WaPUG Autumn Meeting 1994

Real Time Control in The Hague

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Introduction

This paper sets out the work that was carried out by DHV Environment & Infrastructure for the first stage of the implementation of Real Time Control of the sewerage system and Sewage Treatment Works serving The Hague and surrounding areas. The investigative and modelling work was carried out between March and October 1994. The Water Quality Board and the various Municipalities involved are currently discussing the implementation of the control system.

The Hague

The Hague (Den Haag) is internationally known as the home of the International Court of Justice but it is also the seat of the Dutch Parliament and the home of the Dutch Royal Family. The city of The Hague lies on the western coast of Holland as shown in Figure 1 and has a population of 445,000, the surrounding area has a further 255,000 bringing the total population for the area to 700,000. The topography of the region is extremely flat with extensive parts of the catchment below sea level and with a maximum elevation of 4.00 m above mean sea level.

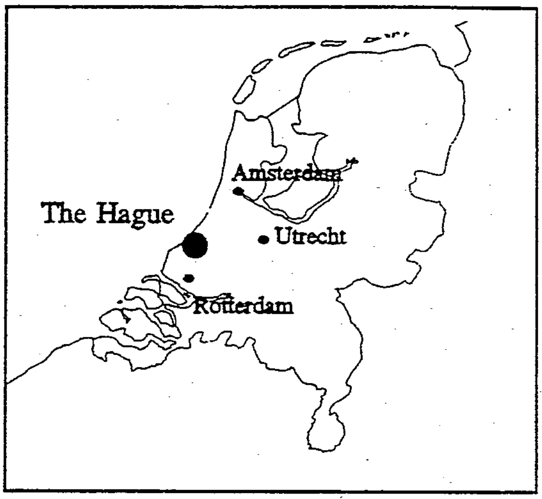

Figure 1 - Location Plan

Sewer Network

The Hague and the surrounding area is served by a network of combined sewers and pumping stations which discharge to the Houtrust Sewage Treatment Plant with the final effluent discharged into the North Sea. The STP has a biological treatment capacity of 8.7 m^3/s and a hydraulic capacity of 11 m^3/s. All flows to the STP are pumped and the installed maximum pumping capacity is 11 m^3/s with all flows in excess of 8.7 m^3/s discharged directly into the North Sea via a by-pass.

The catchment for the Houtrust STP includes a total impervious area of 3,045 ha and encompasses several outlying cities and small municipalities. A simplified representation of the sewerage system is shown in Figure 2. The sewerage system is combined and because of the flat topography of the area most of the sewers are laid to flattish gradients. A total of 30 Pumping Stations transfer flows between sub-catchments and ultimately to the STP. In common with most sewerage networks in Holland there are numerous Combined Sewage Overflows which spill into slow flowing city canals and ditches.

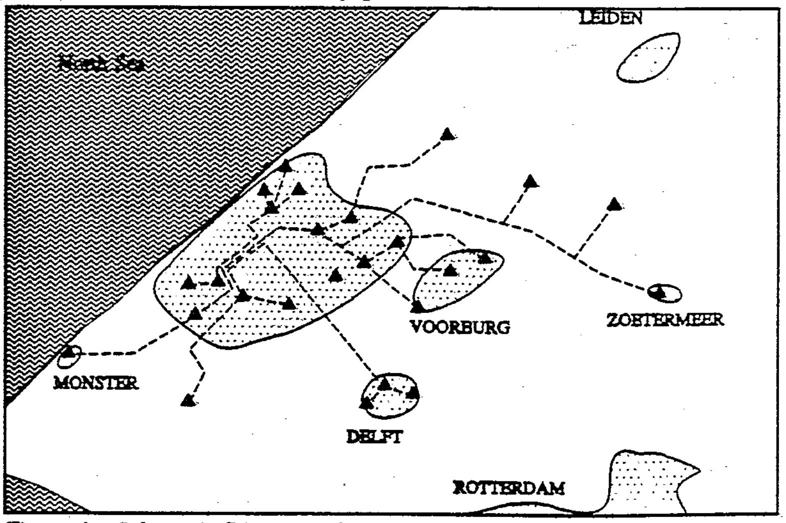

Figure 3 - Schematic Diagram of Sewerage Network

The organisational structure and responsibilities for sewerage and sewage treatment in Holland are different from that in the UK. The sewer networks are owned and maintained by the local Municipality who (in principle) finance any necessary work and maintenance from the local taxes. Water quality control and the regulation of discharges to surface water (rivers, canals etc) are the responsibility of the Regional Government but in practice network is structured with gravity sewers draining to pumping stations with the flows then either pumped to another area or directly to the STP. The hydraulic modelling identified any hydraulic deficiencies within the network and enabled the operation of the pumping stations and CSOs to be simulated.

The CYCLONE model was then simplified and converted into a LOCUS[2] model (an acronym of Local versus Optimal Control of Urban drainage Systems) which was then used to evaluate alternative RTC strategies and to compare these to the current (uncontrolled) arrangements. A schematic diagram of the LOCUS model is given in Figure 3.

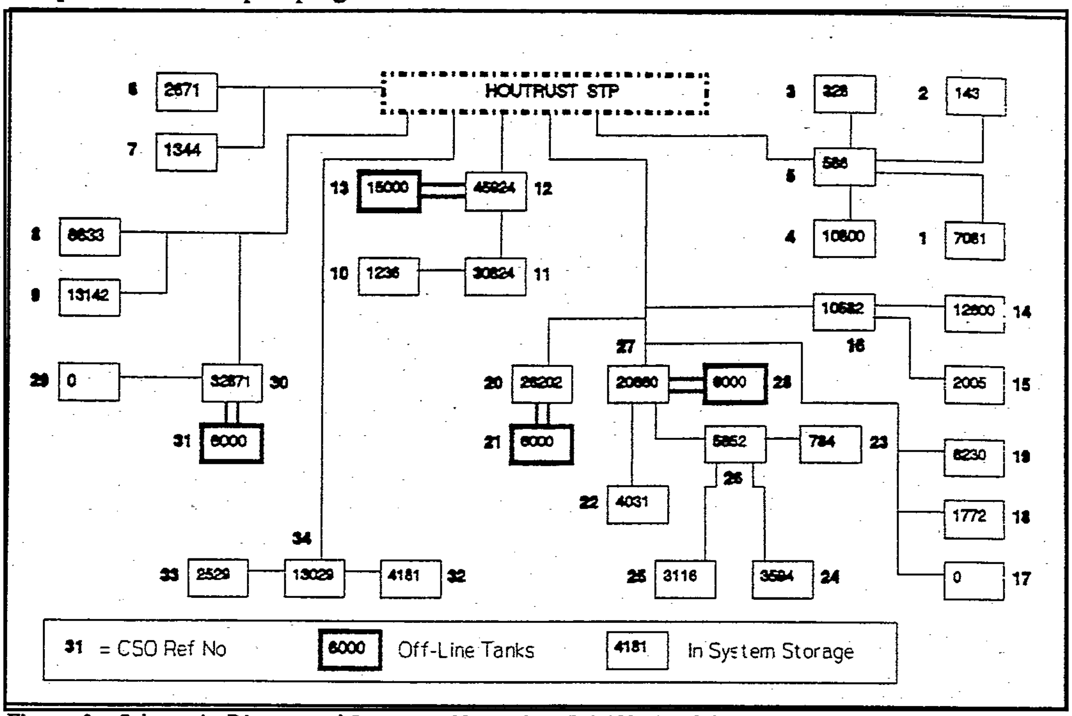

Figure 3 - Schematic Diagram of Sewerage Network in LOCUS Model

This schematic shows each of the 30 drainage areas (and pumping stations) with the finer boxes with the off-line storage tanks (and pumping stations) represented by the bolder boxes. All of the pumping stations have a CSO and these are referenced by their area number.

The analysis carried out utilised a time series rainfall data set derived from rainfall records at Lelystad (1970-1984). Storms with a total rainfall of at least 7mm and up to 18 hours of no rainfall during the storm were selected giving a data set of 490 storms with many of the storms having long durations of up to 48 hours. The rain data was transformed into inflows with 10 minute time steps by applying an initial loss of 1 mm and routing through a linear reservoir with a lag time of 15 minutes.

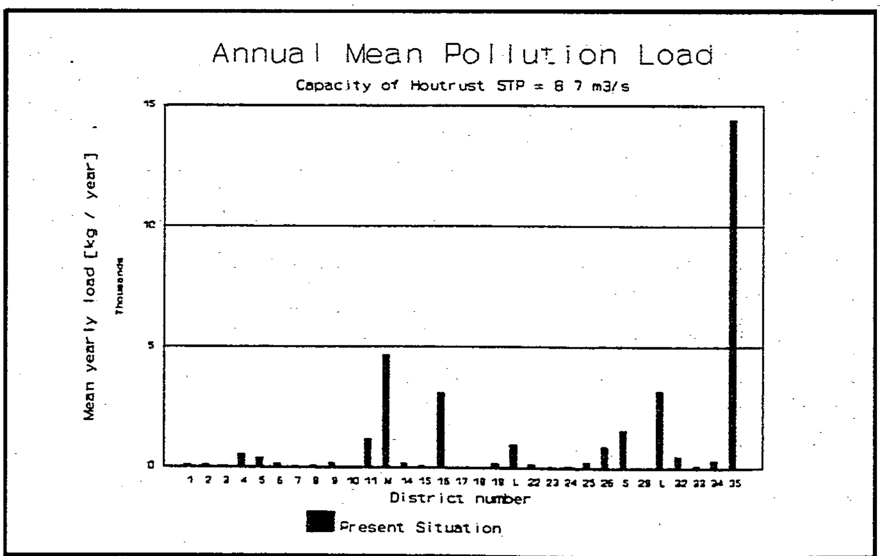

Figure 4 - Mean Annual Pollution Load from CSO's - Existing

The LOCUS model utilses an ideal mixed reservoir model to route pollution loads through the system and apply the relevant degree of dilution to give pollution loads at each CSO. Having run the time series storms the mean annual pollution load spilled at each CSO was determined by dividing the results by 15. The mean annual pollution load spilled at each of the existing (uncontrolled) CSO's is shown in Figure 4. District number 35 is the bypass at Houtrust STP and it can be seen that this has by far the highest pollution load.

2 The LOCUS program was developed by DHV in collaboration with Delft University of Technology

variable. For example, to control the use of storage it is necessary to increase the unit costs of storage with increased filling. A formula for such a function reads:-

$$cv_i^t = \frac{V_i(t)}{V_{i,\max}} \cdot \kappa_i \qquad (5)$$

where κ_i is a constant, denoting the maximum unit cost of V_i (which may differ for every node). The unit costs of overflows can be determined on the basis of the function and sensitivity of the receiving water. As overflows are to be prevented as much as possible their unit costs (co_i^t) should obviously be given a greater value than the costs of storage (cv_i^t) and transport (cq_i^t). On this basis it is possible to formulate an Objective Function, which is valid for all operational conditions. Substitution of Eq. 4 in Eq. 1 yields a non-linear programming (NLP) problem.

In deriving the operation strategy we can replace the NLP problem by a succession of LP problems. This means that at each time step of the simulated inflow hydrograph the optimization problem, as described by Eq. 1, 2 & 3, is re-formulated using the results of the preceding time step.

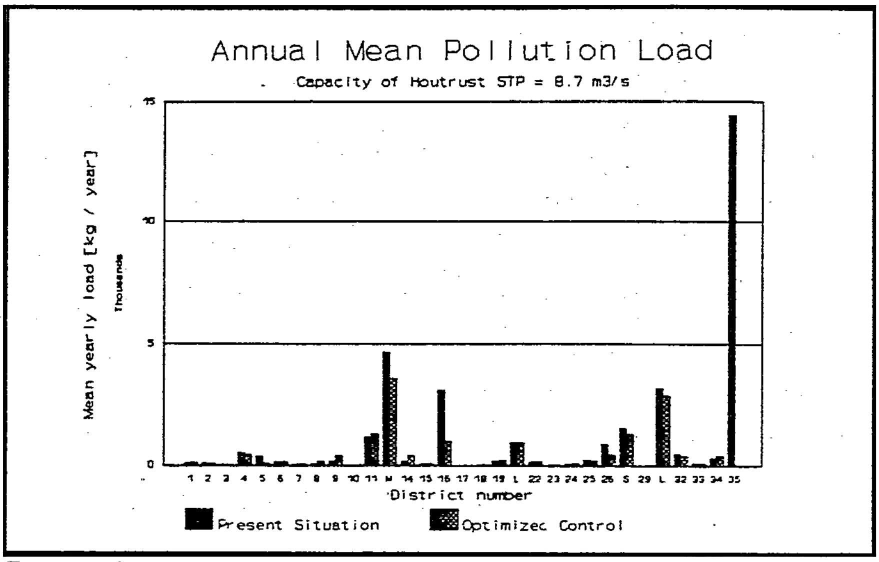

Figure 6 - Mean Annual Pollution Load from CSO's - Existing & Optimised

The LOCUS program incorporates this approach and has the main advantage of allowing the use of a powerful network flow algorithm, by which the model is fast enough to simulate time series events.
The work carried out using the LOCUS model has shown that the criteria set out in the Operational Objectives can be met with the peak discharge kept below 8.7 m^3/s (ie 79% of installed capacity) and the annual pollution load reduced at most CSO's as shown in Figure 6 where the existing (uncontrolled) and the controlled scenarios are compared.

Control System

Having demonstrated that the Operational Objectives can be met the next stage is to translate these into Operational Control rules and then design the control system. For the system at The Hague there is a degree of conflict between the objectives of the Municipalities and those of the Water Quality Board. The Municipalities are seeking for RTC to modify the performance of their sewerage networks to save the cost of building additional storage to meet the new criteria whereas the Water Quality Board are seeking to reduce the peak discharges to delay construction of a new STP or extension of the existing one. At the current time priority is being given to the latter though in the future this may change. DHV's client is currently considering whether the RTC system should aim for all CSO's to spill simultaneously or for more complex control with CSO's selected to spill to less sensitive receiving waters. Once the Client has selected the preferred option the detailed design of the control system will be undertaken.

The control system will be designed on the basis of keeping the local control of all the existing pumping stations fully operational but with the refinement of a central Programable Logic Controller being able to override the "Set Point" at each pumping station thus varying the pump start and stop levels. The control system will be based throughout on water levels and not on flows. The system is most likely to initially be a reactive system with increases in water level at a number of key locations in the network used to register any storm flows. Once storms are registered the central PLC will come into operation and if need be override the local control of the pumping stations. Due to the flat nature of the catchment the response time of the sewerage network is quite long thus allowing a reactive RTC system to adequately operate the system. Investigations are also currently