Fast-Track Provision of St. Aidans Reverse-Osmosis Water-Treatment Plant

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Abstract

As a response to the drought of 1995–96, Yorkshire Water constructed an emergency water-treatment plant to treat water from a flooded opencast site at St. Aidans near Leeds. The main process was low-pressure reverse osmosis to remove ammonia and trace organic micropollutants to produce the required water quality at all times. This paper describes the plant which was designed and constructed in thirteen weeks – a fast-track project which was made possible by the close cooperation between the client, the consultant, and the contractor.

Key words: **Fast-track project; reverse osmosis; St. Aidans.**

Introduction

The 1995–96 drought, which hit hardest in Yorkshire, prompted a series of emergency engineering schemes to alleviate the worst effects. Most of these schemes involved the construction of pumping stations and pipelines to move water more efficiently around the county and to utilize existing resources better. However, none of these schemes provided 'new' water except for the St. Aidans scheme which was to abstract and supply 20 Ml/d of water from a flooded opencast mine. The project was to design and build a suitable treatment plant within thirteen weeks.

Resource

St. Aidans lagoon was formed by the flooding of opencast mine workings adjacent to the River Aire south-west of Leeds. In 1988, the river burst its banks due to an undetected geological fault, causing the side wall to fail. The lagoon which quickly formed was 70 m deep with a capacity of approximately 17 million m^3. British Coal Opencast, then owners of the site, had to re-establish the route of the river and the adjacent Aire and Calder canal. This was completed in April 1995 and the lagoon was isolated from the river. In August 1995, the new owners of the site (RJB Mining) started pumping the contents of the lagoon back into the river so that the remaining 2.5 million tonnes of coal could be mined. Following the publicity regarding the drought, RJB Mining offered the use of the water in the lagoon to Yorkshire Water to help overcome the drought problem. The resource, although limited, was expected to last twelve months at 20 Ml/d.

Raw Water Quality

The River Aire at St Aidans is of poor quality. It is downstream from major sewage-treatment works in Leeds and Bradford and most of the chemical and textile industry in West Yorkshire. An intensive sampling programme was undertaken on (a) the quality of the water throughout the 70-m depth of the lagoon and (b) the sediments. The results showed that, following the impoundment into St. Aidans, a large degree of self-purification had occurred, and the water was of a quality suitable for potable use – albeit with extensive treatment. The Environment Agency (from its own monitoring) also considered the quality of the water to be category A3. A typical analysis of the raw water is shown in Table 1. In addition, there had been large blooms of blue-green algae in the lagoon; therefore there was a likelihood of algal toxins being present at certain times of the year.

Process Selection

The main treatment issues were the high concentration of ammonia and the range of trace organic micropollutants which were present, including algal toxins. A complicating factor was that there could be some change in raw-water quality as the lagoon was drawn down. Between the line of the new river channel and the lagoon there was a substantial amount of rockfill and, as the lagoon was emptied, the pressure on the walls could be reduced – releasing water from the rockfill back into the lagoon. For these reasons, a treatment process giving maximum security with the most consistent and reliable water quality was required; accordingly, reverse osmosis (RO) was chosen. It was thought that conventional treatment followed by ozone and granular activated carbon treatment could not reduce the ammonia content sufficiently or give complete security against the wide range of trace organics which were present.

A preliminary process outline was produced and an intensive two-week pilot programme was carried out. This was used to derive a suitable pretreatment process to produce a feed to the RO with a 'silt density index' of 4.0 so that a reliable flux rate and a reasonable interval between membrane cleaning could be obtained. Three different RO membranes were evaluated and compared in terms of operating pressure and final water quality. These were from Dow Filmtec which operated at 14 bar pressure, Hydronautics (11.5 bar) and Fluid Systems (8

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Table 1 Typical analysis of raw water

Colour (°H)	12.8	MCPP† (µg/l)	0.32
Turbidity (FTU)	4.7	MCPA‡ (µg/l)	0.17
Conductivity (µs/cm)	790	Total pesticides (µg/l)	0.87
pH	7.9	Nonyl phenol (µg/l)	1.3
Amm. N (mg/l)	4.5	Pentachlorophenol (µg/l)	0.39
NO_2 (mg/l)	0.19	2–4 dinitrophenol (µg/l)	0.40
Iron (mg/l)	0.12	2–4 dinitrobutylphenol (µg/l)	0.38
Manganese (mg/l)	0.26	Alkalinity (mg/l $CaCO_3$)	170
Total dissolved solids (mg/l)	540	Hardness (mg/l $CaCO_3$)	220
Total organic carbon (mg/l)	5.9	Chloride (mg/l)	120

†(RS)-2-(4-chloro-o-tolyloxy) propionic acid
‡(4-chloro-2-methyl phenoxy) acetic acid

bar). The flux rate for the three membranes was 21.4 l/h. m^2. All three membranes produced a permeate of similar quality, therefore the decision was taken to use Fluid Systems model TFC ULP 8821 on the basis of its lower operating pressure.

A problem with the choice of RO was that the membranes, although in use elsewhere in the world (particularly the USA), did not have approval under Regulation 25(1)(a) of the Water Supply (Water Quality) Regulations 1989. However, the Fluid Systems membrane was approved by the US Food and Drugs Administration, and an application had been submitted for Reg. 25(1)(a) approval, but final approval was not imminent. Yorkshire Water then decided to use the membrane under the terms of Regulation 25(1)(b) which requires 'the undertaker to be satisfied that the substance or product, either alone or in combination with any other substance or product in the water, is unlikely to affect adversely the quality of water supplied'. Accordingly, Yorkshire Water carried out detailed tests on the permeate from the membranes to determine whether any trace organic compounds were being leached out. Yorkshire Water also retained an independent consultant from the National Centre for Environmental Toxicology to give an assessment of the raw and treated water quality and of the implications of using this type of membrane. In addition, permission was given by Fluid Systems for Yorkshire Water's assessor to study the evidence in front of the committee reviewing the submission for Reg. 25(1)(a) approval. He concluded that the proposed use should not cause any adverse effects on water quality.

The final process design is shown in Fig. 1. Water is pumped from the lagoon into a balancing tank. It is then coagulated with ferric sulphate and an anionic polymer prior to multi-media pressure filtration. The media is (top to bottom): 300 mm of anthracite to help maintain output during a blue-green algae bloom, 100 mm of manganese dioxide to provide catalytic manganese removal, 600 mm of 16/30 filter sand, and 225 mm of fine garnet over a coarser garnet layer on 400 mm of graded gravels. Further polishing prior to the RO is provided by 5 micron cartridge filters and then a UV disinfection stage to try and reduce bio-fouling of the membranes. After RO, post treatment is provided to render the water more palatable and to comply fully with the Drinking Water Inspectorate regulations. Initially, a high dose of chlorine is added to oxidize any residual ammonia from the RO stage and to provide safety disinfection. Carbon dioxide and lime are added to increase the alkalinity to 25 mg/l $CaCO_3$, as it was expected to blend the water with a harder supply in distribution to achieve compliance. However, when the plant was commissioned, this water was not available and further hardness had to be added using calcium chloride to attain 150 mg/l $CaCO_3$. This combination is used because a major industrial customer requires a water of fairly low alkalinity for use in his process. After a 30-min contact period, dechlorination is provided by sodium bisulphite to control chlorine residuals prior to distribution. Provision was made to dose sodium orthophosphate for plumbosolvency control but, so far, tests have shown that this is not required.

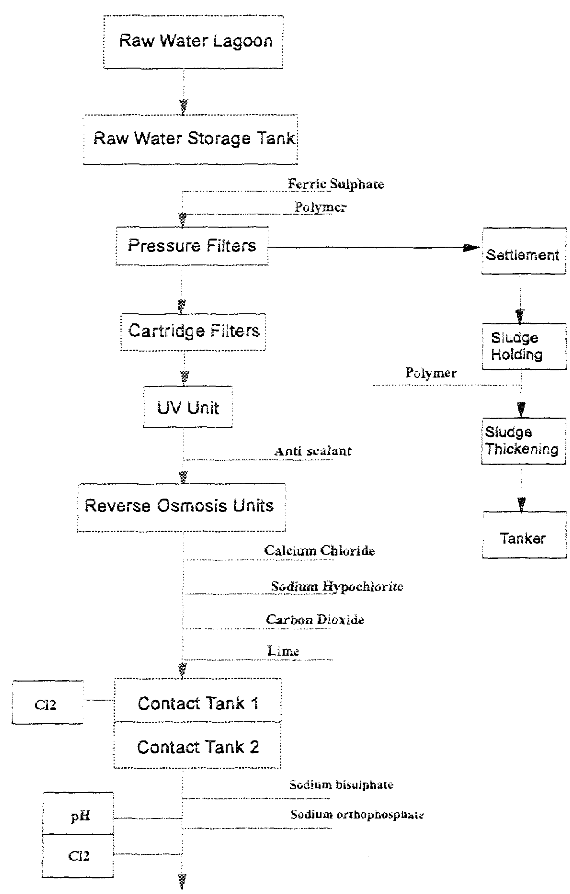

Fig. 1. Flow diagram of St. Aidans water-treatment plant

Feasibility Study

Following the process selection, Brown & Root Consultants were asked to carry out a feasibility study covering the intake, water treatment plant, water transmission, interconnection to an existing trunk main, pumping plant and power supplies. Sites both north and south of the River Aire were considered and the main issues were (a) guaranteeing the water-treatment process, (b) discharge of the wastewater, (c) water-treatment works' location, (d) crossing the waterways with a pipe, and (e) capital and operating costs. A matrix of all the options was drawn up, balancing risk against operating costs. Sites south of the river were excluded due to the high-risk element of crossing the waterway with a raw-water pipe – even though Yorkshire Water owned the land. Of the sites north of the river, the adopted option was one which gave the best balance between risk and cost, which sited the works at the east end of the lagoon with a new intake, connecting the treated water output into the Brayton to Kirkhamgate trunk main with waste discharge back to the River Aire.

Contract Award

Tender documents were compiled within ten days, then issued to selected specialist companies for competitive bidding on 4 April 96. The completed documents were then returned to Yorkshire Water Services for opening on 12 April 96. The tender documents included the I.Chem. E.Red Book form of contract. None of the tenders addressed the hazards highlighted in the 'competency and adequacy of resources' in relation to Construction Design and Management Regulations. All tenderers were invited to present their bids and to be interviewed on 16-17 April by a panel comprising representatives from Yorkshire Water Services and Brown & Root Consultants.

On the 25 April 96, ACWa Services Ltd were invited to proceed with procurement in accordance with the programme shown in Table 2. The total price for the scheme was £8 million; this included £4.2 million for the plant and £2.5 million for one year's operation by ACWa.

Project Management

The scheme was project-managed from site with support as required from the head offices of the client, project managers, contractors and sub-contractors. All decision-making parties were resident on site to resolve day-to-day progress problems. A management meeting was held every week to discuss progress and problems. Meetings were kept brief and all attendees were encouraged to make a commitment to accelerate progress with a team ownership of all issues.

Table 2. Contract programme for mechanical and electrical plant

Task	Duration (days)
Total contract period	100
Handover and design	35
Mechanical procurement	77
Electrical procurement	68
Mechanical installation	63
Electrical installation	82
Testing and commissioning	39
YWS quality tests	14

St. Aidans Plant

The St. Aidans water-treatment works was designed for ease of removal, transportation and installation, mainly due to its short-term life at its present location. The pressure filters and reverse-osmosis plants were constructed as six independent 3333 m^3/d streams with common header pipework to give maximum operational flexibility. The separate streams will also allow the plant to be used in smaller modules at a later date after removal from St. Aidans . A general view of the plant is shown in Fig. 2.

Works' Rating

Raw water input to the works was 25Ml/d, allowing 20 Ml/d to supply and 5 Ml/d as waste via the RO reject. An additional 6 Ml/d were abstracted and run to waste to increase the rate at which the lagoon was emptied.

Intake and Raw-Water Pipeline

This pipeline comprises 3 duty and 1 standby electro-submersible pumpsets, each rated at 323 m^3/h at 85 m head, located within a floating pontoon which is anchored with steel guide ropes in the middle of the lagoon about 500 m from the shore. The power-supply cables from the shore to the pontoon are suspended beneath foam-filled floating buoys. The pumps are started and controlled automatically by signals from a level transducer located in the raw-water tank. Each pump discharges into a common header pipe from which the raw water is pumped on-shore via a 500 m fused-welded floating 560 mm dia. MDPE pipeline. The pipeline is buried from the shore to a position just inside the treatment works' fence.

Raw-Water Tank

The raw-water tank acts as a buffer between the raw-water pumps and the treatment plant, and presents stable suction conditions for the filtration plants. The 500-m^3 tank is manufactured from commercial-grade glass fused to steel tanks of bolted-panel construction designed to sp. gr. 1.0.

Filter-Feed Pumps

Six 30-kW filter-feed pumps each rated at 175 m^3/h at 4.8 bar discharge into a common header tank.

Pressure Filters

Eighteen carbon-steel skid-mounted pressure filters are arranged in six streams of three filters, each skid weighing 18 tonnes (without the media). Common inlet and outlet pipework are provided to the filters in each stream to allow the three filters to operate in parallel. Each filter is 3 m dia. with a height of 3.2 m and is epoxy-coated internally and externally. Each set of filters is

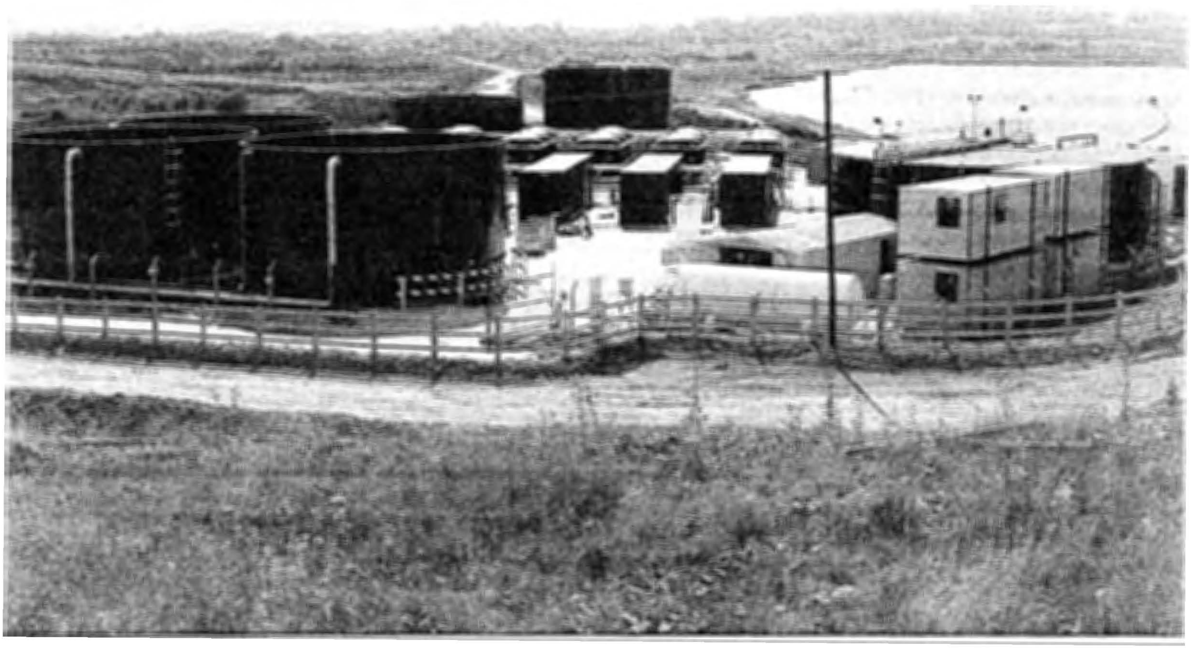

Fig. 2. General view of St Aidan's water-treatment plant

complete with a dedicated backwash pump, blower, programmable logic controller (PLC), control panel and motor start panel which will facilitate the possibility of future relocation of individual streams to separate sites. Backwashing of each set of three filters will take place sequentially over a 2.5-h period, with only one filter being off line at any time. The minimum number of filters available for service will be 17, with one in backwash.

Reverse-Osmosis Plants

The plants comprise six autonomous two-stage RO streams, each comprising duty/standby cartridge filtration units containing multiple-disposable cartridge filters rated at 5 micron, UV disinfection units with a transmission value of 95% in a 10-mm cell, an anti-scalant dosing system, and a high-pressure pump rated at 175 m^3/h at 11 bar. The RO configuration is an array of 27 GRP pressure tubes set in two stages, the first of eighteen tubes and a second stage of nine tubes to allow operation at 80% recovery. Each pressure vessel contains seven RO membranes each 200 mm dia. and 1.0 m in length, which were loaded according to a computer-ordered array provided by the manufacturer to equalize flux rates between the tubes and across the plant. These are housed in purpose-built air-conditioned stainless-steel lined standard shipping containers. A common 'cleaning in place' system is provided for periodic cleaning of the RO membranes.

Treated-Water Tank

The treated-water tank is made of glass fused to a steel-bolted construction with a sealed roof and two concentric compartments. The outer compartment provides a chlorine contact period of 30 min and has a capacity of 442 m^3. The inner compartment has a capacity of 223 m^3 and provides balancing for the treated-water pumps.

Treated-Water Pumps

Three duty/assist/standby fixed-speed horizontal end-suction pumpsets, each rated at 420 m^3/h at 8 bar, complete with isolation valves, discharge check valves, discharge flow meter, pressure gauge and pressure switch, are provided. A 25 m^3 capacity surge vessel is provided on the pumping main immediately after the treated water pumps to dampen any pressure surges derived from varying bus main conditions.

Treated-Water Pumping Main

The 2 km pumping main is constructed from 450 mm dia. ductile-iron pipes with flexible joints. From the treatment works, the water main follows the western fence for about 1.5 km; it then turns north to cross the road via a thrust bore and follows an existing track to interconnect with the Brayton to Kirkhamgate transmission main on the suction side of Swillington pumping station. In the event that water leaving the plant is out of pre-set high or low chlorine residual limits, or pH range, automated valves (at the start of the main) divert the flow from supply and back to the lagoon. Water is manually returned to supply, once satisfactory quality parameters have been achieved.

Backwash Water Storage Tank

This 300-m^3 tank is located adjacent to the raw-water tank and is also made of glass fused to a steel-bolted construction with an open top. It is constantly replenished with reject water from the RO units and, when full, overflows to a nearby storm sewer and back to the River Aire as a consented discharge. The tank can also be filled, if necessary, through a branch off the raw-water pipeline.

Backwash Settlement Tanks

Three tanks, each containing 507 m^3, are provided to settle backwash water from the filters with a capacity to hold at least two washes per day. Once settled, the supernatant passes to the storm sewer which discharges into the River Aire via an oxbow lake. The supernatant is made up with raw water from the lagoon and the reject liquor, comprising a total flow discharge not exceeding 11 Ml/d. The maximum reject consent conditions for the major components are shown in Table 3. The volume is monitored and sampled by a flow-proportional composite sampler, from which samples are removed, analysed and stored for 48 h for collection by the Environment Agency as required. The settled sludge is collected in a holding tank for disposal off-site via tanker.

Table 3. Discharge consent conditions

Volume (*m^3*)	6000	o-m-p toluidene (*µg/l* each)	10
pH range	6–9	Diazinon (*µg/l*)	1.6
Total drins (*µg/l*)	0.12	Propetamphos (*µg/l*)	1.6
Suspended solids (*mg/l*)	40	DDT (*µg/l*)	0.1
Cadmium (*µg/l*)	20	2,3,4- nitrotoluenes (*µg/l* each)	10

Chemical Storage and Dosing

Sodium hypochlorite, ferric sulphate, sodium bisulphite and sodium orthophosphate are delivered and stored in intermediate bulk containers, and the plant for these chemicals includes mixing tanks, dosing tanks and metering pumps. Polyelectrolyte is delivered as a powder, and the dosing system comprises a charging hopper, blending unit, dosing tank and metering pumps. Hydrated lime is supplied in 1-tonne bulk bags which are emptied through a 1-tonne charging hopper into a storage tank, then a screw conveyor transfers the lime to a make-up tank and metering pumps deliver it to the dosing point. Liquid carbon dioxide is stored on site in a 15-tonne storage vessel to assist with re-hardening.

Two chemical buildings are provided – one for pretreatment chemicals and the other for post-treatment chemicals. The pretreatment chemical building also contains compressed-air plant for the operation of the pneumatically actuated valves, together with equipment to provide make-up water for the chemical mixing tanks. Calcium chloride tankage and dosing equipment has recently been added to the plant to provide additional re-hardening facilities to attain a 'stand alone' concentration of 150 mg/l (as $CaCO_3$) in the final treated water.

Power Generation Plant

Main electrical power to the site is provided by 2 duty and 1 standby containerized diesel generator sets, each of 1 MW. Fuel storage is held in three welded-steel double-skinned bulk-storage tanks.

Motor Control Centre

The motor control centre room contains a back-to-back motor control centre (MCC) housing the electrical distribution switchgear and the starters for the plant. Control of the starters is carried out by a PLC located in the MCC instrument section. Operational parameters can be altered via an operator message display on the panel. The PLC does not control the RO plants or the pressure filters which have their own PLC controllers. A separate PLC and personal computer are installed to monitor the plant status and generate alarms. All alarms generated by the SCADA package are dialled out to radio pagers held by the on-call operator. High priority alarms are forwarded to the Yorkshire Water Control Centre.

Project Overview

All civil construction including concrete slab for the mechanical and electrical (M&E) plant, reject and out-of-specification pipeline were completed in accordance with the programme to allow the installation of the main treatment works to commence on time. The treated water line installation experienced some slippage mainly due to land access to thrust bore under the highway. The start of the installation of the M&E works accelerated with the 560 mm dia. MDPE floating raw-water pipeline being completed ahead of programme. The installation of all the glass fused to steel tanks, erected by jacking the base ring to the next level and then installing a further base ring (always working at ground level), proceeded ahead of programme. The pressure filters, which were manufactured off site, arrived as planned with media fills on site proceeding at a rapid pace. Some problems were experienced with the fitting out of the RO containers off site, therefore it was decided to deliver them to site for fitting out. Progress of all procurement items was monitored daily with weekly updates of long lead items – especially imported equipment such as RO membranes which were air freighted from the USA. The mid-part of the programme, with 14 sub-contractors employing over 70 tradesmen working in an area the size of a football pitch (including 400-tonne crane etc.) demanded extremely tight management, coupled with the flexibility to change the programme to suit the circumstances. There were no reported injuries during the construction programme.

The relationship between client, project managers and contractor quickly developed into a joint ownership of all the issues associated with a fast-track project.

Table 4. Typical analysis of final water

Colour (°H)	<2.0	MCPP (μg/l)	<0.02
Turbidity (FTU)	<0.15	MCPA (μg/l)	<0.03
Conductivity (μs/cm)	365	Total pesticides (μg/l)	<0.3
pH	8.4	Nonyl phenol (μg/l)	<0.2
Amm.N (mg/l)	<0.03	Pentachlorophenol (μg/l)	<0.5
NO_2 (mg/l)	<0.02	2–4 dinitrophenol (μg/l)	<0.01
Iron (mg/l)	<0.01	2–4 dinitrobutylphenol (μg/l)	<0.01
Manganese (mg/l)	<0.01	Alkalinity (mg/l $CaCO_3$)	38
Total dissolved solids (mg/l)	285	Hardness (mg/l $CaCO_3$)	152
Total organic carbon (mg/l)	0.16	Chloride (mg/l)	85

Problems were discussed quickly with solutions agreed and acted on to progress the work. Without this extremely close partnership it is unlikely that this type of project could be carried out successfully. The weather was also favourable as only two days were lost due to rain. The project finished on time and within budget, i.e. a 20 Ml/d water treatment plant was installed in eight weeks.

Commissioning

During commissioning, the plant was run at full output, but discharging back to the lagoon to enable all the relevant analytical checks to be made. For a period between August 6th and 18th, samples were taken at key points throughout the process and analysed for a full range of physical, chemical and bacteriological parameters. These included a full periodic table scan, broad-spectrum high-resolution gas chromatography/mass spectrometry scans and a volatile organic carbon purge and trap analyses. All results were clear except for some low bacteriological counts (mainly Klebsiella and Citrobacter) from the RO units prior to disinfection, which disappeared when the units were continuously run. All the results were independently assessed and passed by Yorkshire Water and the National Centre for Environmental Toxicology, and the water was put into supply 23 August 1996. A typical analysis of the final water quality is given in Table 4.

Conclusions

1. Reverse osmosis was a suitable treatment method for producing high-quality potable water from the St. Aidans source.
2. This treatment method allowed fast-track construction and was successful in providing extra water to help Yorkshire Water alleviate the effects of the drought.
3. The close partnership formed between the client, consultant, and contractor was a major factor in the success of the project.

Acknowledgements

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