HYDROWORKS RTC MODELLING FOR ABERDEEN

Richard Ashley*, Francis Budge† & Robert Fleming*
*Wastewater Technology Centre, University of Abertay Dundee
†Director Halcrow Scotland

Aberdeen Sewerage

Aberdeen, located in the North East of Scotland, is a thriving city with a population of 215,000. It lies between two major salmon fishing rivers flowing east from the Cairngorms, the River Don to the north and the River Dee to the south of the main city. Its industries encompass paper making, waste paper recycling, fishing, fish processing, agricultural produce processing (chicken, dairy goods, potatoes, beef, pork), oil industry servicing, heavy engineering, tourism, providing services for the city and hinterland of a further 200,000 population.

The core of the sewerage network serving Aberdeen was built in 1868-1892, with major extensions in 1898-1906 (Girdleness short sea outfall) and 1978-1988 (Nigg Headworks and 2.5km tunnelled long sea outfall). The system conveys 80% of the city's sewage south via two major siphons (Garthdee and Torry) under the River Dee to the Bay of Nigg, to the south east of the business and commercial districts. The main part of the sewerage network is the Northern District Sewer (NDS), which serves the densest populated areas and connects the northern part of the catchment, via the harbour area, to the treatment plant in the south at Nigg. This passes flows through the harbour area via the Torry siphon, which is a 2.4m diameter pipe with a bifurcation wall so that flow can be passed through one or both semi-sections. Traditionally only one lenticular shaped section has been open at any one time in order to control sedimentation in the pipe. There are some 92 combined sewer overflows (CSOs) within the two main catchments, of which more than six regularly cause intermittent spillages into the Rivers Don and Dee. The North East River Purification Board (NERPB) has asked that these discharges be screened and spill volumes reduced.

A third catchment to the north west of the city, which also includes Dyce Airport, serves about 20% of the population and much light industry. This area drains to the Persley wastewater treatment works (WWTW) which provides a 20:30 standard effluent for discharging into the River Don.

Sewerage Analysis

Grampian Regional Council commissioned the Aberdeen Drainage Detailed Hydraulic Study from September 1993 to examine the CSOs and report on the measures necessary to meet the requirements of the Urban Wastewater Treatment (Scotland) Regulations and the concerns of the Regulator, NERPB. A system of five WALLRUS models was initially created using record drawings and manhole records and set up specifically to study CSO operation. Limited surveys of manholes and of all CSOs, combined with short term (5 weeks) and long term (6 months) flow surveys were necessary to verify the models and to ensure that the operation of the system was fully understood. Even without setting up the models, the surveys suggested that there could be significant backing-up in the system as a result of the operation of the headworks, possibly as far as the two siphons. The detailed WALLRUS model of the north west catchment was used initially to examine whether Persley WWTW and the sewerage network immediately upstream (much of which is separately sewered) could accept runoff containing de-icing and anti-freezing agents from the Airport for treatment. As the potential BOD loading was greater than the WWTW could handle the alternative was examined of pumping balanced flows into the NDS for conveyance to the Nigg Headworks. This increased the potential for spillage from several key overflows, and it was decided that separate arrangements would have to be made for the Airport drainage

The lower parts of the two major catchments were examined in greater detail by converting the WALLRUS models into HYDROWORKS. A revised NDS model covered the sewerage areas near the harbours, the two siphons (at Torry and Garthdee), and the two trunk sewers leading to the Nigg Headworks, the Western District Sewer (WDS) and NDS. Subsequently the whole system was converted in late 1994 to HYDROWORKS, albeit with two 'satellite' areas because of the size of the model. This facilitated a more detailed dynamic study of the lower catchment and the performance of several CSOs as potentially affected by the operation of the Nigg Headworks. The study concluded that most of the sewerage network operated satisfactorily, with nearly all CSOs spilling only after Formula A flows had passed forward. It also provided confirmation of the large unscreened CSO spillages which concerned the NERPB, although only one major CSO spilled prior to Formula A being reached. The HYDROWORKS model of the harbour area indicated that the operation of the Headworks some 1.0km downstream could be affecting some of the CSO operation.

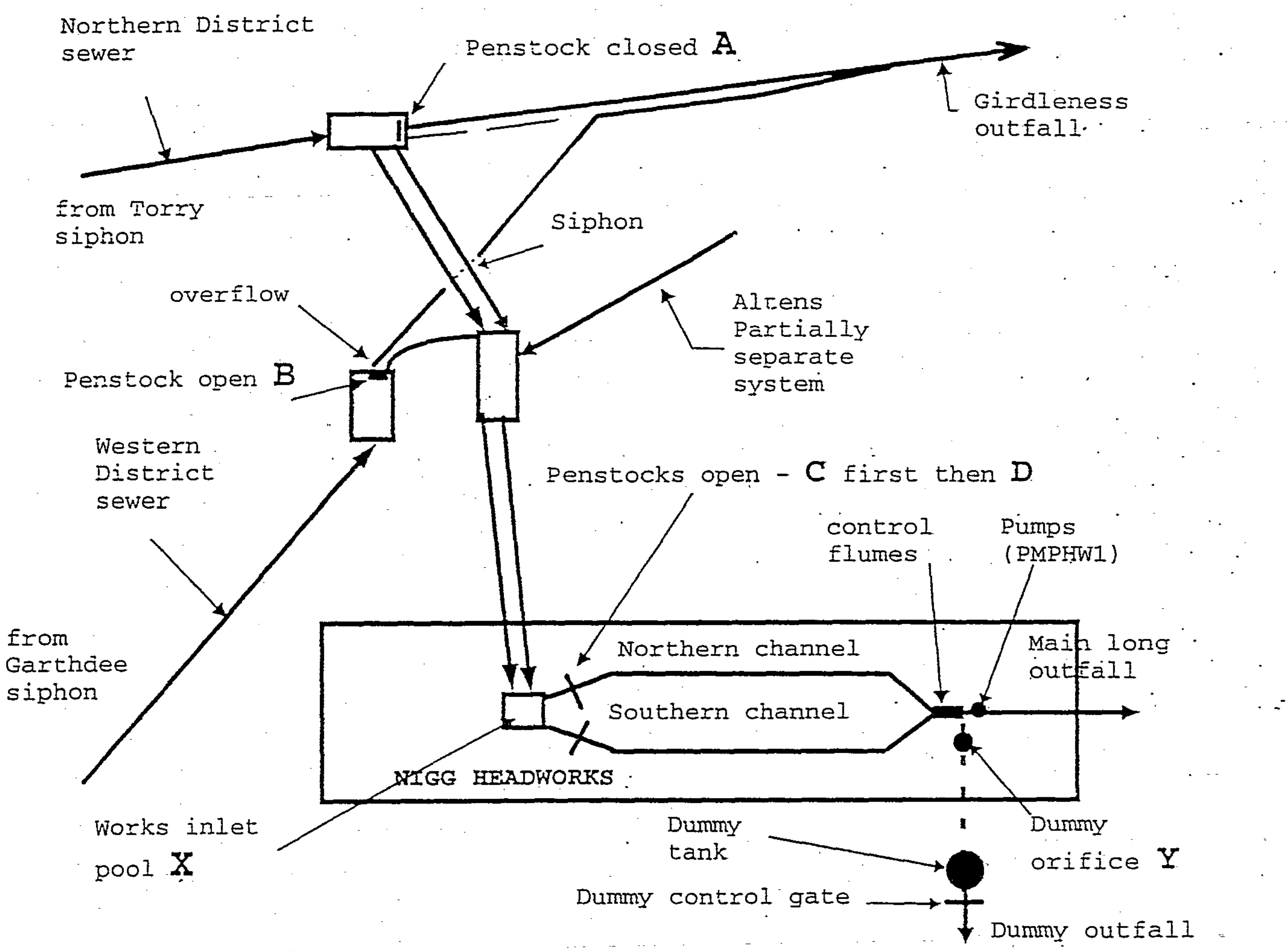

Figure 1 – layout of headworks and incoming sewers showing dummy timer arrangements and normal penstock operation

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Level at X (m) original	Flow into works (m^3/s)	Gate A	B	C	D
1.25	≤ 3.15	x	✓	x	✓
1.75	≤ 5.90	x	✓	✓	✓
2.25	≤ 6.30	x	x	✓	✓
2.5	> 6.30	✓	x	x	x
key x - closed ✓ - open					

Table 1: operating sequence for gates

Treatment Works & Interaction with Sewerage

The Nigg Headworks commissioned in June 1988: comprises an inlet chamber followed by north and south channels. each channel having a 150mm coarse screen. two 5mm drum screens. two Dorr-type detritors. and flow measurement prior to combining in an archimedean screw lift tidal pumping station designed to lift 6.3m^3/s flows up to 7.2 metres for discharge out to sea into 31 metre water depth via a 2.5 metre diameter 2.5km long tunnelled outfall. The system layout is shown diagrammatically in Figure 1. Initially it was believed that the works was protected by reference to a level monitor in the inlet manhole to the works (at X). The levels in this manhole correspond to flows as controlled by twin flumes just prior to the screw pumps. The original design operation levels in the inlet pool have since been 'adjusted' by trial and error. Normal mode is for the NDS flows to proceed to the works. The penstock into the Girdleness outfall is kept closed. WDS flows pass through the open penstock into the twin 1800mm sewers at the junction chamber.

Initially it was stated by the works manager that when flows into the works reach about 5.3-5.5m^3/s (corresponding to the original design levels in Table 1). the level in the inlet pool is such that it instigates the closure of a penstock some 500 metre upstream on the WDS (at B). This closure takes 4 minutes. following which. the effects take some 5-10 minutes to manifest themselves at the headworks. The unscreened WDS flows meantime, spill over the overflow into the Girdleness sewer outfall. 30 minutes after closing the penstock. it is re-opened automatically. If flows have subsided at the inlet pool. then it remains open. otherwise the cycle is repeated. This penstock opening and closing leads to a pulsing of the flows into the works if these remain high. and this cycling can occur many times in a severe storm (eg 11 cycles in a storm on 9.9.95) and because of the time delays the recorded flows into the works at WDS penstock closure can exceed the notional instigation flow. Clear evidence for backwater effects in the models showed surging of depths and velocities at least as far back as the WDS and NDS. This aspect of the operation is the primary controller of the hydraulics of the existing system for the flows near the works.

Attempts to replicate this behaviour using either the inlet pool levels or the flow to the works as 'controls' were initially unsuccessful. Subsequent discussions and consultation with recent records showed that the control flow in fact varies between 5.9m^3/s and 6.3m^3/s. Even with the WDS closed flows may still increase due to the NDS inputs. If these reach 6.3m^3/s. then the NDS penstock is automatically opened and the works is closed. In practice. if the works manager is present. these thresholds may be over-ridden. For example. under such conditions, inlet flows temporarily up to more than 7m^3/s have been achieved.

The Headworks can shut down automatically in an emergency. In this instance the penstock on the WDS closes and a penstock on the NDS opens to pass all flows unscreened into the twin culverts to the Girdleness outfall. This can happen when the screw pumps are overcome. or when the drum screens are clogged with grit blocking the launder channels threatening to flood the Headworks. Such large unscreened discharges have incurred the displeasure of the NERPB and consequently emergency procedures have been instituted to prevent or considerably reduce such occurrences.

The parallel Aberdeen Wastewater Treatment Study recommended changes to the Headworks including bringing all stormwater overflow arrangements to a location just upstream of the inlet chamber, screening all overflows through 6mm aperture before discharging via Girdleness outfall, remove larger grit particles from the flow, and minimise grease entering the Headworks. In conjunction with this, several of the upstream CSOs could be closed or modified, the trunk sewer penstocks sealed, and the two Torry siphon 'pipes' operated either singly or together depending on the flow.

HYDROWORKS RTC was used in order to fully understand the operation of the existing system and to ensure the viability of the new treatment inlet arrangements. The model was constructed to meet the following objectives:

- Assess the operation of the existing system – especially the backing up and transient flow effects
- Determine the optimum operation of the two channels in the Headworks
- Determine the optimum operation of the two siphon penstock gates at Torry to ensure no adverse upstream effects (i.e. premature CSO operation or flooding) when at high flows
- Check if the recommended arrangements to improve the Headworks and close certain CSOs are hydraulically viable at up to 1 in 100 year storm events
- Establish the likely frequency of stormwater spillages to Girdleness outfall with these improvements, including indications of duration, event volumes, and annual volumes using various time series rainfalls.

Application of RTC

Superficially the utilisation of HYDROWORKS RTC appeared straightforward. Hydroworks can model 'variable sluice gates' (VSG) in RTC mode. Unfortunately the RTC options do not (at present) include time 'switches' for gates (only pumps) and as gate B re-opens automatically after 30 minutes, this could only be modelled by interrupting runs and re-setting the gate manually, or by use of 'dummy' unit controllers. Consequently each gate (Table 1) has been modelled as a VSG. This arrangement was initially coupled with a dummy pump (at Y, Figure 1) discharging into a storage tank which would fill in 30 minutes. When the flow in the inlet to the works reached 5.3/5.9 m^3/s, the dummy pump was switched on and pumped 50l/s into the tank. Simultaneously, the WDS gate was closed. Once the tank was full, the pump switched off and the WDS gate would re-open.

Problems were encountered with this arrangement. The dummy pump (50l/s rated) was found to be too coarse in terms of performance to act as the primary timer. The rate of build up to the rated discharge was inadequate, and timings varied between 6 minutes and continuous switch-on! When the pump was replaced by a closely controlled variable orifice, constrained to pass precisely 50l/s, the system was then found to operate at virtually precise 30 minute closure times. The RTC operation was also found to be particularly sensitive to downstream effects, i.e. with a controller closed downstream, backing-up could alter assumed zero flow conditions, hence the dummy outfall pipe had to be set to be very large. Run times were another problem. The PC used has a 100MHz processor, but runs last anything up to 7 hours. In order to improve the turn-round time, the bottom end of the system was isolated in a 'core' model into which hydrographs were fed. This helped to allow RTC finalisation, but suffered initially from some inexplicable problems in software operation (WALLRUSisms!).

The verification events were not particularly severe and flows to the works just reached 5.3m^3/s for only one of the events. Model operation was satisfactory for this, but subsequent design storm runs up to 100 year return period failed to shut the works. Control using either option of inlet pool level or flow produced very similar results. Subsequent revision to control at the revised flow of 5.9m^3/s has shown that the existing system does not experience backing-up for the 1km upstream to the Torry siphon, although pipe full conditions occur and flows are relieved by spills from an overflow just downstream of the siphon. Work is progressing to assess the effect of the new layout for screening, modifications (including some closures) to CSOs and the best way of operating the Torry twin 'pipes'. The WSD gate (B in Figure 1) will be removed and the overflow sealed. VSGs have been incorporated at the new screened overflow, at the inlets to the siphon, with options for control to ensure that at the lowest flows the effects of sedimentation can be minimised.

Conclusion

The Aberdeen sewerage and Nigg treatment plant interact and any analysis must take this interaction into account. HYDROWORKS is a useful tool to assess whether interaction is occurring by causing backwater to influence the premature operation of CSOs and sedimentation or other effects on siphons. Most large WWTW are operated manually to some extent and the control 'rules' for the operation of gates and valves etc may not be amenable to modelling in a passive mode. RTC type models are essential under such conditions, not only to confirm levels of service from improved infrastructure, but also to develop operational rules once the new system has been commissioned.

Acknowledgement

This paper expresses the views of the authors, and whilst being presented with the permission of the Director of Water Services, Grampian Regional Council, it does not necessarily reflect his views.