# Tophill Low WTW

## nitrate reduction on one of Yorkshire Water's key strategic water treatment works

by Richard Hoyle CEng MIET

Yorkshire Water's Tophill Low WTW provides a maximum of 68Ml/d of potable water for the city of Hull. Water is abstracted from the River Hull and treated in the works before being pumped into the city's water distribution network. Nitrate concentrations in the river have been steadily increasing over a period of years and on occasions exceed the nitrate limits set in the Water Supply (Water Quality) Regulations. During periods of exceedance the plant had to be shut down, putting additional pressure on the water supply network to maintain supplies. To improve water supply resilience and to ensure high standards of water quality for thousands of Hull's residents, Yorkshire Water appointed Amey to design and construct a new £7.5m treatment facility within the existing site to reduce the nitrates to an acceptable level.

*Pipe gallery and general access way - Courtesy of Amey*

### Tophill Low WTW - the need for improvement

Nitrate concentrations in the River Hull have been steadily increasing over a period of years and on occasions exceed the Prescribed Concentration or Value (PCV) of 50mg/l $NO_3$ which is a requirement of the Water Supply (Water Quality) Regulations. During periods of exceedance the works had to shut down and during the five year period from January 2007 to December 2011 the PCV had been exceeded for 106 days with the River Hull nitrate concentration peaking at 64mg/l in November 2009.

### The preferred process

To comply with the Water Supply (Water Quality) Regulations, Amey was contracted by Yorkshire Water to construct an Ion Exchange (IEx) nitrate removal plant at Tophill Low WTW sized to treat 22Ml/d by a compliance date of 31 March 2015. The plant is installed downstream of the existing rapid gravity filters in a side stream arrangement.

Following treatment the flow is blended with the remainder of the WTW flow to ensure that a target nitrate concentration of 44mg/l $NO_3$ is met.

### Investigation (feasibility) phase

During the investigation stage three technologies were evaluated:

- ***Reverse osmosis***: An established treatment technology utilising pressure to force water through a membrane leaving concentrated contaminant on one side and treated water on the other.
- ***Electro-dialysis reversal***: Another established membrane treatment process, but utilising electrical charge as the driving force rather than pressure.
- ***Ion exchange***: A physical/chemical process using suitably selected resins to replace undesirable ions (e.g. nitrate) with more passive ions in the treated water.

After an extensive evaluation process during the investigation phase, ion exchange was shown to offer the best TOTEX based solution and Acwa Services Ltd's NITREAT system was selected. This system offered the added benefits of the smallest plant footprint and the lowest wastewater flow of the three processes considered, and offered the best all-round technical and TOTEX solution.

### Plant configuration

With the process confirmed the preferred plant configuration comprised a side stream ion exchange plant capable of treating 22Ml/d to 5mg/l which when blended with the remainder of the WTW flow, would reduce the nitrate levels to an overall target level of 44mg/l of $NO_3$ at peak nitrate levels and peak flow. This is well within the limits for drinking water quality and would future proof Tophill Low against any anticipated increase in nitrate levels.

The proposed solution also resulted in the construction of one of the largest plants of its type in the UK.

The remaining challenges were to integrate the plant into the existing works and manage the waste flows. The former required due consideration of chemistry, hydraulics, MEICA, SCADA and telemetry amongst other design related considerations.

Ion exchange resin is extremely vulnerable to chlorine attack and so careful consideration was given to where the proposed plant would interconnect in to the existing process. This chosen location, the RGF outlet chamber, resulted in the need to relocate sodium hydroxide and chlorine dosing point of applications and the provision of a new flow meter and static mixer to control the flow split and to ensure adequate chemical mixing.

The IEx plant hydraulics required the provision of a lift stage at its inlet to enable sufficient head to be generated to pass through the resin vessels. The MEICA, SCADA and telemetry interfacing required a thorough review of all site systems and their interconnection to determine capacity and the optimum connection points.

In discussions with Yorkshire Water and the Environment Agency it was originally agreed to install a transfer pipeline to take the waste flow 12km from Tophill Low to Beverley WwTW. This was further developed during the detailed design phase.

### Detailed design, construction, commissioning and handover

A number of Health & Safety elements were assessed, investigated and put in place before the work could begin. Taking into consideration additional noise levels throughout the construction period, it was agreed that the working hours would be 7.30am-5.30pm; this would also minimise the impact on the nature reserve.

During the initial detailed design phase considerable problems were encountered with the hydraulics, particularly the tie-ins to the existing RGF outlet pipework. The proposed addition of a static mixer meant that space was very limited. In addition the proposed area was found to be heavily congested with existing services. The initial solution needed to be reduced in size to enable it to be constructed within the space available.

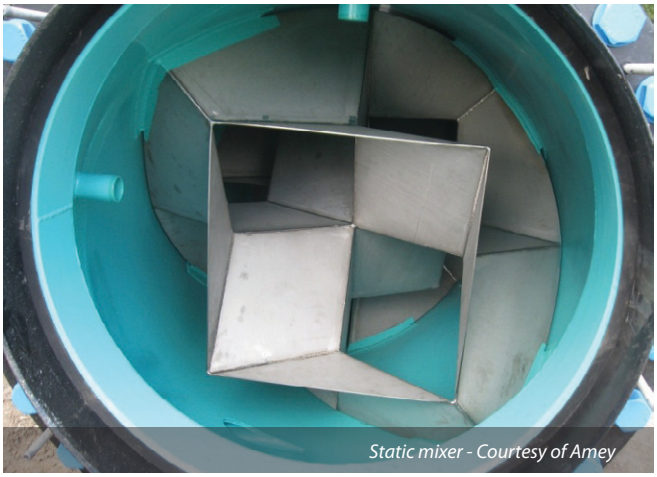
Yorkshire Water and Amey worked together discussing methods to combine the flow split, flow return, chemical mixing and flow measurement into a single compact structure so that it could be constructed off-line in the designated area. By doing so it was possible to satisfy the constraints outlined above and it was also possible to minimise the shutdowns required to connect it to the existing RGF outlet pipework.

The return flow pipe was provided complete with weir discharge chamber arrangement to provide a hydraulic break, thereby minimising the possibility of air entrainment in the resin vessels and discharge pipework.

Due to concerns regarding air entrainment the initial lift stage (in-line pumps and pipework) was amended to a wetwell/drywell inlet pumping station incorporated into the building footprint which would provide a degassing facility for any entrained air in the system.

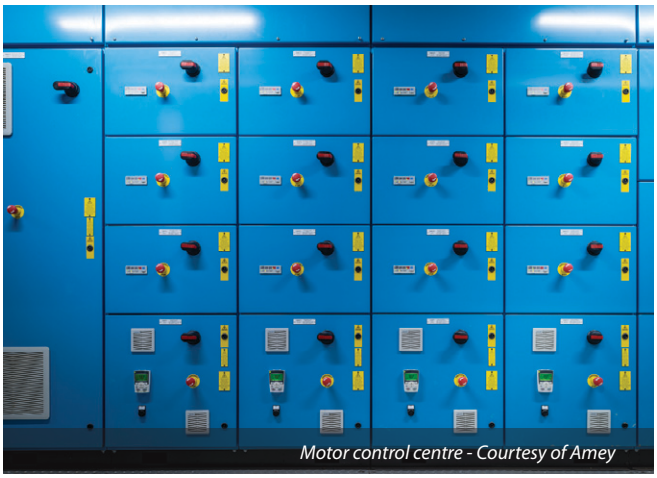
With the process supplier on-board and the hydraulic issues resolved the final solution was starting to take shape. The final solution comprised of the following key components:

- A nitrate removal building comprising of a wetwell/drywell inlet pumping station, nitrate removal process, MCC room and water quality monitoring room.
- External civil works comprising bunds for two salt saturators and a softener waste storage tank, tanker access, hard standings etc.
- A flow split and return flow structure complete with static mixer and flow meter.



*Static mixer - Courtesy of Amey*

*Softener waste storage tank and main ion exchange nitrate removal plant building - Courtesy of Amey*



*Motor control centre - Courtesy of Amey*

- Relocation of existing chlorine and caustic dosing points into the new mixing chamber to accommodate the new nitrate plant.
- A wastewater transfer pumping station.
- All associated interconnecting pipework, MEICA, SCADA and telemetry.

### Disposal of waste flows

Disposal of the waste flows from the process proved to be arguably the most challenging aspect of the project. The Acwa IEx process produces a small volume of waste for disposal (approximately 130m$^3$/day on maximum flow, maximum concentration for this plant). This waste contains high concentrations of nitrate, sulphate, sodium and chloride.

Following lengthy consultations between Yorkshire Water, Amey and the Environment Agency (EA), local discharge into the River Hull was agreed to be the most appropriate discharge option rather than pumping 12km to Beverley WwTW. At the proposed discharge point the river is tidal and able to receive the flow within acceptable EA discharge limits.

With local discharge to the tidal section of the River Hull agreed as the preferred option with Yorkshire Water and the EA, an engineering solution was needed to safely transfer the flows taking into account the problems associated with the waste flow itself. This prompted a thorough review of the initial solution and the development of the solution below:

- Gravitate nitrate waste flows from the main IEx building to an external pumping station for transfer of the flows to the river. This removed the need for a sump in the building, pumps and pipework, a large waste storage tank and associated concrete bund.
- The provision of surface mounted positive displacement pumps in a GRP enclosure with suction lines extending into the wetwell as opposed to the more traditional submersible pump configuration. This was required as submersible pumps were not recommended by pump suppliers for pumping flows with high brine concentrations.
- Gravitate the softener waste flows from a waste storage tank in the external bund to the wetwell. This removed the need for a further set of transfer pumps and pipework.
- The addition of a potable water flushing system to wash the pump and pipework thereby ensuring that the chances of scaling were reduced/eliminated.

A further issue with the waste flow is that the mixing of the softener waste flow and the nitrate waste flow almost instantly creates calcium carbonate ($CaCO_3$) and calcium sulphate ($CaSO_4$) both of which lead to scaling problems. If left unchecked this leads to pipework blockages and plant downtime so steps were needed to separate them as much as possible to minimise this.
Clearly both the softener waste flow and the nitrate waste flow would come into contact and to prevent scaling an anti-scalant is added into the softener waste. The properties of the anti-scalant begin to dissipate after approximately 12 hours; therefore the solution needed to ensure that the waste is transferred to the river prior to this to prevent scaling.

Consideration had to be given to the fact that if the flow stops for any reason (e.g. due to plant or pump failure), the clock keeps ticking for the waste contained in the pumping station and rising main before scaling begins. To manage this the following control sequence was developed:

- Nitrate waste flow arriving at the transfer pumping station under gravity would be discharged to the river under level control.
- Upon low level in the transfer pumping station and high

*Salt saturators and bund - Courtesy of Amey*


*Raw water pumps - Courtesy of Amey*

level in the softener waste tank flow would be discharged from the tank into the external pumping station via an actuated valve.
- Softener waste arriving at the transfer pumping station would be discharged to the river under level control.
- When the softener waste tank is empty the actuated valve closes.
- Following closure of the softener waste tank actuated valve and upon low level in the transfer pumping station a potable water flushing volume from a local potable water main would gravitate to the transfer pumping station.
- The flushing water arriving at the transfer pumping station would be discharged to the river under level control and in doing so would flush the whole system.

The above solution effectively provided a pulse of nitrate waste flow, followed by a pulse of softener waste tank flow, followed by a pulse of potable water through a single rising main to a river outfall structure. This method of operation minimised the contact time between the waste flows, provided an efficient and effective transfer system, was a lower TOTEX cost than originally proposed, and was fully in compliance with the requirements of Yorkshire Water and the Environment Agency.

Once at the river a cost-effective method of discharging into the river was explored by connecting into an existing reservoir overflow chamber. Following further investigation and discussions with the reservoirs Panel Engineer the existing overflow arrangement was found to be symphonic and unsuitable. A compromise arrangement of connecting into to an existing outfall structure was subsequently agreed with the EA which required passing the rising main through an existing flood embankment.

During construction of the main building consideration had to be given to the close proximity of an existing raw water main. The solution required the use of sheet piles as temporary works that were then used as part of the permanent works.

## Protecting the nature reserve

A further complication of the site is that Tophill Low has an adjacent nature reserve which is a haven for thousands of birds, butterflies, dragonflies, amphibians and even the occasional grass snake.

Parts of the reserve (two raw water reservoirs) have been declared as Sites of Special Scientific Interest and are nationally important for birds.

The wastewater pipeline needed to cross the reserve and careful consideration had to be given to its route and the timing of the construction work. Environmental and ecological assessments showed that the proposed solution had negligible impact on the reserve as the interest feature for the site, wintering wildfowl, was unlikely to be disturbed by the installation of the pipeline as the route selected was as far away from the reservoirs as possible.

As a further mitigation the work was undertaken outside the wintering period. It was concluded that the impact on the nature reserve would be relatively minor given the extent of the reserve compared to the area of the proposed works, its short duration and the temporary nature of the works.

The plant now constructed and in operation provides an innovative solution to the removal of nitrates at Tophill Low. Along the way, many technical challenges have been encountered and overcome to the satisfaction of Yorkshire Water and the Environment Agency through collaborative working between all parties involved.

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