Main outfall
150356_oslo.2	Weir	Transfer overflow
150377.2	Weir	Transfer overflow

4.3. Hydrology and runoff modelling

This section discusses the importing of runoff models from the MOUSE hydrology (HGF) file into InfoWorks CS. Runoff from impervious surfaces was straightforward to import as both Mike Urban and InfoWorks CS use a fixed percentage runoff model in which a proportion of the rainfall landing on impervious surfaces generates runoff. The impervious surface areas for each subcatchment are recorded in the HGF file as are the fixed percentage runoff values.

Runoff from pervious surfaces is modelled using the Rainfall Dependent Infiltration (RDI) model in Mike Urban. This model has been used to represent runoff from pervious surfaces (the fast runoff component) as well as infiltration from soil and ground water storage (the slow runoff component). This model is not available in InfoWorks therefore an approximation using available models was required.

The New UK runoff model was used to represent runoff from the paved and pervious surfaces and the InfoWorks infiltration model used for infiltration flow into the network. In order to make as much use of the available Mike Urban model data as possible, the pervious surfaces were all assigned to the New UK runoff model rather than attempting to re-extract surface areas from primary data. The infiltration model was applied to all subcatchments.

Mike Urban uses a time-area curve to route runoff into the drainage system, this is not supported in InfoWorks. InfoWorks uses the Wallingford routing model which consists of a double linear reservoir. The Wallingford model is controlled by a routing coefficient for which the typical values for surface types are well understood.

4.4. Dry weather flows

Dry weather flow profiles, per capita flows and subcatchment populations were available from the Mike Urban model as MS Excel spreadsheets. These were imported directly to InfoWorks wastewater profiles and applied to the relevant subcatchments on the basis of the subcatchment populations. No trade flow profiles were used in the Mike Urban model.

5. MODEL VERIFICATION

5.1. Verification data

The model has been verified against observed rainfall and flow data measured between June and November 2010. This consisted of two rainfall records referred to as RM Blindern and RM Shell. The Blindern record was used for the period June to the end of July 2010, and then the Shell record was used from August to November 2010. There was a short period of overlap in July which showed the gauges to be well correlated. Figure 19 shows the location of the gauges. The Shell gauge is located centrally within the modelled catchment while the Blindern gauge is approximately 2km to the east. Both gauges are at an elevation of approximately 100m.

The modelled areas range from close to sea level up to 500m elevation. Given such a wide range in topography it is likely that there is a substantial spatial variation in the rainfall from the low ground in the south to the uplands in the north. This is not accounted for in the model and may be a source of error in verifying and using the model.

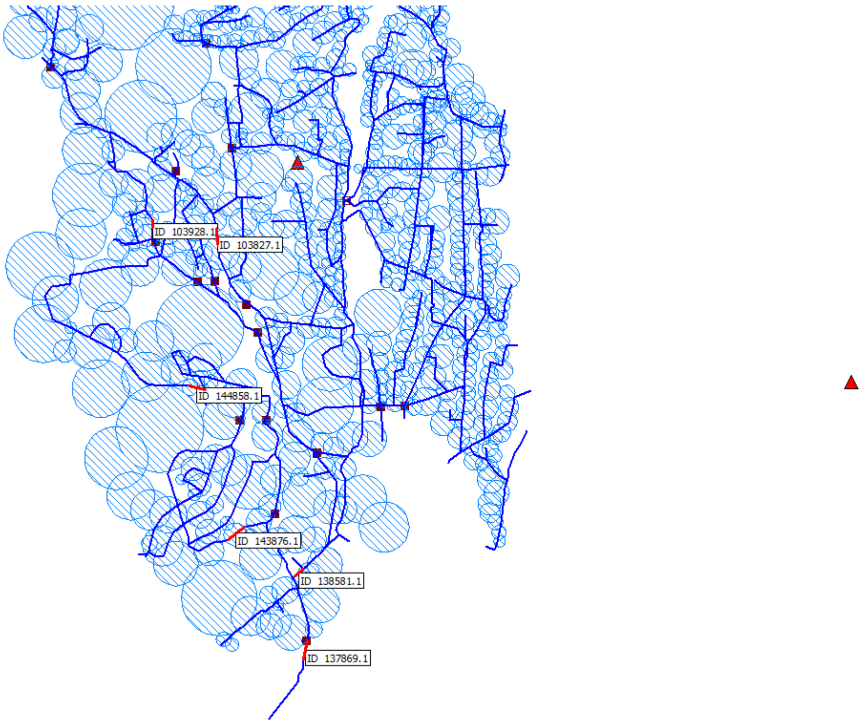


Figure 19. Location of raingauges used for verification of the model: Blindern within the catchment, and Shell 2km outside the catchment

Flow data was available for the same period as the rainfall for the western portion of the model and was imported for a selection of the gauges used for the original verification. The full set of verification locations was not used as the variable time step of the verification flow dataset made importing the data into InfoWorks CS a very time consuming process. The following links were used for verification purposes 103827.1, 103928.1, 137869.1, 138581.1, 143876.1 and 144858.1.

5.2. Verification results

The hydraulic system and some of the hydrological parameters from the Mike Urban model were successfully imported into InfoWorks. However, the RDI model used to represent pervious surface runoff in Mike Urban was not imported as it is not supported by InfoWorks CS. Therefore the verification process centred around developing a suitable pervious runoff model. The New UK runoff model is widely accepted in the UK drainage modelling community and was applied to the areas assigned to the RDI runoff model in Mike Urban on the basis that these areas had been assigned as giving a pervious contribution to runoff. However, the New UK model did not provide an adequate representation of infiltration into the pipe system which is observed to occur after rainfall. Therefore a ground infiltration module was added to the subcatchments. This takes a proportion of the rainfall which is not runoff from the pervious surfaces and routes it though a reservoir to provide an infiltration hydrograph for each subcatchment.

Figure 20 shows an example of a storm hydrograph at one of the verification flow monitor locations. The green trace is the modelled flow arising from the impervious surfaces only (modelled using a fixed percentage runoff model). The red is the modelled flow arising from the impervious and pervious surfaces (modelled using the New UK runoff model). The blue trace is the flow arising from the impervious surfaces, pervious surfaces and the infiltration flows. The infiltration model generates a substantial volume of flow after the main peak and was required to match observed flow hydrographs.

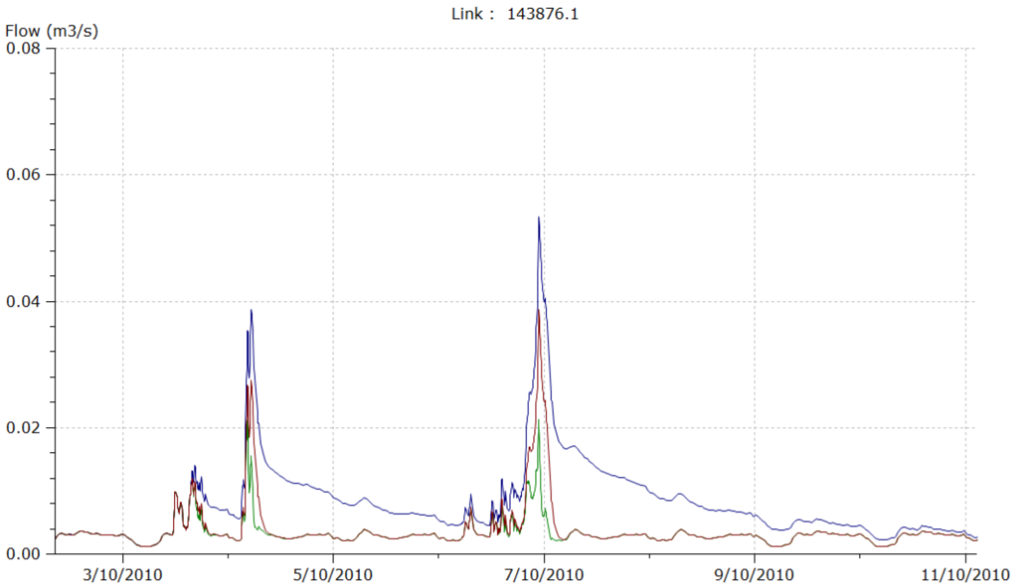


Figure 20. Modelled flow hydrographs showing impervious surface flows (green), impervious + pervious surface flows (red) and impervious, pervious and infiltration flows (blue)

The fixed percentage model was used in the Mike Urban model and is also used in InfoWorks. A routing coefficient factor of 4 was used to represent rapid runoff from impervious surfaces. A range of different parameters sets were tested for the New UK model used to model the pervious surfaces. The final model uses a soil type 2 (representing a relatively permeable soil) with a depth of 200mm and a routing coefficient factor of 20 was used for the pervious areas.

The infiltration parameters for percentage infiltration and the delay between rainfall and infiltration were adjusted incrementally until a good fit with observed hydrographs was found.

5.3. Areas for model improvement

The import of the model from Mike Urban to InfoWorks has, as far as possible, replicated the Mike Urban model. Where this has not been possible, a calibration process has been undertaken. This means that the parameters sets and runoff surfaces used in the model are unlikely to be the same as those which would be used if the model was being built using InfoWorks. For example, the pervious areas have been converted from RDI to New UK runoff; however, these are distinctly different models so the assignment of pervious surfaces might have been different if InfoWorks had been used to build the model. The following areas of uncertainty have been identified;

- Some of the gauges measuring the larger flow rates show a higher dry weather flow than modelled. This is surprising given that the same dry weather flow profiles and population figures have been used in both Mike Urban and InfoWorks. The difference may arise from long term baseflow in the Mike Urban model which is not being replicated in InfoWorks. A seasonally varying baseflow component could be developed if required.
- It has been difficult to achieve a match in the peak flows of +20% or -10% which is the range that should be achieved for a well verified model. This may be due to inaccurate or highly spatially varying rainfall due to the wide range in catchment elevation, inaccurate verification flow data or inappropriate runoff modelling parameters. Without much more detailed analysis on an individual storm and flow monitor basis it is not possible to ascertain the source of the inaccuracy or the measures needed to improve the verification of the model further.

6. ADAPT APPLICATION ON THE PILOT CATCHMENT OF HOFFSELVA, OSLO

6.1. Performance expectations

The Hoffselva catchment is a relatively steep 10km2 largely residential catchment. It suffers from 21 overflows which operate too frequently, and in particular there is one that discharges into a lake which is used for recreational purposes which requires addressing as a matter of urgency. In addition there are 58 locations where basements flood. With the relatively complex interconnecting network and large number of issues to address, the use of an optimising tool clearly has advantages over a manual approach for assessing a range of suitable solutions.

VAV, the organisation responsible for operating the drainage system in Oslo, expects a very high standard of CSO performance and also level of service against flooding. The tool is ideal for assessing a wide range of possible levels of service. The following options have been selected for developing options and showing the capabilities of the tool to produce solutions.

Scenario 1 – The use of attenuation tank storage to reduce CSO spills to achieve 3 spills a year;

Scenario 1A –Scenario 1 but the Lake CSO to only have 1 spill per year;

Scenario 2 – The use of pipe upsizing to address the CSO spills to 3 spills per year;

Scenario 2A – Scenario 2 but the Lake CSO to only have 1 spill per year;

Scenario 3 – The use of both attenuation tanks and pipe upsizing to address CSO spills to 3 spills a year AND to address the flooding of basements to meet the 1:10 year level of service;

Scenario 4 – the use of Basins, Infiltration soakaways, Rainwater harvesting and Surface water disconnections to address the CSO spills to 3 spills a year;

Scenario 5 – the use of Basins, Infiltration soakaways, Rainwater harvesting and Surface water disconnections to address both the CSO spills to 3 spills a year and to address the flooding of basements to meet the 1:10 year level of service.

It should be noted that Scenarios 1 to 3 use traditional sewerage asset proposals, while Scenarios 4 and 5 uses SuDS techniques of reducing volumes of runoff.

The basis for the use of SuDS across the catchment will be based on the STORM study carried out by Sieker for the same catchment.

This version of the report is only reporting on Scenario 1, and 1A; the final version will include scenarios 2, 2A, 3, 4 and 5 once the SuDS elements of the tool, which is still being finalised, have been completed. The analysis of scenarios 2 and 2A were found to be generally unsatisfactory and the results are therefore not included in this report.

6.2. Model preparation

A key constraint of the tool is that every link and node needs to be included in the model as new elements cannot be introduced or existing model elements removed during the analysis. Thus every possible site of an attenuation tank or a pipe that might be altered in size has to exist in the model at the start of the analysis.

As the number of combinations of possible options increases exponentially, the maximum number of variables has been set at 20. For a model of this size and using only the one design storm, this limit requires computing run times of between one and three days (based on relatively standard computing power).

There are two main issues to consider in preparing a model for an ADAPT analysis: the first is that when considering the use of attenuation tanks the depth of the tank must be set such that water levels upstream do not cause a problem upstream. This involves setting a level for a pass-forward overflow. The second task when using pipe size increases is making sure the appropriate range of pipe sizes can be used. For instance a pipe downstream of an overflow with a low level weir may never be able to utilise the capacity of a large pipe, therefore weir levels may need to be modified, or invert levels lowered.

The initial model, although verified, has very low weir levels at the CSOs. This results in spills taking place at very low flow rates. It was therefore decided to modify all the CSOs overflows (except the lake one which had a head-discharge curve), so that the pipe downstream could operate in surcharge before a spill took place. What this meant in practice was that for the attenuation storage options the weir levels were increased a little to the soffit level of the outgoing pipe if it was lower, but leave it unchanged if it was higher. However for the options using pipe up-sizing, to make sure the capacity of any increased pipe size was used if it was enlarged, the weir levels were all raised to 1m from the ground level.

These changes were seen as being practical changes to ensure the ADAPT analysis resulted in valid solutions. It is recognised that these changes could not be arbitrarily made in a real study without the intention of actually effecting these changes.

To illustrate the differences these changes make, Table 7 has been provided which shows a comparison of the spill volumes for the three initial models; the verified model, the initial attenuation storage model and the pipe upsizing model. It can be seen that the verified model generally has larger spill volumes than the storage model. However this is not universally true as a reduction in spill from a CSO upstream sometimes results in more spills further downstream even if the weir level was raised. Similarly the pipe upsizing model has much less spill taking place with only 4 spills for the 3:1 year event and 7 spills for the 1:1 year event. Similarly the volumes spilt are generally much reduced. Although this means solutions are not comparable in terms of capital costs, it allows ADAPT to find appropriate solutions.

Table 7. CSO spill volume (m3)

	ORIGINAL MODEL		TANK MODEL		PIPE MODEL	
US Node ID	0.33 YRP event	1 YRP event	0.33 YRP event	1 YRP event	0.33 YRP event	1 YRP event
103851	0	0	0	0	0	0
103862	34.5	121.09	23.34	112.66	0	20.72
103878	0	0	0	0	0	0
103934	19.43	173.16	31.4	227.56	79.14	499.46
103934_2	25.39	119.07	9.09	49.8	0	0
112969_oslo	34.9	505.63	8.22	245.7	0	68.51
113039	0	0	0	0	0	0
113074	0	17.43	0	17.4	0	19.84
136412	0	0	0	0	0	0
136415	0	0	0	0	0	0
137869	976.68	3138.6	1018.86	3415.21	0	0
143847	0	0	0	0	0	0

144718	132.21	555.59	143.1	598.21	4.09	104.03
144765	0	0	0	0	0	0
144787	63.11	335.77	0	27.23	0	0
144817	0	0	0	0	0	0
147789	0	0	0	0	0	0
148332_oslo	0	0	0	0	0	0
265233	0	0	0	0	0	0
77529	93.97	486.96	94.08	486.3	38.08	209.76
159996_oslo	252.33	891.51	269.73	961.24	267.62	1025.93
spills	9	10	8	10	4	7

6.3. ADAPT results

6.3.1. Option 1 - Storage tanks to control CSO spills to 3 times a year

The objective in the Hoffselva is to stop 21 CSOs from spilling for the 0.3 year rainfall event. Ten potential locations for storage tanks with 10 associated orifices were identified and added to the model. Figure 21 shows the Hoffselva network, the storage tanks are shown in blue and the CSO locations are pink. The throttle orifice size and plan area of the tank are ADAPT variables. The weir level from each tank has been set to 1.0m below ground level. Figure 22 shows a cross section of the storage node with associated orifice and weir.

ADAPT was run for 147 generations. The results are presented in Figure 23. The first chart shows the decreasing costs of solutions found as the runs progressed. The grey circles represent the solutions which failed to prevent the CSOs from spilling. The coloured circles represent the solutions that were successful.

The second chart zooms is on the last generation of results. ADAPT was stopped after 147 generations after 2 days of run time. However, it can be seen that it was still finding slightly better solutions.

The third chart shows the solutions in the final generation with different asset modification costs. Each point has been labelled with the chromosome ID enabling the detailed data of each solution to be matched to them. Three solutions have been singled out and the detailed data is presented in Table 8, Table 9 and Table 10.

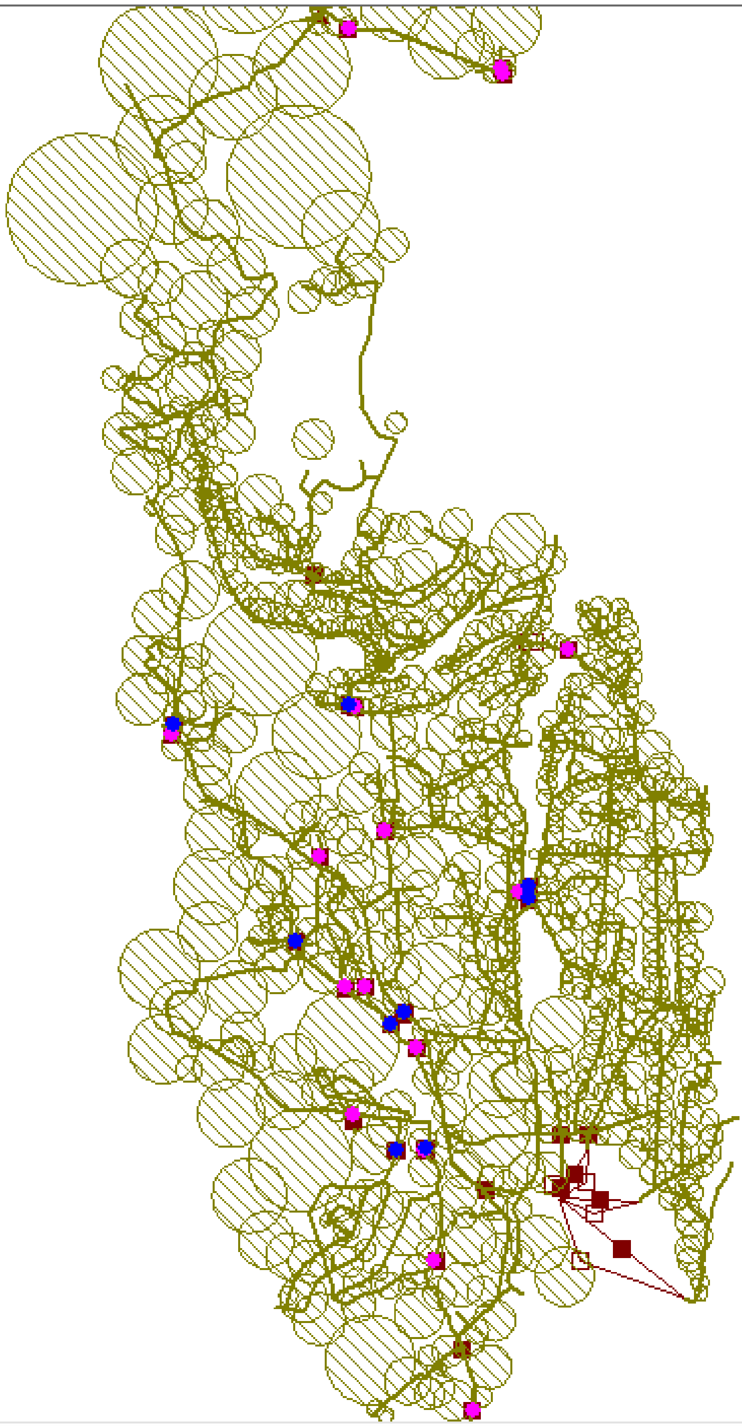


Figure 21. The Hoffselva pilot catchment showing potential locations of storage tanks (blue) and CSOs (pink)

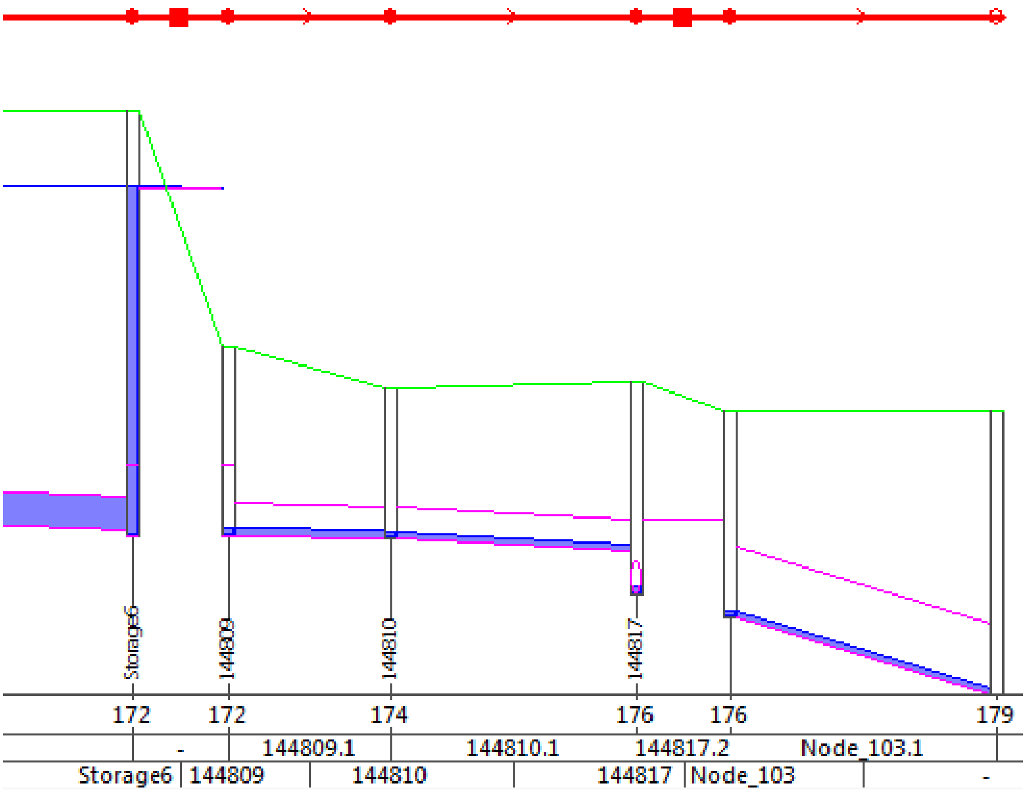


Figure 22. Long section through storage tank with associated orifice and weir and downstream CSO.

It is up to the user of ADAPT to decide at which point to stop running ADAPT. ADAPT will continue until the number of generation specified in the setup menu has been reached. It is possible to restart ADAPT if the solutions ADAPT has provided are not sufficiently optimised. One of the ways to see if ADAPT is still finding better solutions is to see if the rank 1 solution over the last 10 generations is still reducing the cost.

When tanks are being used in the solution a check must be made on how full the tank gets. It is quite common for ADAPT to find a successful solution (no spill) by choosing a volume and throttle size which is not the most efficient, but which achieves compliance with the criteria. This will be kept as a "good" solution until a mutation finds an improved refinement, but this could take many generations to achieve. Therefore manual interaction can speed up finding the least cost solution, once successful options are being found. Therefore in this run the results were analysed after 145 runs and the best solution at this point was used to add a manual solution, and 2 more generations were run. The manual solution is chromosome 80 (rank 1) of generation 147. The best solution ADAPT produced is chromosome 134. The asset modification cost of the manual solution is 63121 N kr lower than that of ADAPTs best solution. That equates to a further improvement of 2.16%.

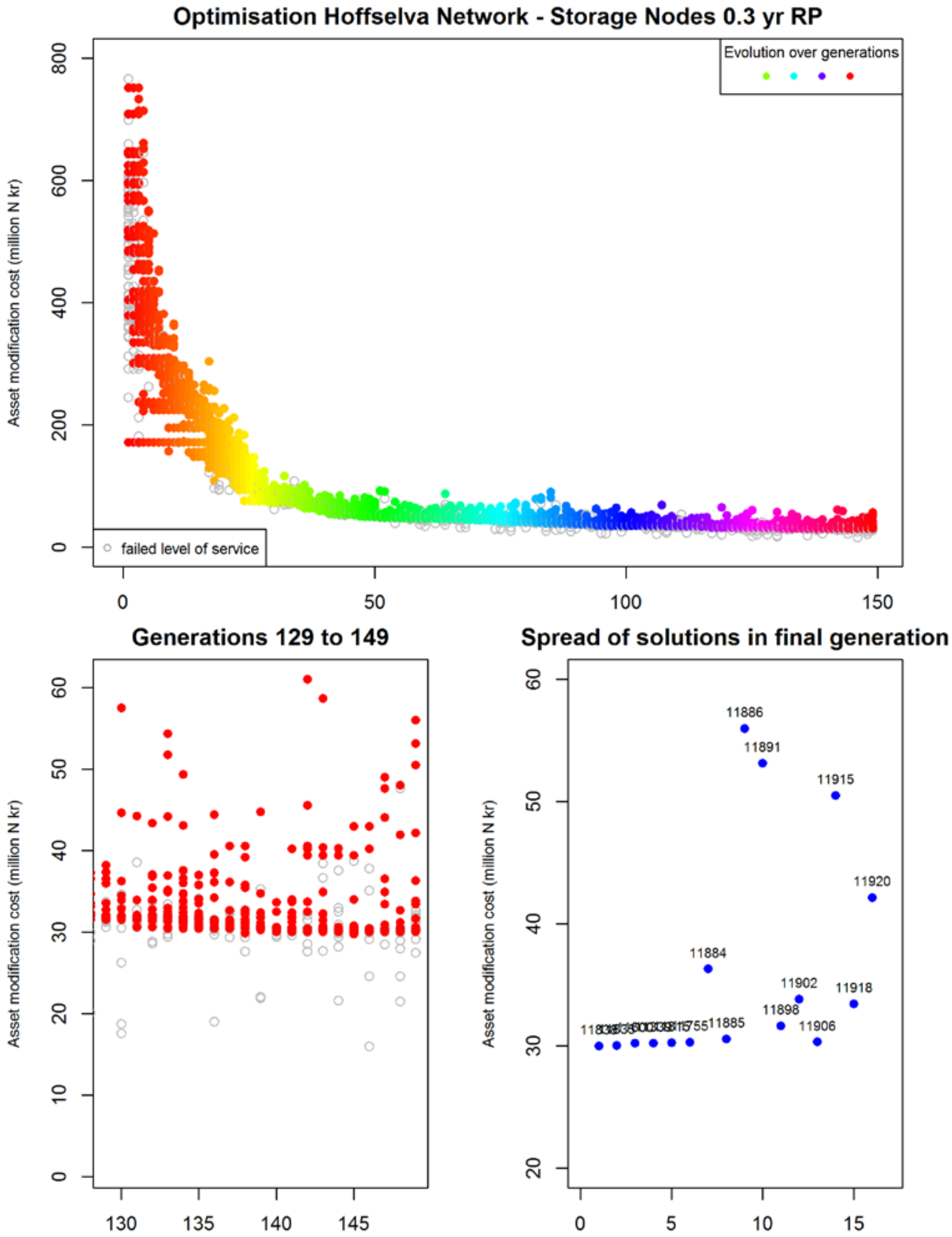
It can be seen that the throttle rate for two tanks are 2l/s and 5l/s respectively. These are very small but this is because the overflow into the lake has a head discharge relationship which operates at very low head. This has been altered in analysis 1A by putting in a simple weir set at the soffit level of the outgoing pipe.

It is important to recognise that the engineer is best given at least the top 3 solutions. Although the tool will find the theoretical "best" solution, the cost basis used in the tool will be an approximation of the actual construction costs, and there are many more issues which need to be considered which might influence the selection of the final option even though many of the issues should have been addressed in making the site selections for the potential solutions. Table 8, Table 9 and Table 10 illustrate the differences between three of the solutions. It can be seen that the differences are fairly nominal between the rank 1 and rank 2 solutions, but the rank 13 solution has one tank which is significantly larger.

The cost of the tanks solution for the lowest cost option is of the order of 30MKr.

Table 8. Solution details rank 1 (Chromosome 11500)

CHROMOSOME ID 11500 RANK 1 – ASSET MODIFICATION COST 30025213 NKR			
Storage Node ID	Total storage volume available at node (m3)	Limiting orifice flow (m3/s)	Fullness of storage node at peak of event (%)
Storage1	215	0.030	100
Storage10	141	0.002	33
Storage2	77	0.005	100
Storage3	171	0.062	64
Storage4	92	0.144	100
Storage5	Original	Original	-
Storage6	269	0.032	99
Storage7	1427	0.568	99
Storage8	253	0.045	100
Storage9	264	0.015	100



The third chart shows the spread of the solution in the final generation. The labels refer to the chromosome ID number and are reference in the solution detail tables. The arrows indicate the solution which are available in the detailed tables.

Figure 23. Results of optimisation for preventing CSO spills to the 0.3 year return period event

Table 9. Solution details rank 2 (Chromosome 11885)

CHROMOSOME ID 11885 RANK 2 – ASSET MODIFICATION COST 30051413 NKR			
Storage Node ID	Total storage volume available at node (m3)	Limiting orifice flow (m3/s)	Fullness of storage node at peak of event (%)
Storage1	215	0.030	100
Storage10	141	0.002	33
Storage2	77	0.005	100
Storage3	171	0.062	64
Storage4	92	0.144	100
Storage5	Original	Original	-
Storage6	269	0.032	99
Storage7	1427	0.568	99
Storage8	253	0.045	100
Storage9	264	0.015	100

Table 10. Solution details rank 13 (Chromosome 11920)

CHROMOSOME 11920 RANK 13 – ASSET MODIFICATION COST 42169053 NKR			
Storage Node ID	Total storage volume available at node (m3)	Limiting orifice flow (m3/s)	Fullness of storage node at peak of event (%)
Storage1	1401	0.03	61
Storage10	131	0.002	35
Storage2	115	0.005	100
Storage3	171	0.055	73
Storage4	92	0.144	100
Storage5	Original	Original	-
Storage6	269	0.036	98
Storage7	1427	0.552	100
Storage8	253	0.05	100
Storage9	264	0.015	100

6.3.2. Option 1A - Storage tanks to control CSO spills to 3 times a year and the Lake CSO to 1 spill a year

To show that ADAPT can be used to assess more than one target level of performance for different parts of the system, and also to examine the consequences of the cost increase of achieving a higher level of service, option 1A set the level of service for the lake CSO to an average of 1 spill a year.

The results show that the tank sizes and throttle rates for the other CSOs remain the same, but the tanks serving the lake CSO were not able to prevent spills taking place from the lake CSO for the 1 year event. It is interesting to note in option 1 that the throttle rates for the tanks serving this CSO are extremely small – only 2l/s and 5l/s. Closer examination of the model shows that this CSO is acting as a relief from downstream flows, and that flows are reversing back to the CSO. This means that the proposed tank locations selected to achieve the level of service for this CSO are not optimally located and a mechanism for controlling flows on other branches is needed. This emphasises the importance of getting a really good understanding of the network before selecting possible sites for making system state changes.

6.3.3. Option 2 – Pipe upsizing to control CSO spills to 3 times a year

The alternative to using tank storage is to increase pipe sizes downstream of CSOs or to use a combination of both pipe size increases and tank storage. This option only looks at pipe sizing increases to find a solution.

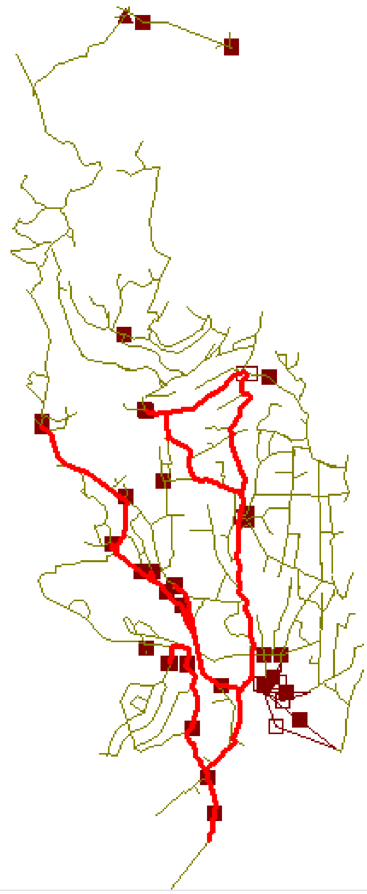
Unfortunately the modifications made to the model to ensure that upsizing of pipes would allow full utilisation of the pipe capacity in providing a solution meant that only 3 CSOs now spill for the 3:1 year event which means that very few changes are needed to the system to make it meet the level of service.

Although this option is not mixing the options of both storage and pipe size increases, it is possible for ADAPT to consider this, and this will be assessed later. However it is important to recognise that although solutions based on storage or enhancing flow capacity should result in roughly the same volume of water passing to the works downstream that there are major differences which should be noted. These are:

- Characteristics of the network
- Least cost solution selection of storage and pipes

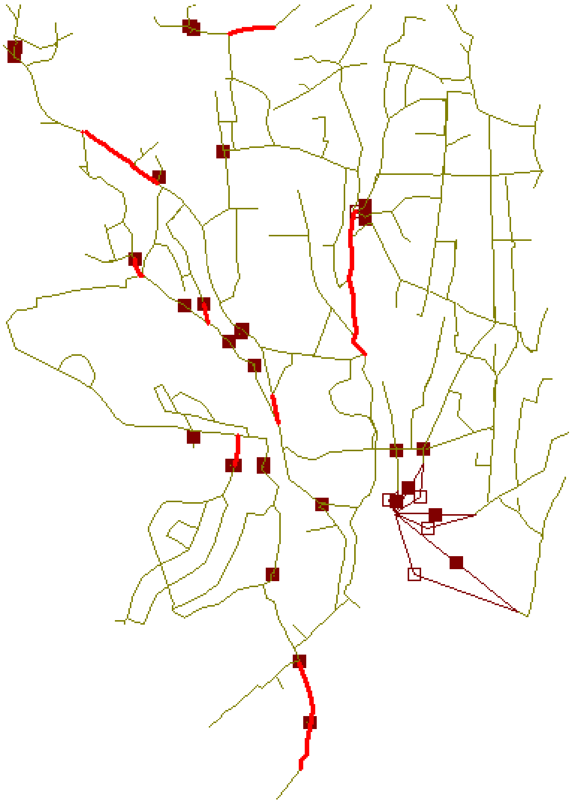
It should be noted that the addition of storage makes the behaviour of the system very different to adding in bigger pipes. The response downstream will be damped, but once the storage is full, then spills will tend to be large. This means that longer storms become the critical events. With increasing pipe sizes the capacity of the system is enhanced whatever the event and therefore more volume of water in total will pass downstream. However there will be high intensity storms which will not be fully captured which would be successfully addressed by the attenuation storage system.

The second issue is that the least cost solution is influence by any "penalty" associated with peak flow and volume control passing downstream. As there is a real cost associated with increasing flows (particularly flow rates) to the works downstream, the penalty boundary cost associated with solution using pipe size increases will tend to be greater. However there is no significant bias where solutions are not mixing storage with upsizing of pipes. It should be noted again that there are only outfall control costs on volumes spilled above the 2 year return period being applied at the outfalls for this analysis.



A total of 37 pipe groups were used as a starting point to run the optimisation

Figure 24. Overview of all pipe groups



After 40 generations a selection of 20 pipes groups was made based on the results of the optimisation

Figure 25. Overview of selected pipe groups

Figure 24 and Figure 25 show first all the pipe groups initially selected based on the initial verified model, and the reduced set based on the revised system with some of the overflows raised a little. Unfortunately the results of the analysis shows some inconsistency and further work is on-going to address this. Therefore this option will be included in the next version of this report later in the project.

6.3.4. Options 3, 4 and 5

Options 3 to 5 have yet to be developed and run. This report is an interim output demonstrating the tool that has been developed and capabilities of it.

7. CONCLUSIONAS AND RECOMMENDATIONS

The conclusions of the work carried out to-date are:

- The Infoworks model reproduces the observed flow data for several of the monitors which were used to calibrating the Mike Urban model;
- The ADAPT tool has been shown to work effectively in exploring possible solutions to meet level of service requirements for CSO spills;
- A detailed understanding of the performance of the system must be gained before using ADAPT to explore options. It is easy to propose sites for possible changes which are not going to provide the most efficient locations;
- From meetings and the model results, it is clear that there are a number of areas of uncertainty regarding the model's accuracy and its representation of the real system. These should be followed up before any analysis and solutions are carried out for making actual changes to the network in the future.

The recommendations for further work are:

- More time should be spent getting a detailed understanding of the model and its performance followed by reconsideration of potential changes and re-use of ADAPT to explore realistic options;
- All areas of uncertainty regarding the model's accuracy and its representation of the real system needs to be resolved;
- The tool needs to be run for options 2, 3, 4 and 5. Option 3 will test the tool on achieving level of service for both flooding and CSO spills and using both pipe size increases and storage tanks. Options 4 and 5 will provide SuDS based results to compare with asset based solutions for options 1 and 3;
- The tool should be developed to assess whole life costs which incorporates both capital costs and operational costs. This is particularly relevant in comparing SuDS based solutions with asset based proposals due to the reduction in runoff volume from the SuDS based systems. This should be carried out with a time series analysis of all rainfall events run on the final solutions developed for each option;
- Investigation into the programming of works is also needed. As this is an exercise in progressing towards a sustainable future for cities it is important to understand how it is possible to change from the present state to the future system without incurring problems such as temporarily worsening the performance of the system at certain locations. This exercise may result in showing that certain types of system upgrade (such as pipe size increases) are far more constrained than other options such as SuDS.

REFERENCES

DHI, 2011, Oslo commune Tiltaksanalyse – Hoffselva MIKE URBAN model.

Catchment-wide study of SUDS implementation in Oslo Hoffsvela and generating disconnection potential maps, Ingenieurgesellschaft Prof. Dr. Sieker mbH. 2014

SAM: System based analysis and management of urban flood risks: A new procedure for performance assessment of sewerage systems. Report SR700 r1.0. HR Wallingford, 2009.

Artificial Intelligence for flood risk management. STREAM R.Eng. (not yet published) W Sayers.2010 – 2013.

APPENDICES

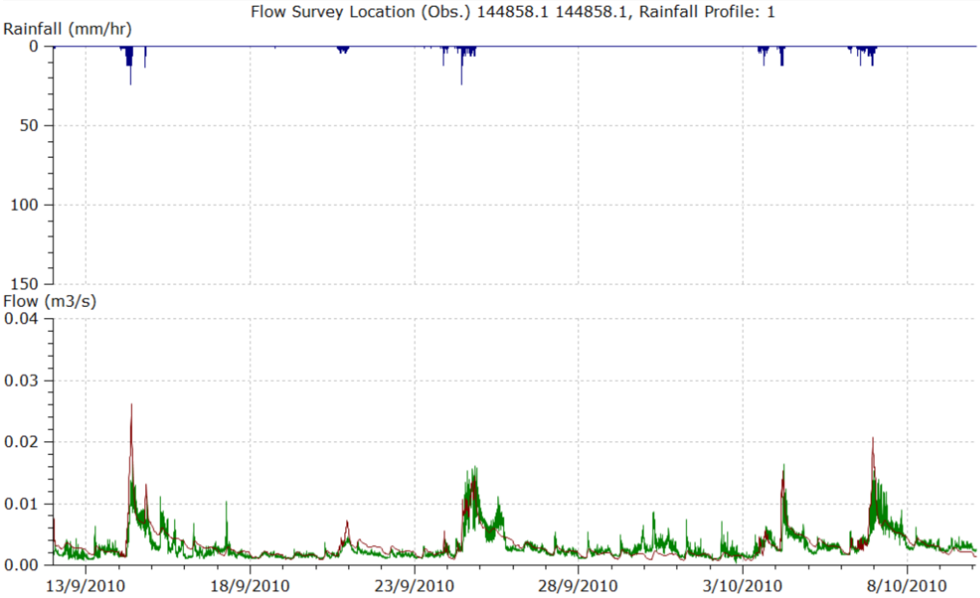
A. - A Technical summary of ADAPT

To be produced when ADAPT is finalised.

B - The verification of the Infoworks model

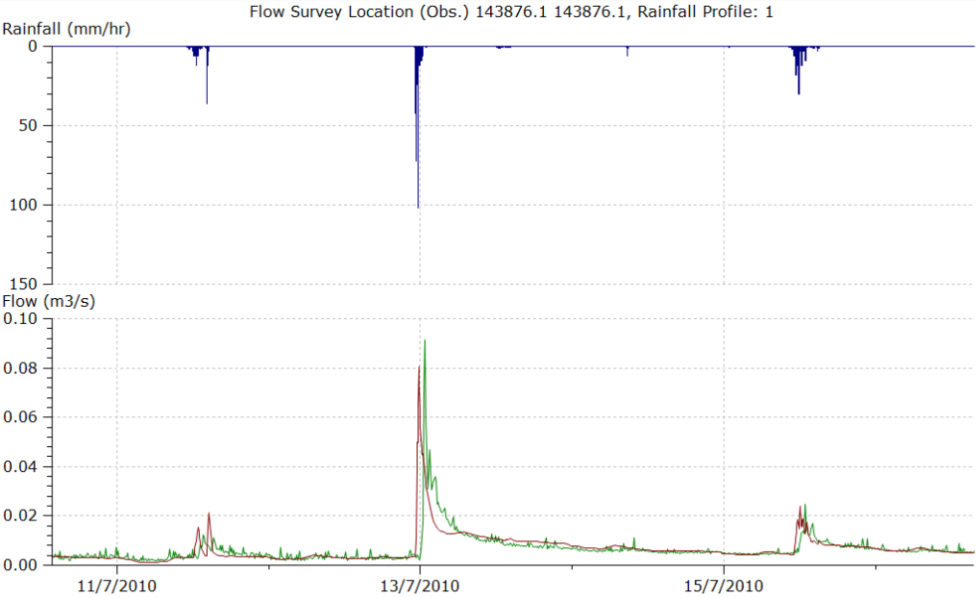
The following figures illustrate the fit between observed and modelled flows in the final version of the InfoWorks model. These show plots from recorded flow information against the predictions of the Infoworks model using the observed rainfall data.

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:36) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>144858 flow (07/11/2012 10:52:21)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>144858 (26/11/2012 16:08:32)



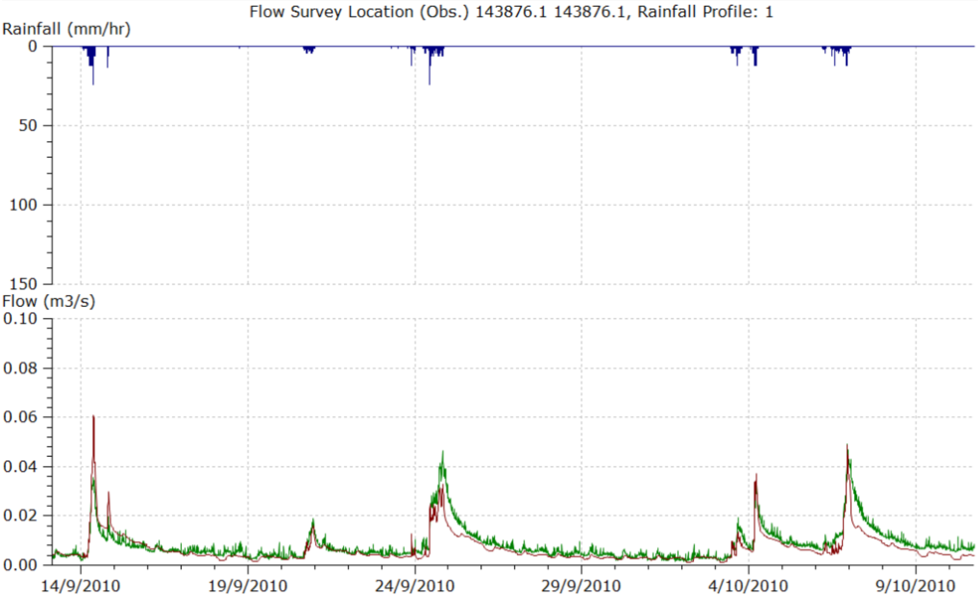
	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Volume (m3)
Rain	133.960	24.000	1.580			
Obs.				0.000	0.017	7284.887
...Soil2_Blindern_Shell_combined_New				0.001	0.026	7857.001

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:28) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>143876 flow (07/11/2012 10:52:12)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>143876 (07/11/2012 11:01:48)



	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	39.900	102.000	3.019			
Obs.				0.002	0.092	**3457.912**
...Soil2_Blindern_Shell_combined_New				0.001	0.081	**3449.643**

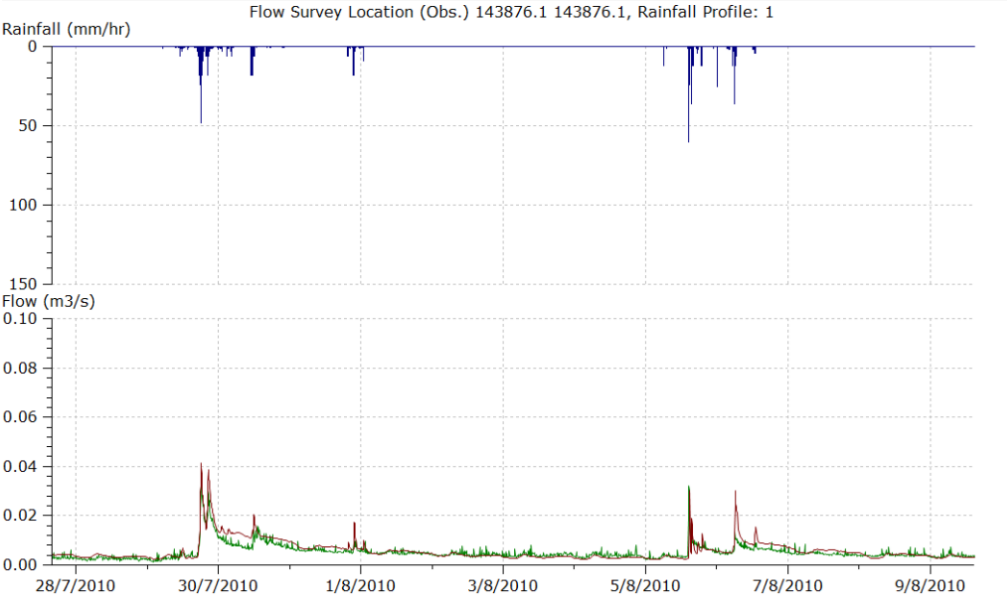
Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:28) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>143876 flow (07/11/2012 10:52:12)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>143876 (07/11/2012 11:01:48)



	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	132.198	24.000	1.582			
Obs.				0.002	0.049	**19733.430**
...Soil2_Blindern_Shell_combined_New				0.001	0.061	**15907.409**

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:28) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>143876 flow (07/11/2012 10:52:12)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>143876 (07/11/2012 11:01:48)

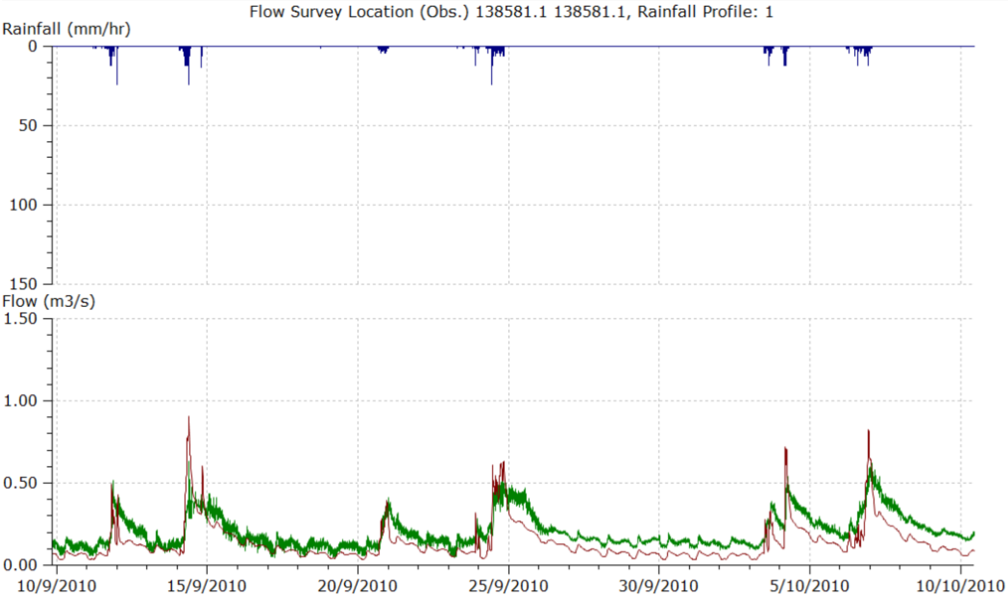
Flow Survey Location (Obs.) 143876.1 143876.1, Rainfall Profile: 1



	Rainfall Depth (mm)	Rainfall Peak (mm/hr)	Rainfall Average (mm/hr)	Flow (m3/s) Min	Flow (m3/s) Max	Volume (m3)
Rain	57.300	60.000	0.883			
Obs.				0.001	0.036	5810.890
...Soil2_Blindern_Shell_combined_New				0.002	0.041	6437.494

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:18) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>138581 flow (07/11/2012 10:51:53)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>138581 (07/11/2012 11:01:27)

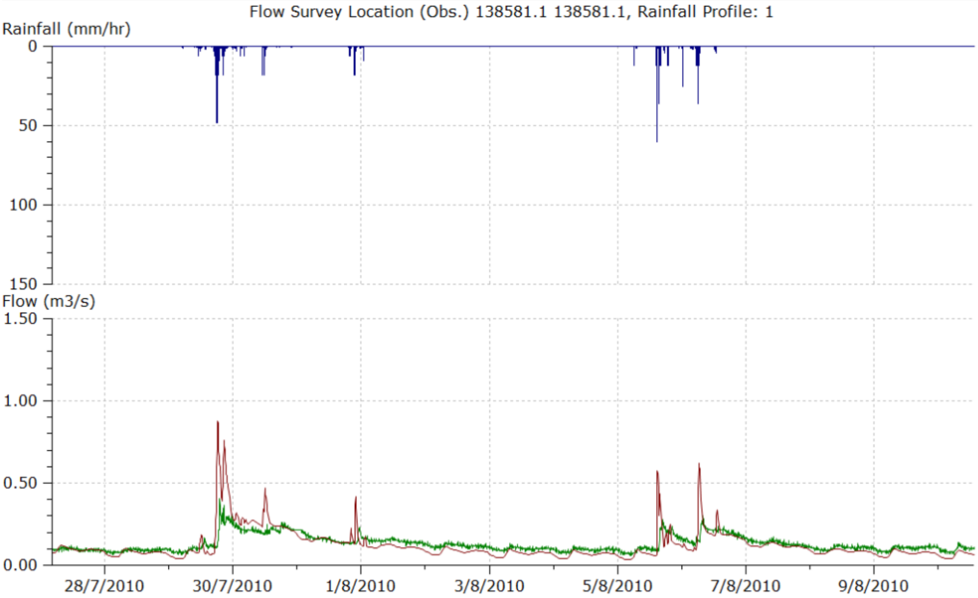
Flow Survey Location (Obs.) 138581.1 138581.1, Rainfall Profile: 1



	Rainfall Depth (mm)	Rainfall Peak (mm/hr)	Rainfall Average (mm/hr)	Flow (m3/s) Min	Flow (m3/s) Max	Volume (m3)
Rain	149.198	24.000	1.435			
Obs.				0.040	0.631	539254.279
...Soil2_Blindern_Shell_combined_New				0.033	0.908	365675.332

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:18) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>138581 flow (07/11/2012 10:51:53)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>138581 (07/11/2012 11:01:27)

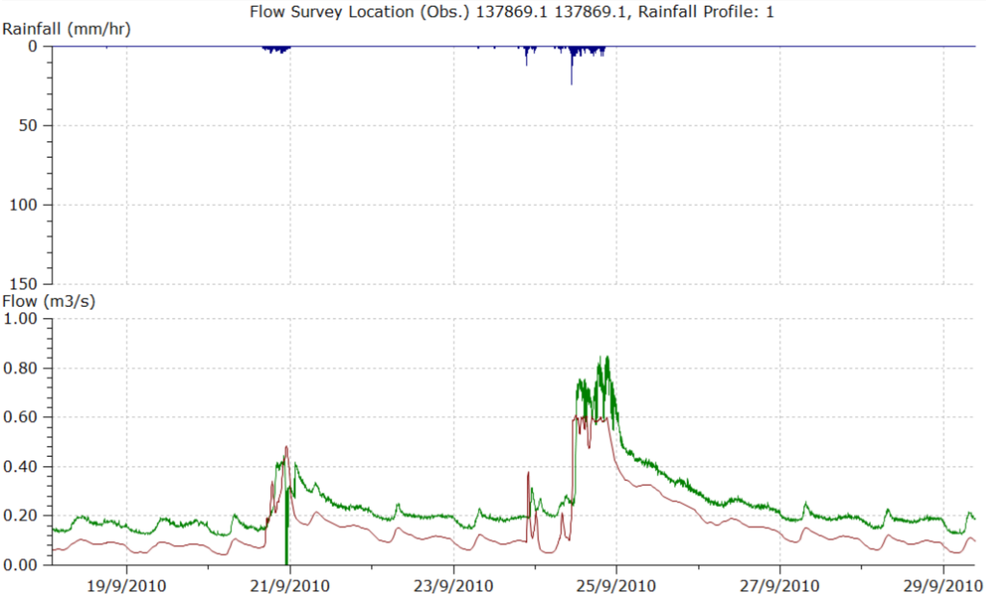
Flow Survey Location (Obs.) 138581.1 138581.1, Rainfall Profile: 1



	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	57.300	60.000	0.883			
Obs.				0.059	0.404	**161668.834**
...Soil2_Blindern_Shell_combined_New				0.035	0.879	**148965.118**

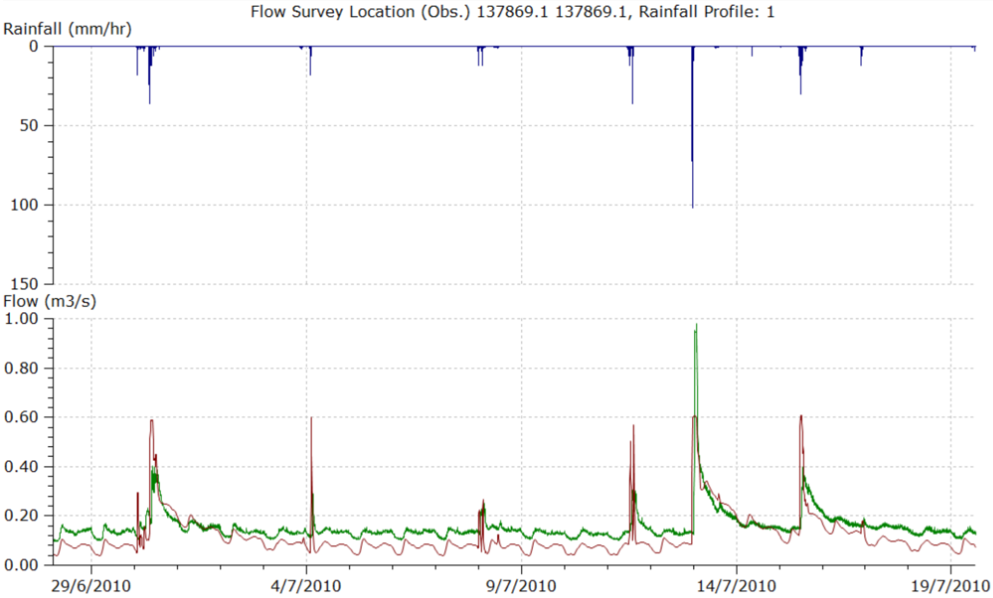
Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:11) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>137869 flow (07/11/2012 10:51:40)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>137869 (07/11/2012 11:01:12)

Flow Survey Location (Obs.) 137869.1 137869.1, Rainfall Profile: 1



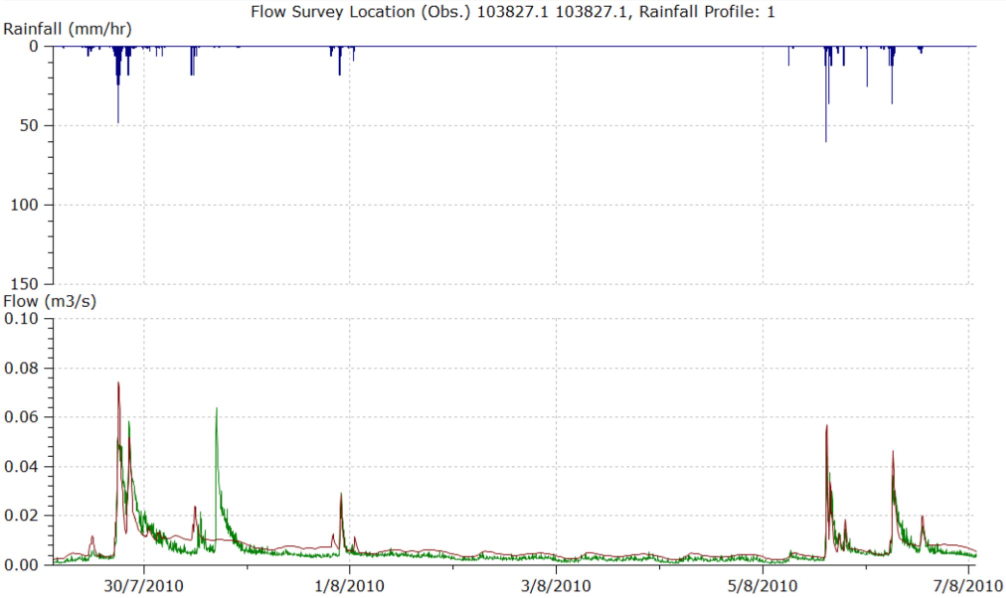
	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	48.399	24.000	1.238			
Obs.				0.000	0.850	**234945.391**
...Soil2_Blindern_Shell_combined_New				0.043	0.608	**149871.072**

Observed / Predicted Plot Produced by gfw (12/12/2012 16:55:11) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>137869 flow (07/11/2012 10:51:40)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>137869 (07/11/2012 11:01:12)



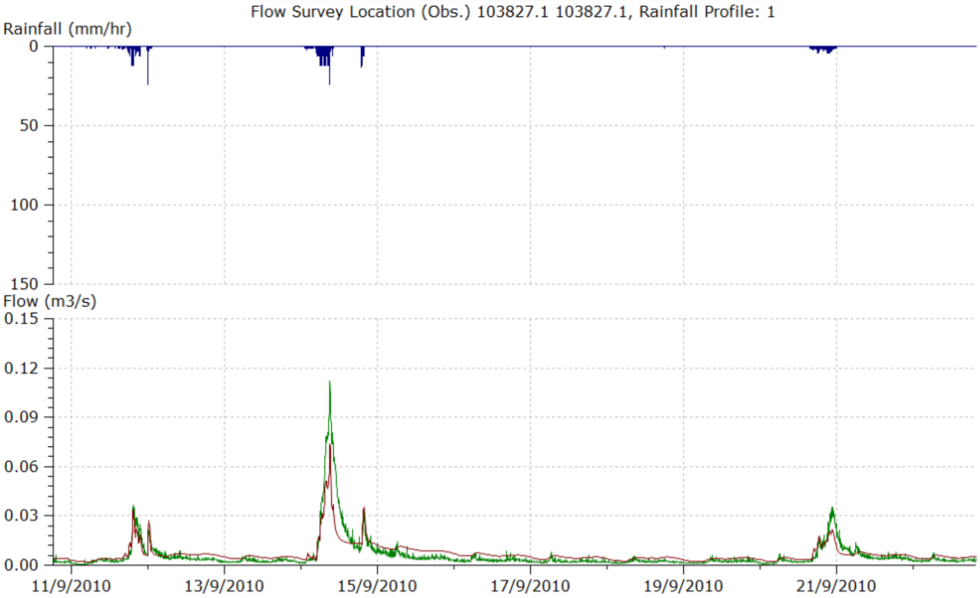
	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	72.800	102.000	1.502			
Obs.				0.097	0.980	**288779.510**
...Soil2_Blindern_Shell_combined_New				0.040	0.610	**218356.071**

Observed / Predicted Plot Produced by gfw (12/12/2012 16:54:46) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>103827 flow (07/11/2012 10:51:12)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>103827 (07/11/2012 10:56:18)



	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	57.300	60.000	0.883			
Obs.				0.001	0.064	**4537.744**
...Soil2_Blindern_Shell_combined_New				0.002	0.074	**5429.328**

Observed / Predicted Plot Produced by gfw (12/12/2012 16:54:46) Page 1 of 1
Flow Survey: >Oslo>Flow Survey Group>103827 flow (07/11/2012 10:51:12)
Sim: >Oslo>Verification>FINAL Full model Drog S16 infiltration soil 2 Routing 4imp and 10per>Soil2_Blindern_Shell_combined_New (29/11/2012 10:36:26)
Graph Template: >Oslo>Graph Template Group>103827 (07/11/2012 10:56:18)

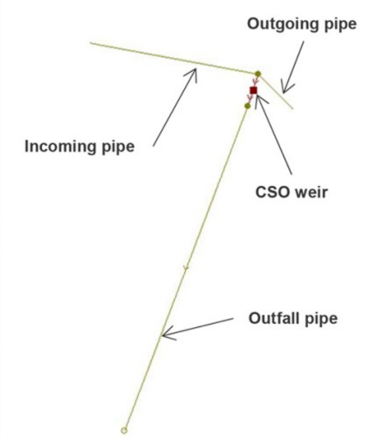
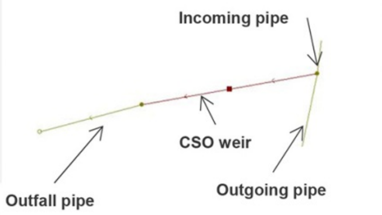


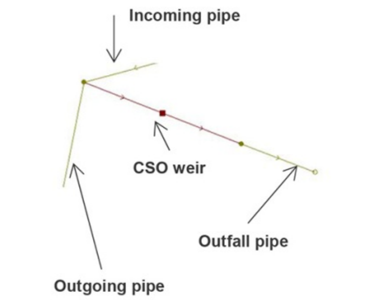
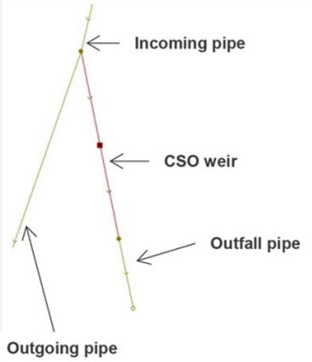
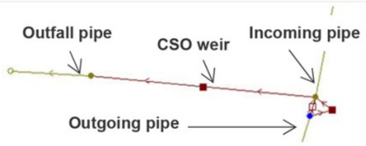
	Rainfall			Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	**Volume (m3)**
Rain	63.199	24.000	1.620			
Obs.				0.001	0.112	**6106.188**
...Soil2_Blindern_Shell_combined_New				0.002	0.074	**7150.093**

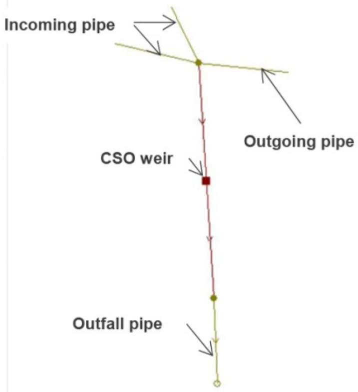
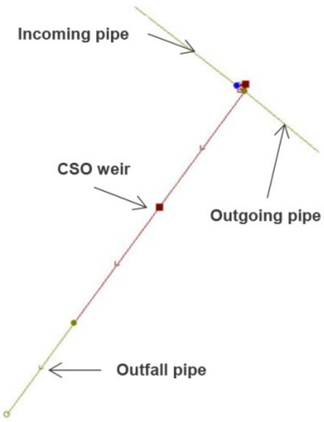
C - Modifications of the CSOs in the model

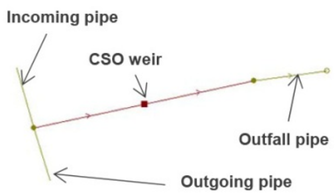
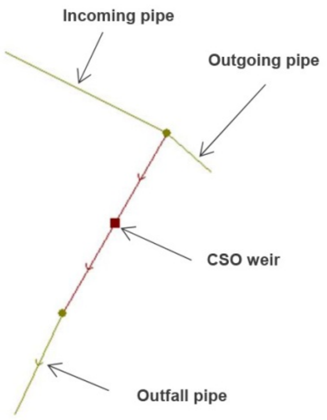
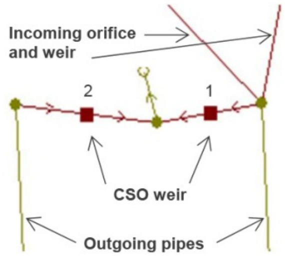
The information in Table C.1 summarises all the information that is used in the model for this study. It should be noted that CSOs in the catchment are not designed in the traditional fashion of using an exit throttle pipe to stimulate the discharge of runoff. Usually the outgoing pipe is the same size as the incoming pipe. In addition many of the weirs are set at a level below the outgoing soffit and therefore spills start to take place before the downstream pipe is operating in surcharge.

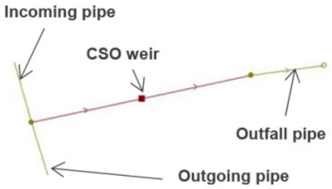
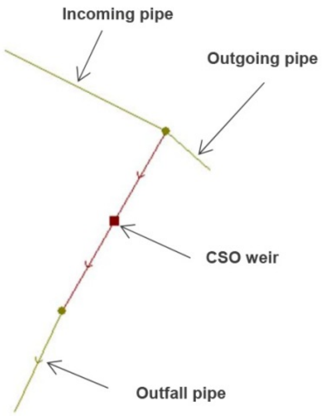
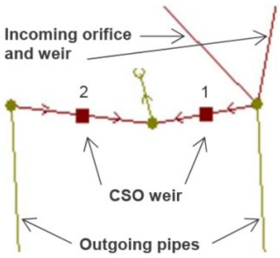
The decision was therefore taken to make two versions of the network with a slight modification for the model used for using with SuDS and attenuation tanks, while increasing the weir levels significantly for the option looking at the use of pipe upsizing. This is necessary as pipes would not be able to convey more water if they only operate part full.

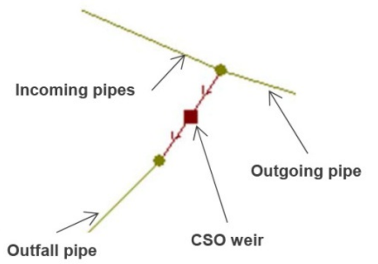
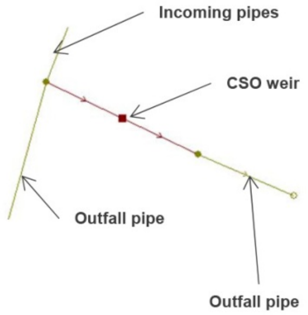
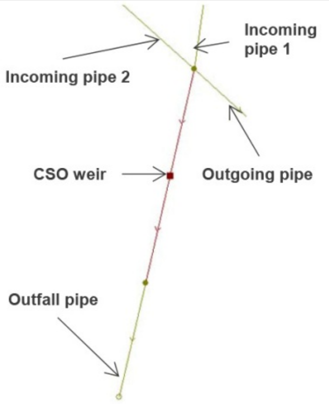
CSO reference	CSO details		Model UC	Model S	Model P
148332_oslo.2		Incoming pipe ø (mm)	300	300	300
		Incoming pipe DSIL (m AD)	178.26	178.26	178.26
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	178.26	178.26	178.26
		CSO weir crest level (m AD)	178.51	**178.64**	**179.50**
		CSO weir length (m)	0.47	**2.00**	**2.00**
		CSO ground level (m AD)	180.00	180.00	180.00
		Outfall pipe ø (mm)	150	**1000**	**1000**
		Outfall pipe USIL (m AD)	178.26	178.26	178.26
137869.2		Incoming pipe ø (mm)	530	530	530
		Incoming pipe DSIL (m AD)	38.13	38.13	38.13
		Outgoing pipe ø (mm)	450	450	450
		Outgoing pipe USIL (m AD)	38.13	38.13	38.13
		CSO weir crest level (m AD)	38.78	38.78	**41.5**
		CSO weir length (m)	1.67	1.67	**2.00**
	Notes: Associated storage node: Storage7	CSO ground level (m AD)	42.22	42.22	42.22
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	38.00	38.00	38.00
143847.2		Incoming pipe ø (mm)	380	380	380
		Incoming pipe DSIL (m AD)	56.39	56.39	56.39
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	56.37	56.37	56.37
		CSO weir crest level (m AD)	56.73	**56.75**	**58.80**

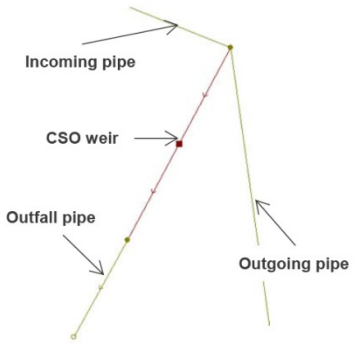
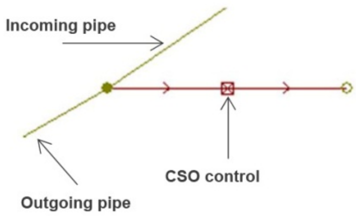
CSO reference	CSO details		Model UC	Model S	Model P
		CSO weir length (m)	1.16	1.16	**2.00**
		CSO ground level (m AD)	59.36	59.36	59.36
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	55.1	55.1	55.1
144817.2		Incoming pipe ø (mm)	450	450	450
		Incoming pipe DSIL (m AD)	93.03	93.03	93.03
		Outgoing pipe ø (mm)	450	450	450
		Outgoing pipe USIL (m AD)	92.44	92.44	92.44
		CSO weir crest level (m AD)	93.48	93.48	**94.5**
		CSO weir length (m)	0.32	**2.0**	**2.0**
		CSO ground level (m AD)	95.44	95.44	95.44
	Notes: Associated storage node: Storage6	Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	92.1	92.1	92.1
144787. 2		Incoming pipe ø (mm)	230	230	230
		Incoming pipe DSIL (m AD)	100.75	100.75	100.75
		Outgoing pipe ø (mm)	230	230	230
	Notes: Associated storage node: Storage5	Outgoing pipe USIL (m AD)	100.62	100.62	100.62
		CSO weir crest level (m AD)	100.72	**100.85**	**103.50**
		CSO weir length (m)	3.74	3.74	**3.7**
		CSO ground level (m AD)	104.41	104.41	104.41
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	100.1	100.1	100.1

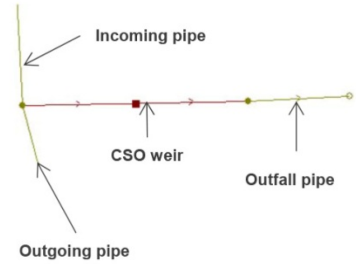
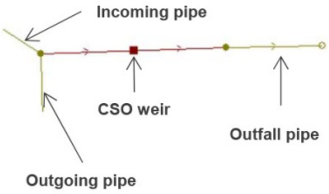
CSO reference	CSO details		Model UC	Model S	Model P
144765.2		Incoming pipe 1 ø (mm)	300	300	300
		Incoming pipe 1 DSIL (m AD)	107.33	107.33	107.33
		Incoming pipe 2 ø (mm)	300	300	300
		Incoming pipe 2 DSIL (m AD)	107.33	107.33	107.33
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	107.28	107.28	107.28
		CSO weir crest level (m AD)	107.48	**107.66**	**109.00**
		CSO weir length (m)	0.96	**2.00**	**2.00**
		CSO ground level (m AD)	109.96	109.96	109.96
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	102.60	102.60	102.60
103862.2		Incoming pipe ø (mm)	300	300	300
		Incoming pipe DSIL (m AD)	109.61	109.61	109.61
		Outgoing pipe ø (mm)	300	300	300
		Outgoing pipe USIL (m AD)	109.59	109.59	109.59
		CSO weir crest level (m AD)	109.82	**109.89**	**111.00**
		CSO weir length (m)	0.97	**2.0**	**2.0**
		CSO ground level (m AD)	111.73	111.73	111.73
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	104.60	104.60	104.60
103851.2		Incoming pipe ø (mm)	300	300	300
		Incoming pipe DSIL (m	105.69	105.69	105.69

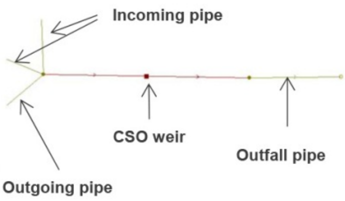
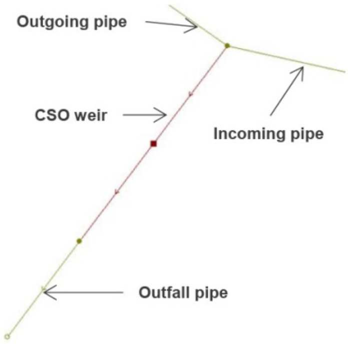
CSO reference	CSO details		Model UC	Model S	Model P
		AD)			
		Outgoing pipe ø (mm)	300	300	300
		Outgoing pipe USIL (m AD)	105.67	105.67	105.67
		CSO weir crest level (m AD)	107.35	107.35	109.5
		CSO weir length (m)	1.08	1.08	2.00
		CSO ground level (m AD)	110.16	110.16	110.16
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	107.1	107.1	107.1
103878.2		Incoming pipe ø (mm)	380	380	380
		Incoming pipe DSIL (m AD)	107.25	107.25	107.25
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	107.23	107.23	107.23
		CSO weir crest level (m AD)	107.83	107.83	**109.00**
		CSO weir length (m)	0.38	**2.00**	**2.00**
		CSO ground level (m AD)	109.88	109.88	109.88
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	107.10	107.10	107.10
103934_2.2 & 103934		Incoming orifice IL (m AD)	112.74	112.74	112.74
		Outgoing pipe 1 ø (mm)	380	380	380
		Outgoing pipe 1 USIL (m AD)	112.73	112.73	112.73
		Outgoing pipe 2 ø (mm)	230	230	230
		Outgoing pipe 2 USIL (m AD)	112.72	112.72	112.72
		CSO weir crest level 1 (m AD)	113.08	113.08	113.08

CSO reference	CSO details		Model UC	Model S	Model P
		AD)			
		Outgoing pipe ø (mm)	300	300	300
		Outgoing pipe USIL (m AD)	105.67	105.67	105.67
		CSO weir crest level (m AD)	107.35	107.35	109.5
		CSO weir length (m)	1.08	1.08	2.00
		CSO ground level (m AD)	110.16	110.16	110.16
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	107.1	107.1	107.1
103878.2		Incoming pipe ø (mm)	380	380	380
		Incoming pipe DSIL (m AD)	107.25	107.25	107.25
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	107.23	107.23	107.23
		CSO weir crest level (m AD)	107.83	107.83	**109.00**
		CSO weir length (m)	0.38	**2.00**	**2.00**
		CSO ground level (m AD)	109.88	109.88	109.88
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	107.10	107.10	107.10
103934_2.2 & 103934		Incoming orifice IL (m AD)	112.74	112.74	112.74
		Outgoing pipe 1 ø (mm)	380	380	380
		Outgoing pipe 1 USIL (m AD)	112.73	112.73	112.73
		Outgoing pipe 2 ø (mm)	230	230	230
		Outgoing pipe 2 USIL (m AD)	112.72	112.72	112.72
		CSO weir crest level 1 (m AD)	113.08	113.08	113.08

CSO reference	CSO details		Model UC	Model S	Model P
		CSO weir length (m)	2.4	2.4	2.4
		CSO ground level (m AD)	198.5	198.5	198.5
		Outfall pipe ø (mm)	300	**1000**	**1000**
		Outfall pipe USIL (m AD)	196.68	196.68	196.68
113074.2		Incoming pipe ø (mm)	200	200	200
		Incoming pipe DSIL (m AD)	125.71	125.71	125.71
		Outgoing pipe ø (mm)	200	200	200
		Outgoing pipe USIL (m AD)	125.71	125.71	125.71
		CSO weir crest level (m AD)	127.78	127.78	127.78
		CSO weir length (m)	2.00	2.00	2.00
		CSO ground level (m AD)	130.10	130.10	130.10
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	127.10	127.10	127.10
77529.2		Incoming pipe 1 ø (mm)	300	300	300
		Incoming pipe 1 DSIL (m AD)	155.87	155.87	155.87
		Incoming pipe 2 ø (mm)	250	250	250
		Incoming pipe 2 DSIL (m AD)	155.87	155.87	155.87
		Outgoing pipe ø (mm)	300	300	300
		Outgoing pipe USIL (m AD)	155.50	155.50	155.50
		CSO weir crest level (m AD)	156.42	156.42	**158.00**
		CSO weir length (m)	1.3	1.3	**2.00**
		CSO ground level (m	158.8	158.8	158.8

CSO reference	CSO details		Model UC	Model S	Model P
		AD)			
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	155.6	155.6	155.6
144718.2	 Notes: Associated storage node: Storage4	Incoming pipe ø (mm)	380	380	380
		Incoming pipe DSIL (m AD)	98.74	98.74	98.74
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	89.71	89.71	89.71
		CSO weir crest level (m AD)	99.76	99.76	**101.0**
		CSO weir length (m)	0.5	**2.0**	**2.0**
		CSO ground level (m AD)	101.61	101.61	101.61
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	99.1	99.1	99.1
159996_oslo.2	 Notes: Associated storage node: Storage9 and Storage10	Incoming pipe ø (mm)	380	380	380
		Incoming pipe DSIL (m AD)	112.77	112.77	112.77
		Outgoing pipe ø (mm)	380	380	380
		Outgoing pipe USIL (m AD)	112.76	112.76	112.76
		CSO control IL (m AD)	113.51	113.51	113.51
		CSO limiting discharge (m^3/s)	0.5	0.5	0.5
		CSO ground level (m AD)	114.88	114.88	114.88
136415.2		Incoming pipe ø (mm)	150	150	150
		Incoming pipe DSIL (m	415.59	415.59	415.59

CSO reference	CSO details		Model UC	Model S	Model P
		AD)			
		Outgoing pipe ø (mm)	150	150	150
		Outgoing pipe USIL (m AD)	415.59	415.59	415.59
		CSO weir crest level (m AD)	416.12	416.12	**419.5**
		CSO weir length (m)	1.14	1.14	**2.00**
		CSO ground level (m AD)	420.30	420.30	420.30
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	415.10	415.10	415.10
136412.2		Incoming pipe ø (mm)	150	150	150
		Incoming pipe DSIL (m AD)	413.69	413.69	413.69
		Outgoing pipe ø (mm)	150	150	150
		Outgoing pipe USIL (m AD)	413.69	413.69	413.69
		CSO weir crest level (m AD)	414.28	414.28	**414.50**
		CSO weir length (m)	1.14	1.14	**2.00**
		CSO ground level (m AD)	415.00	415.00	415.00
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	414.10	414.10	414.10
147789.2		Incoming pipe 1 ø (mm)	150	150	150
		Incoming pipe 1 DSIL (m AD)	413.65	413.65	413.65
		Incoming pipe 2 ø (mm)	200	200	200
		Incoming pipe 2 DSIL (m AD)	413.65	413.65	413.65
		Outgoing pipe ø (mm)	200	200	200
		Outgoing pipe USIL (m AD)	413.62	413.62	413.62
		CSO weir crest level	413.89	413.89	**415.0**

CSO reference	CSO details		Model UC	Model S	Model P
		(m AD)			
		CSO weir length (m)	0.95	0.95	**2.00**
		CSO ground level (m AD)	415.80	415.80	415.80
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	413.10	413.10	413.10
265233.2		Incoming pipe ø (mm)	200	200	200
		Incoming pipe DSIL (m AD)	435.11	435.11	435.11
		Outgoing pipe ø (mm)	200	200	200
		Outgoing pipe USIL (m AD)	435.11	435.11	435.11
		CSO weir crest level (m AD)	435.51	435.51	**437.0**
		CSO weir length (m)	1.52	1.52	**2.00**
		CSO ground level (m AD)	437.77	437.77	437.77
		Outfall pipe ø (mm)	1000	1000	1000
		Outfall pipe USIL (m AD)	434.10	434.10	434.10

ADAPT
A Drainage Analysis Planning Tool
D 43.2

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265122.