Chapter 17

# Planning and Constructing the Reservoir

Robert Ovens and Sheila Sleath

*This chapter is primarily based, with full permission, on the personal recollections of John Winder, and The Empingham Reservoir Project (Rutland Water) by A J H Winder MA FICE (formerly Chief Resident Engineer, Empingham Reservoir Project), R G Cole FICE (formerly Project Manager, Empingham Reservoir Project), and G E Bowyer BSc FICE (Director of Operations, Anglian Water) which was presented to the Institution of Civil Engineers on 14th May 1985 and published in the* Proceedings of the Institution of Civil Engineers*, Volume 78, April 1985.*

The project to build Rutland Water was originally known as the 'Empingham Reservoir Project', or more correctly, the 'Empingham Pumped Storage Project'. It was completed in 1976, being one of the largest water supply schemes undertaken in the United Kingdom, and certainly the largest civil engineering project in Rutland. It involved the construction of an earthfill dam to form an impounding and pumped storage reservoir with a capacity of 124 million cubic metres in the valley of the River Gwash. The reservoir is filled partly by impounding water from the Gwash, but mainly by pumping water from the much larger Welland and Nene. The pumped supply system to the reservoir required river intakes, pumping stations, 14km of tunnelling in Upper Lias clay, and large-diameter pipelines. More pipelines were laid to connect the reservoir to a new water treatment works at Wing, and one major and two minor roads were constructed to replace those lost to the flood. Finally, a great deal of trouble was taken over the landscaping in order to make the reservoir worthy of its setting and suitable for a range of water-based and other outdoor leisure activities.

Large reservoir schemes have a reputation for long gestation periods before their final commissioning, and Empingham was no exception. After completion of the Pitsford Reservoir Scheme in Northamptonshire in 1956, Leonard Brown, then Engineer to the Mid-Northamptonshire Water Board (MNWB), and Thomas Hawksley, a consultant civil engineer, started searching for a suitable site for the next major water development that, in their opinion, would undoubtedly be needed in the area. The need arose from a steady increase in demand for water in the East Midlands in the 1960s, accelerated by the expected requirements of the five planned expansion areas of Corby, Daventry, Northampton, Peterborough and Wellingborough.

Leonard Brown set out the criteria for the new reservoir site:

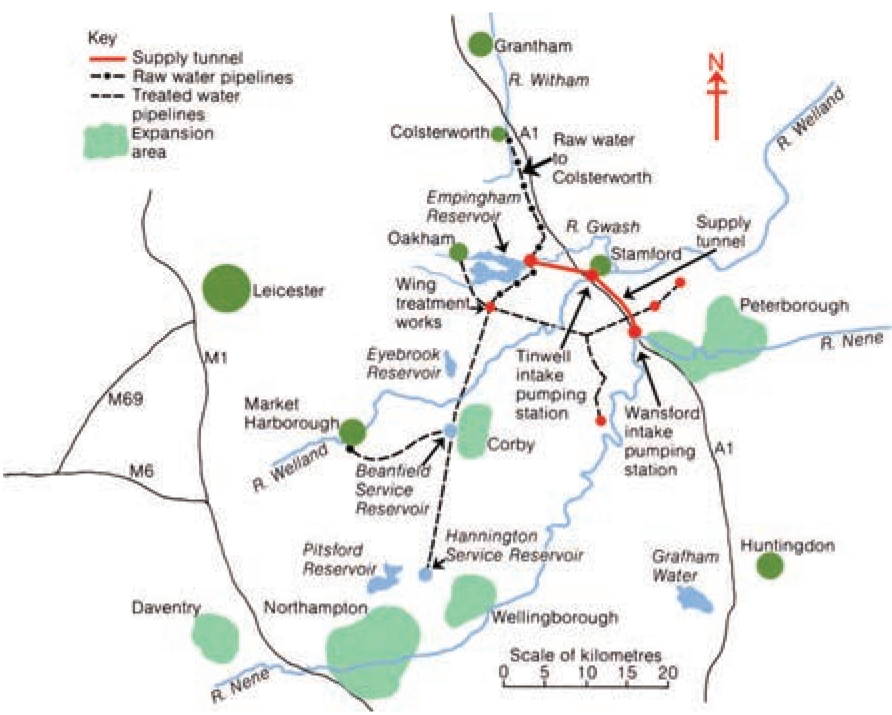
'The valley must have a suitable shape, so that the reservoir will hold plenty of water, the ground must be strong enough to bear the weight of the dam, and the dam of course mustn't leak so the geology must be right. There must be plenty of local material from which to build the dam, there must be a river reasonably near so that a large quantity of water can be obtained to fill the reservoir, and lastly of course the site must be sufficiently near the centres of population where the water is wanted, so that the pumping costs are not too high.'

By 1967 the Gwash valley upstream of Empingham and the nearby Chater valley to the south-west of Manton had been selected as the most suitable sites for storage reservoirs to provide for the predicted demand, estimated at that time to exceed the capacity of available resources by over 300 million litres per day in the year 2001 (*see* Chapter 14 – Rutland Waters).

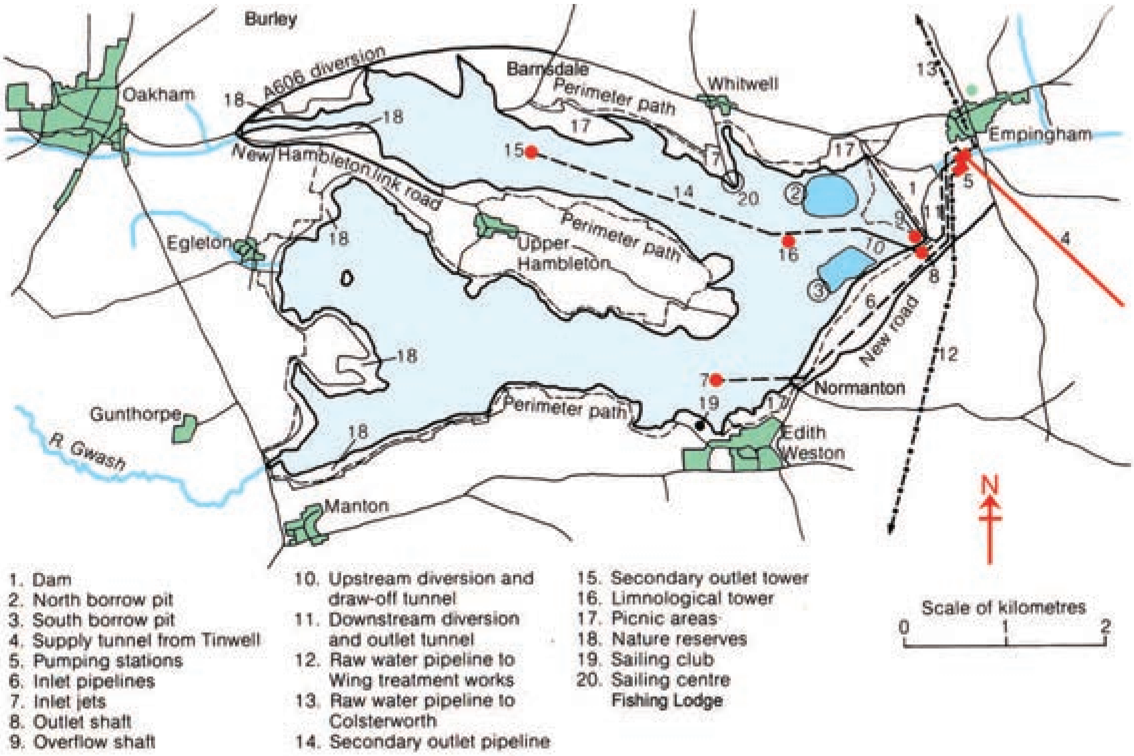
## The Preliminaries

Preliminary geological investigations proved that both the Empingham and Manton sites were suitable for dam construction, and in 1968 a decision was made to proceed with promotion of the reservoir scheme. The original proposal was to promote both reservoirs, but it was eventually decided to proceed only with the Empingham Reservoir, in the knowledge that Manton Reservoir could be developed in the future, as a second stage, if required. The Welland and Nene River Authority (WNRA) took the lead in the joint promotion of the scheme with the Mid-Northamptonshire Water Board. During the construction of the reservoir they were replaced by the Anglian Water Authority, which came into existence as a result of the 1973 Water Act. In 1983 this Authority was renamed Anglian Water.

Despite a concerted campaign by local groups, including Rutland County Council, the National Farmers Union, the Country Landowners Association, the Council for the Preservation of Rural England and Oakham Rural District Council (*see* Chapter 15 – Don't Dam Rutland), the Welland and Nene (Empingham Reservoir) and Mid-Northamptonshire Water Board Bill received Parliamentary approval in May 1970.




*The Empingham Pumped Storage Project* (after the Institution of Civil Engineers)




*An overall plan of the reservoir. Note that a new fishing lodge and restaurant has been built at Normanton since this plan was prepared. The original fishing lodge at Whitwell is now a café* (after the Institution of Civil Engineers)

## Project Organization

Responsibility for the design and construction of the reservoir was divided between the Welland and Nene River Authority and the Mid-Northamptonshire Water Board, the joint promoters of the scheme, and T & C Hawksley, the appointed consulting engineers. The organization of all aspects of the project was under the control of the Empingham Project Committee appointed by the River Authority. This committee was closely involved with the progress of the work and was charged with taking quick and positive decisions. Liaison between all the organizations and contractors involved was provided by regular meetings attended by all parties. Such close co-operation was essential to ensure that the overall project programme was maintained and that technical matters were not overlooked or duplicated.

## Project Design

Because of uncertainties regarding the precise geology of the area near the dam and along the line of the supply aqueduct, final designs could not be completed until after construction had commenced. The successful design was to rely heavily on test results and other data from boreholes and a trial embankment which were to be completed in the first year of the project.

Monthly design and construction meetings chaired by John Winder, Chief Resident Engineer, and attended by his team, design staff, and geotechnical and soils consultants, reviewed instrumentation and test results, decided upon further investigation work, and made design decisions and modifications. Any construction instructions or implications resulting from the meetings were conveyed to the contractors within 24 hours.

### John (A J H) Winder – Chief Resident Engineer for Rutland Water

John Winder spent the first five years of his life in Poona, India, where his father was an Army Medical Officer. Returning to the UK (United Kingdom) in 1927, his family lived at Folkestone, Kent, until his father was posted abroad again in 1932. He then attended boarding schools and from 1935 he was at Shrewsbury. On leaving, he enlisted in the Royal Signals and spent some time on a short course at Oxford on electronics and mathematics. Little did he know it at the time, but a contact made on this course was to have an important effect on the direction of his future career.

After passing out at Catterick, North Yorkshire, in 1941, he joined the Royal Signals and was appointed Signals Officer to 90th (City of London) Field Regiment Royal Artillery. The Regiment was sent in turn to India, Northern Iraq, Palestine and Egypt, where he was transferred to the 'Desert Rats' (the 50th Northumberland Division). He also took part in the invasion of Sicily before returning to the UK in January 1944. On Monday 5th June 1944, John was crossing the English Channel on a landing craft, his destination being Sword Beach where he was about to take part in the D Day landings.

By the end of hostilities the Royal Signals were very busy restoring communications in Germany. This important work meant that he was unlikely to get early release from the army. However he managed to obtain 48 hours leave, and made his way to Oxford University where he visited A H Smith, Warden of New College, whom he knew from his course there in 1940. On his return to Germany, he received a telegram from the War Office giving him immediate release from the Army and instructing him to report to New College at the beginning of October.

In 1949, at the age of 28, he graduated with an honours degree in Engineering Science, but opportunities for young engineers in the UK were very few at that time, and salaries were low. So he looked abroad and early in 1949 he joined the Colonial Engineering Service as a junior engineer in Northern Rhodesia, now Zambia. Here he worked on water supply schemes, roads and bridges before resigning and returning to the UK in 1954.

John now joined consulting engineers Binnie, Deacon and Gourley in London who specialised in water supplies and dams. Until 1957 he served as a Senior Assistant Resident Engineer on the Tai Lam Chung Water Supply Scheme in Hong Kong, building a large concrete dam and three smaller earth dams.

Following his return to London, he married Cherry Lewis in May 1959, and later that month, he left for Nigeria to supervise water supply projects as a relief engineer. In 1960, he again returned to London and his next project was Diddington Dam, now known as Grafham Water (Cambridgeshire), where he was Chief Resident Engineer, living with his family in the village of Brampton, near Huntingdon, a few miles away from the project.

His next move was to Herbert Lapworth and Partners in Westminster who wanted him as their resident engineer for the construction of Scammonden Dam, high in the Pennines, near Huddersfield, West Yorkshire. Again he and his family moved to be near the job, this time to an old vicarage in a remote Yorkshire valley.

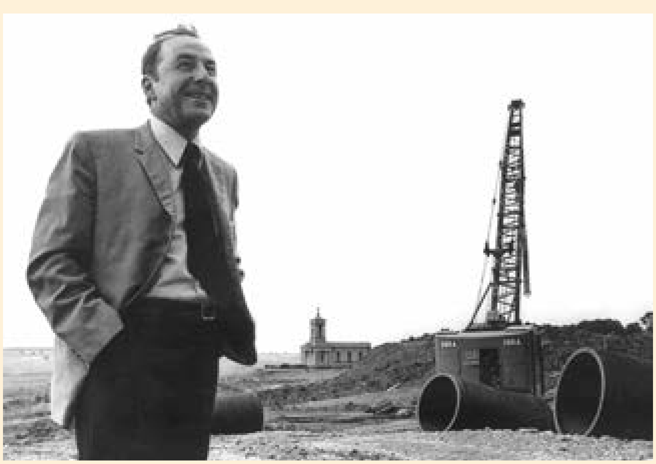
The project involved working closely with the County Council, who were building the M62 motorway, Britain's first mountain highway, which was to cross the valley on the crest of the dam. It was to be one of the highest dams in the UK, and was constructed using rock fill removed from the bottom of the valley. The M62 and reservoir were formally opened by the Queen on 14th October 1971, by which time John had moved to a new project in Rutland.

In December 1969 he was interviewed by T & C Hawksley (later Watson Hawksley), a small but much respected firm of consulting engineers. He was appointed as Chief Resident Engineer, to be in charge of the construction of a large earth dam and water supply scheme at Empingham – the future Rutland Water. On 13th October 1970 he started his new job, living at a hotel in Oakham, by which time there was already a great deal of activity on the site. Again, wishing to have his family with him, they moved to ‘Stone House’ in Wing in 1970.

The story of the building of Rutland Water is told in this chapter. John says, referring to Rutland Water and Grafham Water, ‘. . . I am proud to have played a part in both these projects’. His last day at Empingham was 31st January 1975, but he returned for a ceremony at the outlet shaft on 6th February 1975 for the closing of the scour (outlet) valve and the start of impounding water in the reservoir. For him ‘. . . it was a moment to remember . . .  something important had just taken place, after years of effort by hundreds of people’.

One special aspect of the project that he was pleased to be involved with was the saving of Normanton Church. ‘This was due to be demolished, but several local people wanted it to be preserved and I was one of them, and undertook to look into how it might be saved. We formed the Normanton Tower Trust, to put proposals before the Water Authority which firmly maintained that it must be demolished, and there was no money available to preserve it.

‘We considered excavation all round it, and jacking it up, and moving it bodily, foundations and all, to a higher level. I contacted a firm which specialised in moving historic or important buildings, and they submitted outline plans for how it could be done, and a price for doing it – but the cost was way beyond what might be available.



‘I looked into other alternatives, and realised that it would be very much cheaper to fill round the church with compacted earth to a level higher than the top water level of the reservoir, fill up the crypt and lower levels of the church interior with stone and compacted gravel, put in a false floor at a higher level, and new sills for the windows at a level well above the water level. The cost of doing all this at contract rate prices was reasonable and I discussed it in detail with the Contractor’s Agent, who was looking for a site to dump soil from excavations being carried out from other nearby works, and a low price was quoted.  The cost of demolishing the church was also, of course, saved and the client eventually agreed with our new plan.’

The Normanton Tower Trust raised the money to cover the cost of saving the church building which has become a prominent landmark on the shores of Rutland Water.

After Rutland Water, John was offered a partnership with Watson Hawksley at their new offices in High Wycombe, and continued to work on water supply and reservoir projects. On 30th April 1985, he retired, but continued working as an Inspecting Engineer under the Reservoir Act for a few more years.

*Above Left: John Winder at the scour valve closing ceremony on 6th February 1975 to mark the start of impounding water in the reservoir* (Brian and Elizabeth Nicholls)
*Left: John Winder near Normanton Church* (John Winder)

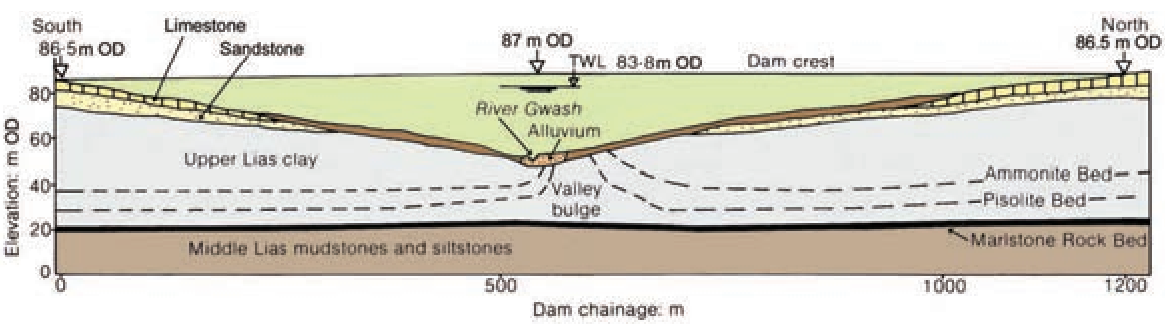
# Geology

Boreholes were drilled to prove the sequence of strata shown on Geological Survey maps and to provide more localised detail. The most significant geological components are the Upper Lias clay and the Marlstone Rock Bed. The Marlstone Rock Bed is a confined aquifer 22m below the valley floor in the vicinity of the dam, and extends under the whole of the reservoir area. It is covered by Upper Lias clay which gradually reduces in thickness along the twin Gwash valleys until the Marlstone eventually outcrops at the head of the reservoir near Oakham. The Marlstone Rock Bed also underlies the route of the tunnels. A 'valley bulge', which runs approximately along the line of the Gwash, results in considerable localised disturbance to the strata above the Marlstone Rock Bed (*see* Chapter 16 – The Geology of the Middle Gwash Valley). This was to result in some serious problems for the dam builders.

The layer of Upper Lias clay was to provide most of the material for building the earth embankment which was to form the dam and also offered a fairly easy excavation route for the supply aqueduct tunnels.

*Right: Drilling one of the test boreholes* (Brian and Elizabeth Nicholls)

*Below: The geological section at the dam site, looking upstream. The Marlstone Rock Bed is too deep to be affected by the valley bulge at this point, but the Upper Lias Clay is severely disturbed* (after the Institution of Civil Engineers)



## The Work Begins

A very rapid start on the construction was necessary because there was a predicted shortfall in water supply by 1976. Consequently, detailed site investigations and site clearance started in June 1970, only a month after Parliamentary approval, and the first major contract, for the River Gwash diversion tunnels, was let in December 1970.

## Site Clearance

By far the greatest task in the site clearance programme was the removal of trees, hedges, shrubs and fences. This started in the dam area near Empingham, and continued along what was to become the south arm of the reservoir. It included the complete removal of Mow Mires Spinney, Cocked Hat Spinney, Brake Spinney and Snowdrop Spinney, and the partial removal of Hambleton Wood, Gibbet Gorse and Half Moon Spinney. Much of this had been completed by mid-1973. Within the next twelve months much of Armley Wood and Barnsdale Wood in the future north arm of the reservoir had been removed, as well as part of Burley Wood for the A606 Barnsdale Hill diversion (*see* Chapter 23 – Fauna and Flora before Rutland Water).

*Below: Site clearance begins in June 1970 near Empingham on day one of the construction of Rutland Water* (Brian and Elizabeth Nicholls Photography)


*Above: One of the many lorry-loads of timber felled during the reservoir clearance programme* (Richard Adams)

*Right: The landscape cleared of hedges and trees near Nether Hambleton* (Richard Adams)

*Clearing trees near Burley Wood for the A606 Barnsdale Hill diversion* (Brian and Elizabeth Nicholls Photography)

Another aspect of site clearance was the demolition of all the dwellings and farm buildings in Nether Hambleton, eight dwellings and numerous farm buildings in Middle Hambleton which were below the high water level, two dwellings at the foot of Barnsdale Hill, and Mow Mires farmhouse in Normanton Park. Some of the demolition rubble was used to create the Nature Reserve lagoons at the western end of the reservoir (*see* Chapter 21 – Lost Homes and Chapter 24 – Tim Appleton MBE – Thirty Years of Rutland Water Nature Reserve).

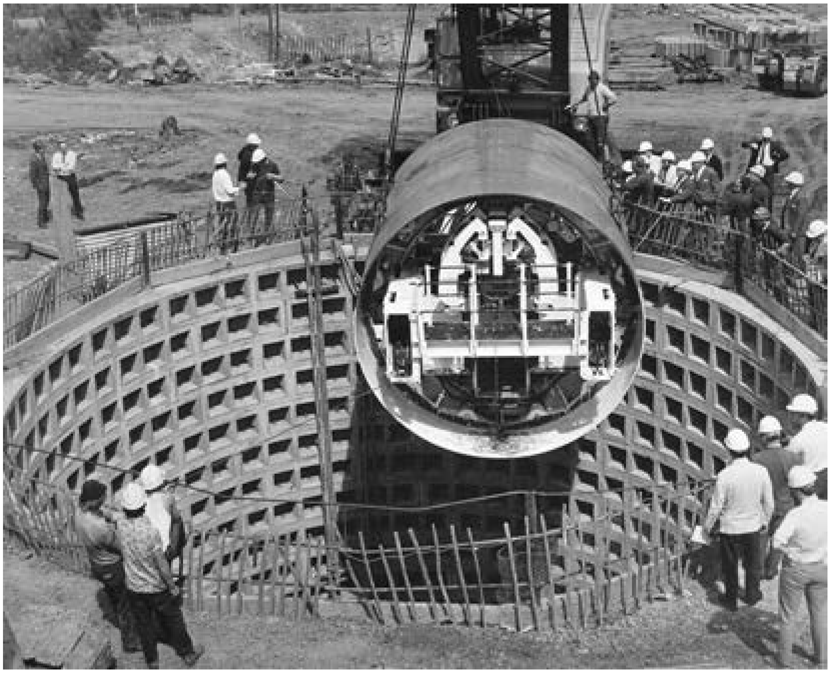
*The end of the day and the end of an era for Red House at Nether Hambleton* (Richard Adams)

# The Diversion Tunnels

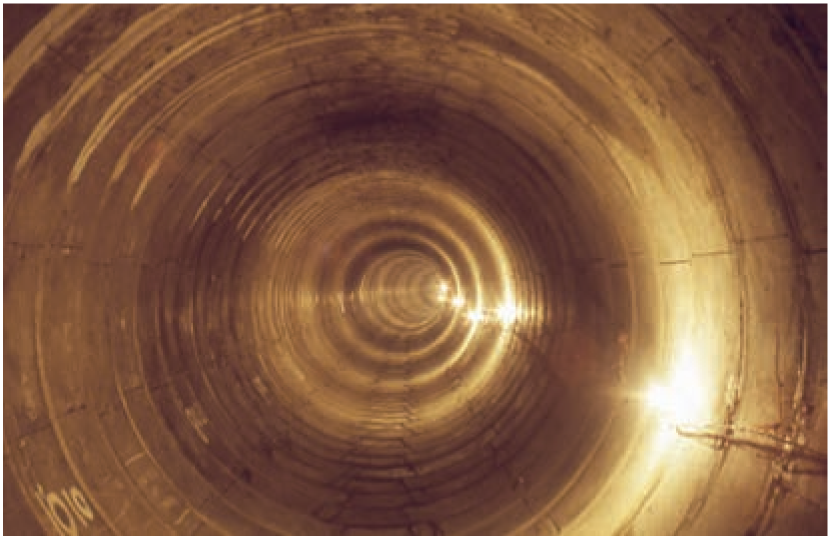
In order to start work in the bottom of the valleys it was first necessary to divert the River Gwash round the dam construction site. For this purpose a tunnel, which would later become a part of the permanent works, was driven from near the upstream toe of the embankment into the hillside on the south side of the valley at the reservoir outlet shaft location. A second tunnel was then driven back from the outlet shaft to the river near the downstream toe. The work was carried out by Edmund Nuttall Ltd before work on the main embankment had started. It also allowed removal of the surface material down to the Upper Lias clay on the embankment site immediately at the start of the main contract.

The outlet shaft, which is 10.7m internal diameter, was sunk first, followed by the two tunnel drives, all three being lined with concrete segments. The upstream and downstream tunnels are 3.7m and 4.4m internal diameter respectively. The upstream tunnel was lined with concrete infill panels and sprayed with an epoxy paint to provide protection against anaerobic water lying for long periods in this section of the tunnel.

*Above: Excavating the reservoir outlet shaft. It is 10.7m in diameter and over 30m deep* (Brian and Elizabeth Nicholls Photography)



*Lowering the tunnelling machine into the outlet shaft* (Brian and Elizabeth Nicholls Photography)



*Right: Looking along the lined upstream diversion tunnel, now the reservoir bottom draw-off tunnel* (Brian and Elizabeth Nicholls Photography)

*Above: The downstream diversion tunnel before the dividing platform was installed. It now carries the overflow water and other services* (Brian and Elizabeth Nicholls Photography)

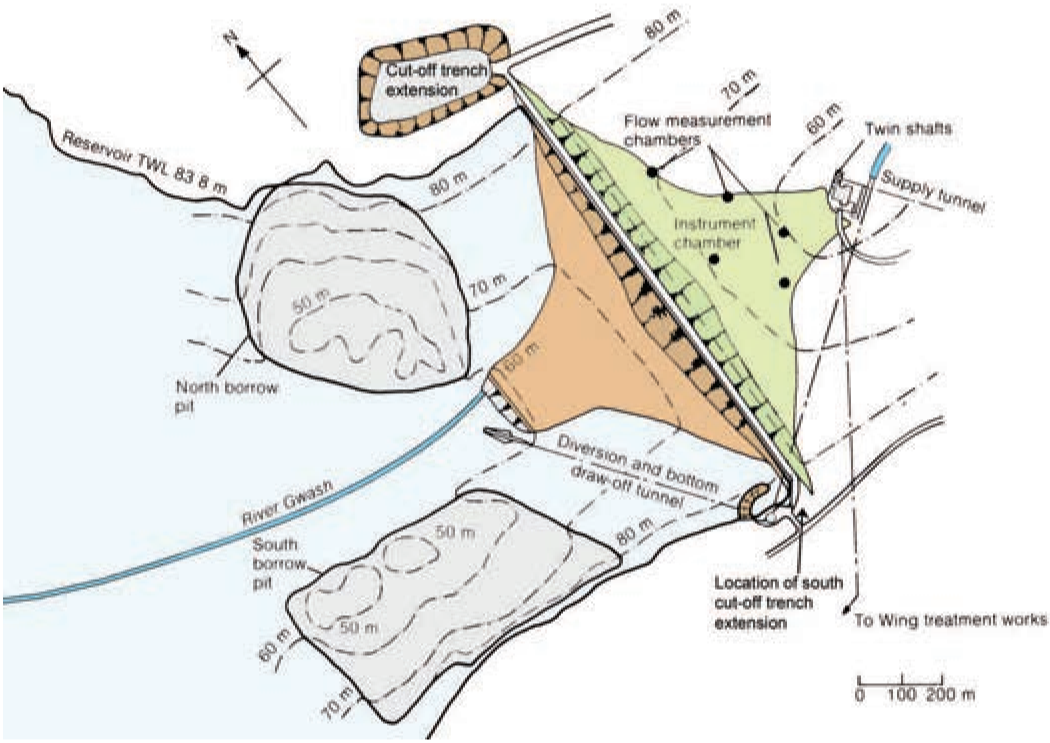
*Left: The entrance to the top half of the downstream diversion tunnel* (Brian and Elizabeth Nicholls Photography)

The downstream tunnel, which was completed later under the main contract, is divided by a platform. In the top half, a 1.2m diameter steel pipe delivers the raw reservoir water to the outlet pumping station from where it is pumped to the water treatment works at Wing, or to Colsterworth, Lincolnshire. The remaining space is used as an access walkway, for power and control cables, and for other services. The bottom half of the tunnel carries the overflow from the reservoir and also any additional water necessary to maintain the minimum downstream flow of the River Gwash, known as the regulation water. It also carries water discharged through the scour pipe. The scour valve can be opened to let water out of the reservoir very quickly. For example, it can be used in an emergency if the dam is damaged or if it is necessary to lower the water level for any reason. The scour valve is also opened to flush sediment out of the reservoir when too much has collected behind the dam. The fast flowing water carries the sediment through the scour and downstream.

At the tunnel exit, there is a stilling basin and tailbay which incorporates a weir for measuring the river regulation water and the overflow water. Water is also discharged here from the Marlstone relief wells. A new river channel has also been constructed downstream from the tailbay to Church Bridge, Empingham, where the total water released is measured.

*An early artist's impression of Empingham pumping station and the realigned River Gwash. The horizon is the crest of the dam* (Anglian Water)

# Empingham Dam – The Embankment




*Plan of the dam and borrow pits* (after the Institution of Civil Engineers)

Empingham Dam, an earthfill embankment 37m high, 1,200m long, and 810m wide at its foundation level, is an important component of the Empingham Reservoir Project. The main geological features of the valley were established before Parliamentary approval by a preliminary site investigation. The Upper Lias clay was the controlling geological factor and it was known that the valley sides were extensively disturbed (*see* Chapter 16 – The Geology of the Middle Gwash Valley). It was also expected that the Upper Lias clay in the valley floor would be affected by valley bulging. The strength of the clay foundation was known to be inadequate to support the weight of an embankment of the specified height. This was the controlling factor in its design and resulted in a wide cross-section with extensive slopes.

It was a planning stipulation that the majority of the material needed for building the dam must be excavated from inside the reservoir area. The Upper Lias clay would therefore be used to build the embankment. At 37m high it would be one of the highest ever built of clay on a clay foundation. If the Manton Reservoir project had gone ahead, the earth embankment there would have been 43m high, and this was considered to be the absolute maximum for this type of dam. It would also have to have been wider at the top to accommodate the 37m necessary for the A6003 which crosses the Chater valley at this point, resulting in a very high volume of clay being required (*see* Chapter 14 – Rutland Waters).

A feasibility study for the Empingham Dam indicated that, even with long slopes, sand drains would be required to ensure the stability of the clay foundation. The sand drains would collect water forced out of the pores of the clay by the weight of the dam above and drain via the drainage blankets within the dam structure.

Before the dam could be designed in detail a site investigation was necessary to gain a detailed understanding of the geology. This had to be completed within the twelve months before the set date for the start of the construction. It was carried out by Soil Mechanics Ltd between August and December 1970 and included drilling boreholes to investigate the structure and properties of the clay foundation beneath the sites of the dam and borrow pits, as well as consolidation and bearing tests. Core samples were initially tested off site, but a well-equipped site laboratory, commissioned during this period, allowed very quick analysis of samples.

While the site investigation was taking place, the availability of suitable materials for drainage, filters and rip-rap was investigated. Rip-rap is rock used on the dam face to reduce erosion by dissipating wave energy.

An understanding of the geology of the valley developed progressively during the investigation. The Institute of Geological Sciences carried out a fossil study of the core samples in order to establish a zoning system within the clay. This enabled the identification of the different types of clay required for the embankment.

It was established at an early stage that, although the valley bulge penetrated 20m below the valley floor, the Marlstone Rock Bed at the dam site was not affected. This was an important discovery as, in this area, it is a confined aquifer containing water under pressure. If a rupture was exposed it would behave as an artesian well and flood the area very quickly. In order to reduce this pressure it was necessary to install relief wells on the downstream side of the dam to control the uplift pressure.

The test results enabled the design of the dam to progress, although considerable uncertainty remained concerning the strength of the foundation clay and the behaviour of the embankment fill material under heavy loading. The solution was to build a trial embankment, but the tight programme meant that this could not be done until after the construction start date. The aim at this stage was, therefore, to progress the design sufficiently to enable tenders to go out for the selection of a main contractor for the construction of the dam and ancillary works.

To enable tenders to be made on a reasonably firm basis, it was decided that the contract should include provisional elements to cater for the uncertainties, with dates by which final decisions must be made. These elements were: the extent of the slopes, the number of drainage layers within the dam, and the spacing of the sand drains. Tenders were invited in May 1971 and Gleeson Civil Engineering Ltd was appointed as the main contractor on 14th September 1971.

A major feature of the contract was the construction of the large trial embankment within the upstream slope and this was to be retained as part of the final embankment. By using steep slopes, a shear stress in excess of that imposed by the final embankment could be imposed on the foundation clay. The trial was to be carried out during the first year of construction, and the slope design was to be fixed four months after its completion.

The trial embankment was built near the south side of the valley floor to avoid the main valley bulge. A trench was excavated into the valley side to ensure that it had a constant height over a length of about 70m, and calculations proved that the stress imposed on the foundation clay would be well in excess of that imposed by the final embankment.

Three failures of temporary steep clay embankments in the borrow pits occurred while the trial embankment was under construction. Data from these failures reduced the need to take the trial bank to failure, and construction ceased when the mean height was 21m. The dynamic performance of the bank and underlying strata was then observed for the next four months.

*The trial bank can be seen upper left in this photograph* (Brian and Elizabeth Nicholls Photography)

After excavation of the soft alluvium in the valley floor down to the Upper Lias clay, the material being taken to spoil heaps or used to make up the lower part of the slopes, the dam site was ready for the installation of sand drains. It is interesting to note here that the engineers were able to map in detail some of the shear surfaces apparent on the face of the newly exposed Upper Lias Clay. Peter Horswill, the site geologist, realised that this had occurred at the end of the last Ice Age, some 100,000 years ago, due to the bottom of the valley bulging upwards as a result of the immense pressure from the weight of the thick ice on the shoulders of the valley.

The sand drains were installed by Soil Mechanics Ltd who commenced work in January 1972. They drilled 10,873 600mm diameter drains to a maximum depth of 18m, using crane mounted augers, within the six-month contract period, a rate of approximately 60 sand drains per day. The drains were filled with sand and the area was flooded between clay bunds or saturated by spray irrigation to ensure consolidation. The drains were made up with additional sand before embankment fill placing started.

*Installing sand drains in the foundation of the dam* (Brian and Elizabeth Nicholls Photography)

*A crawler crane-mounted auger drilling a sand drain* (Brian and Elizabeth Nicholls Photography)

The final design for the dam was decided early in 1973. It incorporated extra information obtained from the trial embankment and borrow pit slips, and the observations of sand drain performance. The slopes needed were found to be smaller than those predicted by the initial design assumptions. More importantly, construction could be completed with much less uncertainty.

Material for the main embankment (dam) was placed using 12 Terex TS24 16 cubic metre twin-engined motor scrapers, ideal for the terrain and short-haul distances between the borrow pits and the embankment site. Bulldozers were used as pushers for the motor scrapers when collecting clay in the borrow pits.

Cut-off trenches, to prevent water leakage round the ends of the embankment, were excavated into the valley sides until the top of the Upper Lias clay was 1.7m above the reservoir top water level. These were then filled with clay to 2.2m above this level. Above this, the excavated surface material was replaced.

*Above: Filling a sand drain* (Brian and Elizabeth Nicholls Photography)

*Left: A heavily loaded Terex motor scraper gets a push from a bulldozer* (Brian and Elizabeth Nicholls Photography)

*Right: Seven of the 12 twin-engined Terex motor scrapers ready for work. View looking from the dam towards Empingham* (Brian and Elizabeth Nicholls Photography)

*One of the Terex motor scrapers emerging from a borrow pit near the dam site* (Brian and Elizabeth Nicholls Photography)

*The south cut-off trench* (Brian and Elizabeth Nicholls Photography)

*The north cut-off trench after being filled* (Brian and Elizabeth Nicholls Photography)

Natural gravels from pits in the Fens were used as filters and drainage materials within the embankment, and because of sporadic high demand these were stockpiled on site.

The Upper Lias clay used for the embankment construction was extracted from borrow pits located below top water level upstream of the dam. They were excavated to full depth in sections, surface material being placed in worked-out areas. The drainage of the underlying Marlstone Rock Bed (*see* later) allowed the borrow pits to be deepened without risk of uplift through artesian pressure. However, a section brought upwards by valley bulging was unexpectedly exposed in the south borrow pit. It was subsequently blanketed with clay to prevent leakage from the reservoir.

*An aerial view of the borrow pits and the embankment, looking east towards Empingham* (RCM)

Dam construction commenced with the placing of clay in the downstream slope. At first, excavation was restricted to the south borrow pit to increase the supply of deeper and drier clay. Fill placing for the upstream slope was restricted in 1972 by the construction of the trial bank. In 1973 the surface materials from the north borrow pit were placed on this slope and thereafter both borrow pits were used.

As the construction progressed, it was found necessary to adjust the water content of the clay. A section of the embankment was marked out and the requisite number of TS24 scraper loads was placed to give an uncompacted layer thickness of about 200mm. This was graded with a bulldozer and the clay was broken up by several passes of a heavy tine harrowing unit. This brought up claystones from the fill which were removed by hand by a gang of six men – claystone is fully-hardened clay material which does not break down when wetted. The contractor then quickly measured the water content using a microwave oven. The amount of water to be added was assessed and then placed using water bowsers equipped with sprays. The clay was then rotavated. Further watering and rotavating was carried out as required and the layer finally compacted.

*Spreading and compacting the clay at the south end of the embankment* (Richard Adams)

*Watering the clay prior to harrowing and further compacting* (Brian and Elizabeth Nicholls Photography)

The embankment was divided into zones using different classes of fill, the classes being decided by the shear strength of the material used. These were established during the preliminary site investigation:

| *Fill class* | *Fill type* | *Shear strength (relative to class A fill)* | *Where used* |
|---|---|---|---|
| A | Upper Lias clay | 1.0 | Shoulders |
| A1 | Weathered Upper Lias clay | 0.6 | Slopes |
| B | Upper Lias clay | 0.5 | Core zone |
| C | Upper Lias clay | 1.1 | Centre |
| D | Alluvium | Not measured | Slope toes |

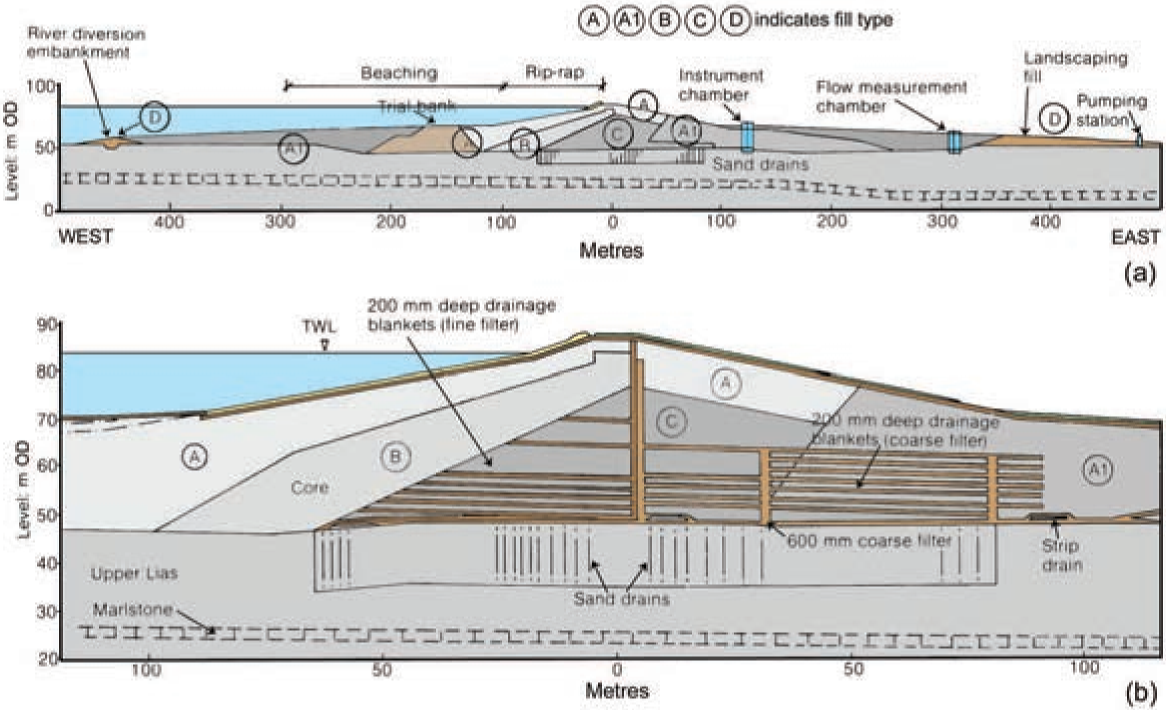
Control of the moisture content proved very difficult as drying-out occurred in sunny or windy weather. During spells of hot summer weather evaporation losses became so great that night working was adopted, the fill being placed late in the afternoon and treated, watered and compacted during the night. The fill was tested the following morning and any areas that did not meet the specification were re-treated the same day.

The specification called for construction to a minimum height of 60m OD by the end of 1972 to ensure early loading of the sand drain zone. To ensure adequate consolidation by the end of construction, a level of 80m OD by the end of 1973 and completion in June 1974 were specified. These targets were met in three periods with winter breaks. The maximum rate of earthmoving achieved was 470,000 cubic metres in August 1973. The total volume of the dam is about 5 million cubic metres.

In order to monitor the condition of the dam continuously, the embankment was furnished with devices to measure water pressure (twin-tube hydraulic piezometers) and movement (inclinometers, settlement gauges and wire extensometers). The installation of these was the responsibility of the Resident Engineer's staff and much of this work was carried out during winter breaks in earthmoving. An extensive system of permanent survey points was also installed, including twelve points on the dam crest, and others on the reservoir shore line near the embankment. Measurements are processed by computer in such a way as to indicate movements relative to the framework of the overall grid of survey points.

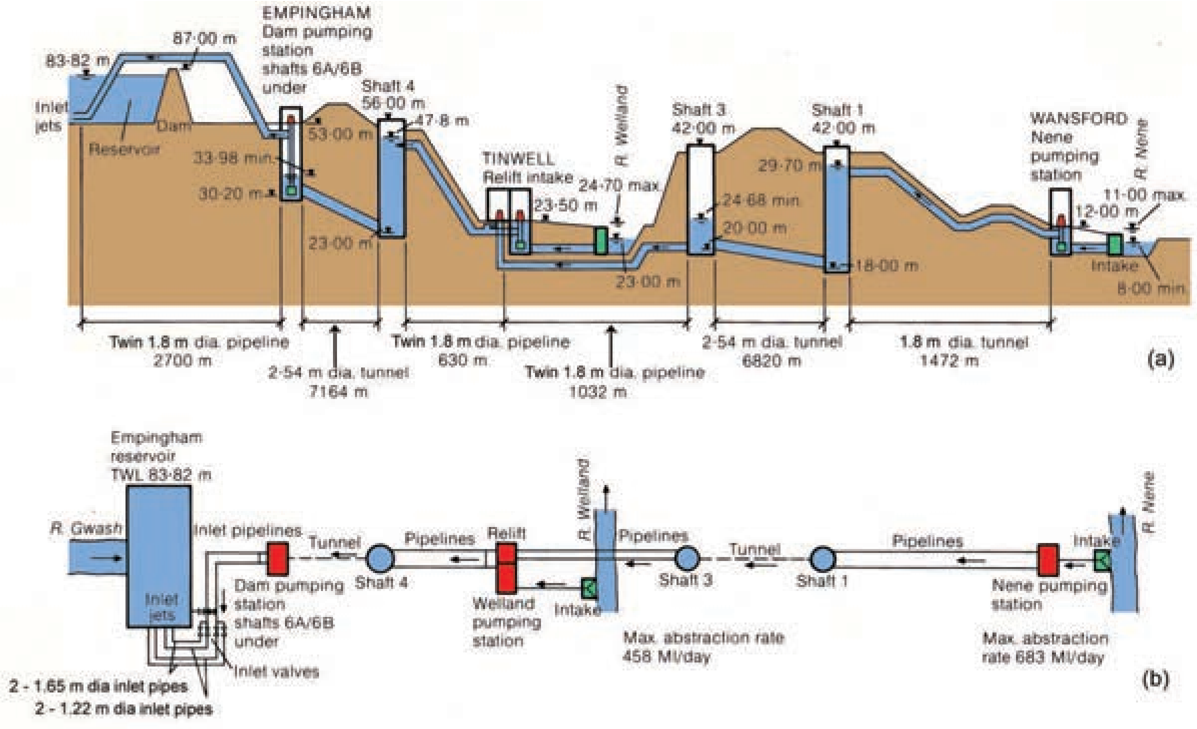
Protection against wave action on the dam was provided by rip-rap and for this purpose Carboniferous Limestone from Crich in Derbyshire was used. It was hauled and dumped by articulated dump trucks and spread by a bulldozer. Final adjustments to produce a dense uniform layer were made by hand. The lower upstream slopes were protected by beaching consisting of limestone and ironstone from site excavations. The rip-rap was extended above the crest of the dam and the inner face was hand-packed to form a dry stone wall on the upstream side of the crest roadway. The downstream slopes were grassed, the topsoil being placed over a layer of granular material to give soil drainage and conditions similar to those on the natural valley sides.

*Below: Sections through the completed embankment: (a) full section (b) centre detail* (after the Institution of Civil Engineers)




*Placing the limestone and ironstone beaching on the upstream face of the embankment* (Brian and Elizabeth Nicholls Photography)

# The Aqueduct System – Supply Tunnels, Pipelines and Pumping Stations




Water from the rivers Nene and Welland is delivered to the reservoir through a supply system of three pumping stations, two tunnels and connecting pipelines. The overall length of the aqueduct system, from the pumping station at Wansford on the River Nene to the inlet jets in the reservoir, is 21km. The design capacity of the system was 1,140 million litres per day, which allowed for the possibility of Manton Reservoir being constructed in the future.

*Above: The schematic diagrams of the water flow system to the reservoir: (a) section, (b) plan* (after the Institution of Civil Engineers)

*Right: Building the River Welland abstraction point at Tinwell* (Brian and Elizabeth Nicholls Photography)

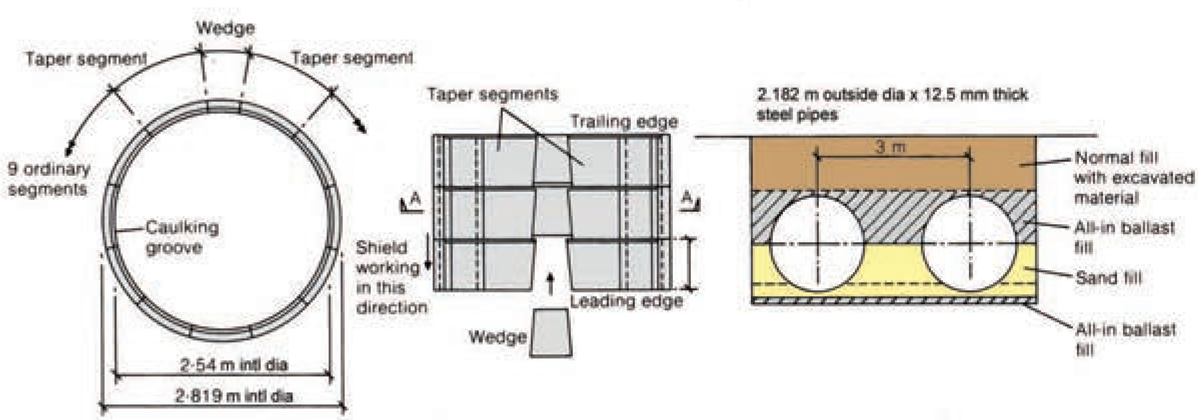
The pumping station at Wansford intake on the River Nene pumps up to 518 million litres per day along twin 1.8m diameter steel pipelines into shaft 1 at the head of the first tunnel. The water then gravitates along the 2.54m diameter concrete-lined tunnel to shaft 3, from which twin 1.8m diameter pipelines cross the geologically faulted and disturbed Welland valley to the Tinwell intake and pumping station. From here, water from the River Welland can be abstracted at up to 363 million litres per day and pumped, together with the Nene water, along twin 1.8m diameter pipelines to shaft 4 at the head of the second tunnel. The water again gravitates along this concrete-lined tunnel to the twin terminal shafts (6A and 6B) located at the toe of the downstream embankment at Empingham. The level of the tunnels was dictated by the hydraulic gradient, the top of the Upper Lias clay, and the location of the Marlstone Rock Bed.

The final lift pumping station is located over the top of these terminal shafts. From here water is pumped via steel pipelines to the inlet jet control valves, followed by four lines of pre-stressed concrete pipes laid on the bed of the reservoir to the inlet jets located in, and pointing up, the south arm of the reservoir.

Preliminary site investigations in 1967 had indicated that it would be possible to drive tunnels between the River Nene at Wansford and the reservoir site at Empingham, except for the Welland Valley crossing where the strata was heavily faulted. By careful choice of levels and route it was also possible to keep the tunnels entirely within the Upper Lias clay, thus enabling soft-ground tunnelling techniques to be used. Tunnel A connecting Wansford to Tinwell was to be 6,820m long, and tunnel B connecting Tinwell to Empingham was to be 7,164m long. The contract for the supply tunnels was let to Edmund Nuttall Ltd in June 1972.

The 2.54m internal diameter tunnels were constructed using the expanding wedge block system developed by the Metropolitan Water Board. The lining ring consists of 140mm thick concrete segments which are expanded against the clay face by a wedge block driven in at the top of the ring by a ram operating from the tunnelling shield.

*Below: Tunnel and steel pipe details* (after the Institution of Civil Engineers)



*Steel pipes being installed near Wansford pumping station* (Brian and Elizabeth Nicholls Photography)

The tunnelling machine consisted of a shield about 3m long with a rotating cutting face on the front and equipment for erecting the lining at the rear. The shield formed an accurate profile in the clay to receive the linings. Behind the shield were sledges with conveyor belts, winches, electric generators, a transformer, pneumatic equipment, segment wagons and spoil wagons. The overall length of this plant was about 44m, and it was operated by a gang of four miners.

The concrete segments for the tunnel lining were cast in moulds on site. After 24 hours in the moulds the segments were kept in the casting shed for a further two days to consolidate, followed by 42 days in outside storage. This was to ensure that they were up to full strength before being used in the tunnel.

At each end of tunnel A, in the Wansford to Tinwell aqueduct, there is a 10.7m diameter shaft (1 and 3), with platforms and staircases for access, made up from bolted reinforced concrete segments. This size was required to cater for the mass oscillation surge that occurs on pump start-up, shut-down, or sudden power failure. At the start of tunnel B, in the Tinwell to Empingham aqueduct, there is a similar shaft (4), and at the Empingham end there are twin shafts (6A and 6B), again of similar size. The twin shafts are connected by a cross tunnel into which tunnel B was driven.

The twin shafts (6A and 6B) at Empingham, situated in the valley bottom, were started ahead of the main tunnel contract to allow for the pumping station above them to be completed according to the contract programme. The shafts were sunk simultaneously, one progressing slightly in advance of the other. One shaft had reached a level of 3m above bottom level when it started to flood, with water eventually overflowing at the top. The second shaft was then deliberately flooded as a safeguard. This water was from the Marlstone Rock Bed, even though it was 14m below the level

*The shield of one of the tunnelling machines* (Brian and Elizabeth Nicholls Photography) of the bottom of the shaft. In order to solve this problem it was necessary to reduce the water pressure by boring a total of eighteen 450mm diameter relief wells to a depth of 40m around the shafts.

When excavation restarted in the twin shafts and connecting tunnel, it was found from the attitude of the Pisolite Bed (a narrow band of coarse-grained limestone within and at the lower level of the Upper Lias clay) that the bottom of the excavation had penetrated the edge of the valley bulge. The steep bedding and disturbed condition of the material had allowed easy access for the water from the Marlstone Rock Bed into the base of the shaft.

The twin shafts were completed satisfactorily, and advantage was taken of the lowered water level to drive about 200m of bolted lining tunnel out from the connecting tunnel. This took the tunnel clear of the area of valley bulging, which would have caused problems as the main tunnel approached Empingham.

*The twin shafts can be seen at the lower left of this picture, which also includes part of Empingham and its medieval manorial earthworks* (Fred Adams)

It was originally intended to drive both tunnels using only one machine, starting with tunnel A from shaft 3. Progress was good for the first 1.5km, until the Pisolite Bed was encountered. It was immediately apparent that it was too hard for the machine to cope with and the contractor had to resort to hand excavation. However, after about 20m a fault was encountered which lowered the bed 2m below the tunnel base, and machine tunnelling could continue once again.

*Empingham pumping station from the dam in 2007* (SS)

However, a new problem now arose which was to slow progress. This was 'overbreak'. The expanding wedge block system relies on the tunnelling machine being able to form an accurate profile in the clay to receive the tunnel lining. If the profile is not circular, then the ring will not be self-supporting. This problem may only become apparent when the tunnel is pressurised. The 'overbreak' was caused by blocks of clay being torn from the face by the tunnelling machine teeth instead of being cut to a neat profile. It was found by trial and error that making up the voids with softened clay provided a satisfactory but slow solution.

Because of these delays, a second tunnelling machine was brought in to excavate tunnel B instead of waiting for the first machine to become available. With two machines at work and with better ground conditions, progress greatly improved. Tunnel A was completed in 54 weeks, and tunnel B in 53 weeks, giving an average rate of progress of approximately 130m per week. The highest output achieved was 51 lining rings, each consisting of 12 segments, covering a distance of 35m in a ten-hour shift. The sheer physical achievement by the tunnel gangs is impressive, especially when it is realised that they lifted and placed each 83kg concrete segment by hand in cramped and confined conditions for ten hours at a stretch, giving a total of 20,000 tonnes lifted in the two tunnels.

*Left: Miners at the Empingham end of the Tinwell to Empingham tunnel celebrating a successful breakthrough* (Brian and Elizabeth Nicholls Photography)

Because of faulting and valley bulging, the tunnels were replaced by pipelines across the Nene and Welland valleys. Twin 1.8m diameter pipelines were laid from Wansford pumping station to shaft 1 and also across the Welland Valley to link shafts 3 and 4.

There were two other problems to contend with in crossing the Welland Valley – the river itself, and the railway line between Leicester and Peterborough. In order to cross the River Welland it was first necessary to de-water the gravels near the river crossing point. The twin pipelines were then laid in a sheet-piled cofferdam taken half-way across the river channel. This allowed the normal flow in the river to continue while the pipes were encased in concrete below river bed level. The sheet piles were then withdrawn and the whole process was then repeated for the other half of the river.

*Above: Pipes were encased in concrete below the bed level of the River Welland* (Brian and Elizabeth Nicholls Photography)

Crossing the railway line with minimal disruption to traffic was another challenge for the engineers. It was decided to route the pipelines through two lengths of bolted tunnel driven under the railway embankment, accessed by drop shafts on either side of the line.

*Right: Crossing the River Welland at Tinwell* (Brian and Elizabeth Nicholls Photography)

## Reservoir Inlet Pipelines

Raw water from the rivers Nene and Welland starts the final part of its journey at the final lift pumping station located over the twin shafts (6A and 6B) near the downstream toe of the embankment at Empingham. From here twin reservoir inlet pipelines run along the southern shore of the reservoir for about 2.7km to the inlet jet control valves at Howells Inlet, near Normanton Church Museum. Four lines of pre-stressed concrete pipes carry the inlet water down into the reservoir from where it is discharged by four jets pointing up the south arm.

*Installing the twin reservoir inlet pipes near Normanton* (Brian and Elizabeth Nicholls Photography)

*The four pipes to the inlet jets being installed across the valley floor near Normanton* (Brian and Elizabeth Nicholls Photography)

*The four inlet jets pointing up the south arm of the reservoir* (Brian and Elizabeth Nicholls Photography)

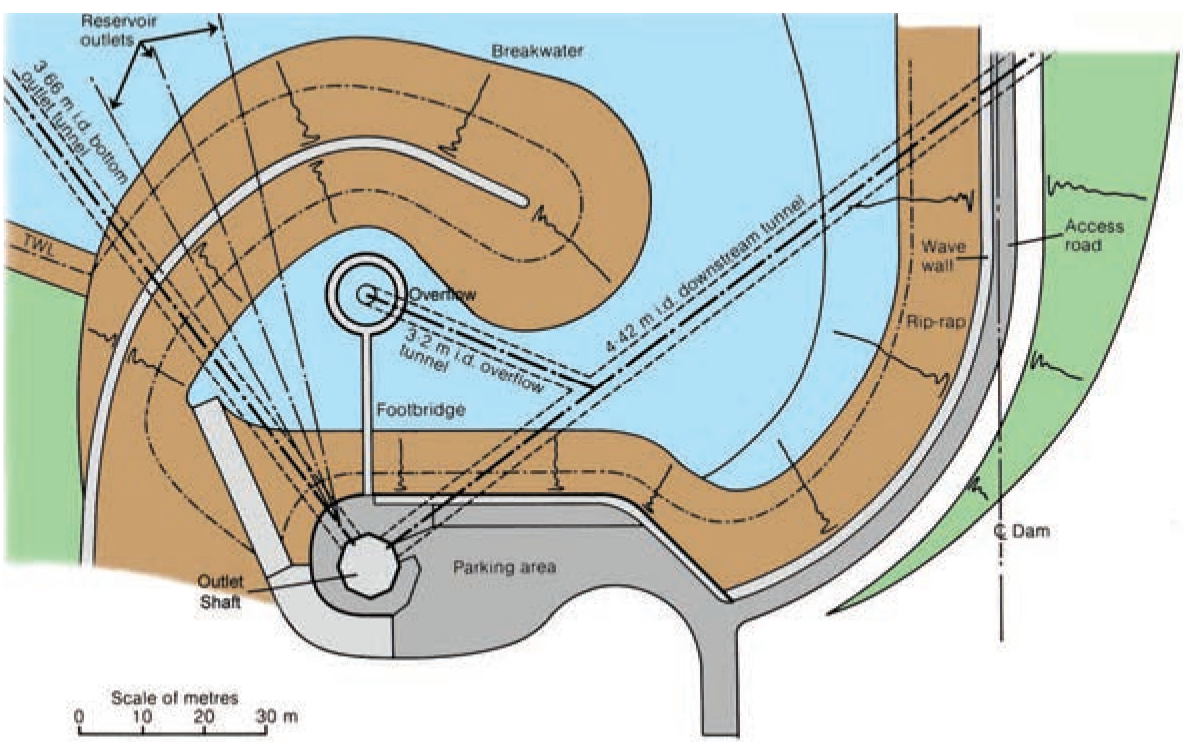
## Outlet and Overflow Works

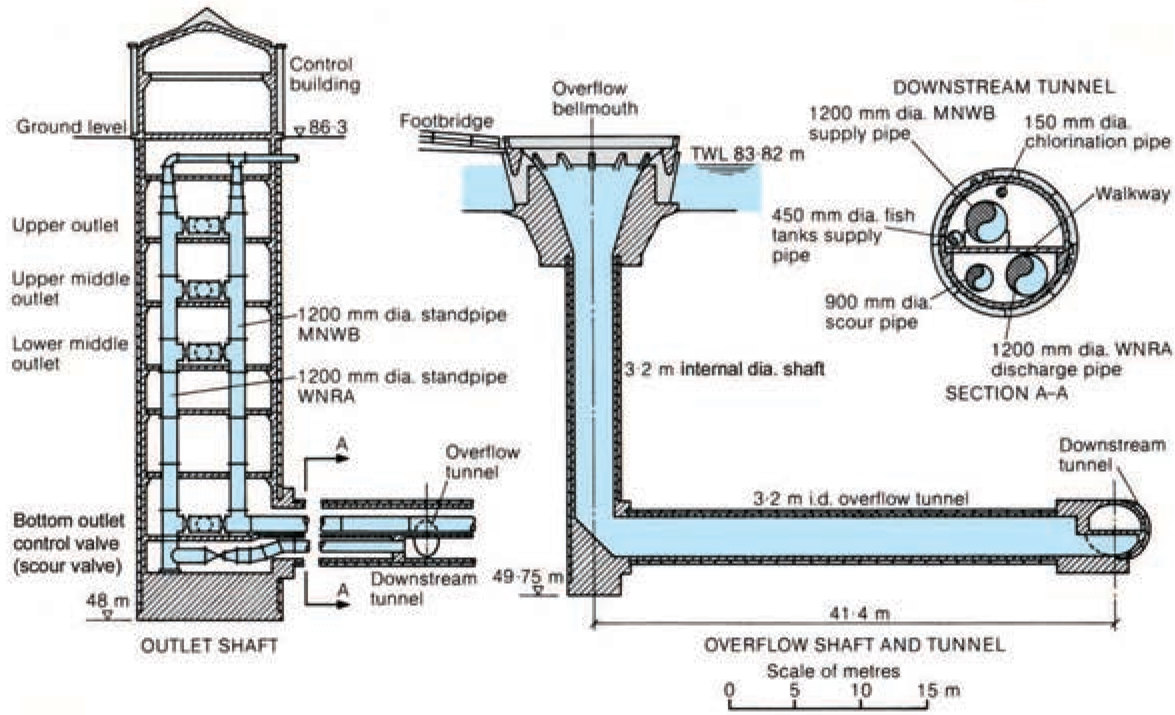
The outlet shaft was sunk early in the project to serve as an access point when the River Gwash diversion tunnels were being driven. At the reservoir outlet, the shaft contains two 1.2m diameter cast iron standpipes with isolating valves, so that water for direct supply to the treatment works and river regulation can be drawn off from different levels, simultaneously if required, to overcome variations in quality. There are four outlet levels. The bottom outlet is through the river diversion tunnel, and the upper three through concrete tunnels, driven from the shaft to concrete forebays.

Water abstracted from the reservoir is piped to the raw water pumping station located alongside the river water final-lift pumping station. From here the raw water is pumped directly to Wing treatment works for treatment and distribution.

The reservoir overflow spillway is adjacent to the outlet shaft. It consists of a concrete-lined shaft with a 12m diameter bellmouth weir. The top level of the weir is 83.82m OD, and this sets the TWL (top water level) of the reservoir. Any water flowing over the weir free-falls to the base of the shaft. It then flows along a short length of overflow tunnel to the bottom half of the downstream tunnel. A breakwater was installed to shield the overflow bellmouth from reservoir wave action and hence prevent surges in the downstream tunnel. In order to avoid flooding problems at the head of the reservoir, the overflow weir was sized so that the water level would not rise more than 150mm above the weir. The system was designed to handle a flow of 18,000 litres per second.

*A plan of the outlet and overflow area at the south end of the embankment* (after the Institution of Civil Engineers)






*Above: Outlet shaft and overflow sections* (after the Institution of Civil Engineers)

*Right: Building the outlet shaft* (Brian & Elizabeth Nicholls Photography)

*Right: Working on the overflow shaft* (Brian & Elizabeth Nicholls Photography)

*Above: Inside the overflow bay during construction* (Brian & Elizabeth Nicholls Photography)

A secondary outlet tower was constructed in the north arm of the reservoir, with a 1.35m diameter pre-stressed concrete pipeline laid in the bed of the reservoir to the main outlet shaft.

*Above: The secondary outlet tower in the north arm of the reservoir near Barnsdale* (Andrew Burns)

*Above Right: Looking along the secondary outlet pipe towards the limnological tower* (Andrew Burns)

## Reservoir Operation, Inlet Works and Secondary Outlet Shaft

Problems of algal blooms and of reservoir thermal stratification leading to the bottom water becoming starved of oxygen (anaerobic) were anticipated at the design stage of the reservoir. In order to overcome the algal problem, it was proposed that the north arm of the reservoir should be operated as a second reservoir, and a model of the reservoir was constructed by the River Authority to prove the feasibility of this proposal. Various combinations of inlet and outlet arrangements were tried using tracer dye to identify and record the different circulation patterns produced. It was found that the most effective scheme was to discharge all the water into the mouth of the south arm through an inlet jet system in the bottom of the reservoir, the four jets pointing up the arm of the reservoir. The normal water outlet is through the main outlet shaft, drawing water from the main body of the reservoir. In this way, the water that enters the north arm of the reservoir will have been subjected to a longer period of retention, and will be of different biological and chemical characteristics from that in the main body. When algal growth is experienced in the main body, it is unlikely to occur at the same time in the north arm and vice versa. To take advantage of this, a secondary outlet shaft and pipeline in the north arm allows water to be drawn from there during periods of bad algal growth in the main body, except at low water levels in the reservoir. In the unlikely case that algal growth affects the whole reservoir, river water can be pumped directly to the treatment works.

*Building the limnological tower near Bull Bridge* (Richard Adams)

To prevent anaerobic conditions through stagnation, Helixor air-guns were installed. These consist of a vertical pipe into which compressed air is introduced at the base. The resulting air bubbles rise in the pipe, drawing water in behind. On exit from the pipe the spiralling cloud of air bubbles entrains a considerable quantity of water, producing a gradual overturn and mixing of water in the reservoir.

A permanent limnological tower was constructed in the main body of the reservoir to monitor biological, chemical and physical characteristics of the water, the results being used to control the operation of the air-guns. Limnology is the study of inland waters and the word derives from the Greek *limne* (lake) and *logos* (knowledge).

The two outlet shafts, together with the limnological tower, the inlet jets in the south arm, the Helixor air-gun installation to prevent stratification, and the diversion of the treated sewage effluent discharge from the Oakham area into one of the nature reserve lagoons, combine to give an overall reservoir operational system which will allow good quality water to be available for both direct supply and river regulation at all times of the year.

## Wing Water Treatment Works

The Wing treatment works receives raw water pumped from the pumping station at Empingham via a single 1.1m steel pipeline. It was designed and constructed by Degremont Laing Ltd and commissioned in June 1977. It can treat up to 285 million litres of raw water per day. From here drinkable water is distributed to both Anglian Water and Severn-Trent Water consumers.

## Seepage Problems

The Marlstone Rock Bed is an aquifer up to 2.5m thick underlying the Upper Lias clay forming the bed of the reservoir, and it provides a potential seepage path for water from Rutland Water. It has been affected by valley bulging, resulting in some outcropping along the valley floor.

Investigations into potential seepage paths were carried out before construction of the reservoir started. These included the cataloguing of old well records, sinking boreholes, analysing river-water chemistry and carrying out field seepage trials. More data were obtained after de-watering of the aquifer following the rupture, early in the construction period, of the base of one of the shafts at Empingham, caused by uplift from the water pressure in the Marlstone. The investigations revealed that the pre-reservoir behaviour of the Marlstone aquifer was controlled largely by an outlet into the adjoining Chater valley, and that changes in groundwater levels there might result in land-slipping. It was therefore concluded that the water pressure in the area near the outlet should not be allowed to exceed pre-Rutland Water levels.

Various means of preventing seepage were considered but the most appropriate solution was to install relief wells downstream of the dam to release the additional water. Soon after the first filling of the reservoir a sudden rise in levels and discharges occurred. Extra relief wells were installed whilst unsuccessful searches were made for connections through the reservoir floor into the Marlstone Rock Bed. In particular, divers inspected the sites of known old wells, including those already backfilled with clay as part of the reservoir clearance works.

Research was also undertaken to locate any possible unrecorded wells, by interviewing local people and inspecting previously unseen records and maps, including those of the Ordnance Survey for 1886. This revealed that four old wells which might have penetrated the Marlstone remained unfilled in the reservoir floor. The largest was 1m square and 8.8m deep but no downward flow could be detected. All four wells were filled and capped between December 1977 and January 1978.

Various other causes were considered but the mechanism is not fully understood. However, the seepages soon stabilized to acceptable values and the behaviour of the aquifer continues to be satisfactory, with a steady discharge from the relief wells of about 185 litres per second.

## Other Works

*The new landscape. Trees planted at Whitwell car park in 1974* (Jim Eaton)

There are number of other aspects of the construction of Rutland Water which are covered in other chapters:

For landscaping and the creation of leisure facilities, *see* Chapter 22 – Rutland Water – Planning and Developing a Water Supply Reservoir as a World-Class Leisure Venue, Chapter 29 – Sailing on Rutland Water – Rutland Sailing Club, and Chapter 28 – Rutland Water Fishing.

For details of the project to save Normanton Church and its conversion into a museum, *see* Chapter 11 – Normanton.

For an account of the work involved in establishing the Nature Reserve, *see* Chapter 24 – Tim Appleton MBE – Thirty Years of Rutland Water Nature Reserve.

For accounts of archaeological excavations in the Gwash valley, *see* Chapter 18 – Brooches, Bathhouses and Bones – Archaeology in the Gwash Valley, Chapter 19 – The Archaeologists and Chapter 20 – Medieval Settlements at Nether Hambleton and Whitwell.

## Filling and Commissioning

The pumps at Wansford, Tinwell and Empingham were first switched on by Dennis Howell, Minister of State at the Department of the Environment, on 15th September 1975. However, due to the severe drought in 1976, only limited pumping was possible for most of the year because of very low flows in the rivers. Filling of the reservoir commenced officially with the closing of the scour valve by A F Skinner, Chairman of the Anglian Water Authority on 6th February 1975 and continued steadily up to April 1979, when the water level first reached the crest of the spillway at 83.82m OD.


*Filling of the reservoir officially commenced with the closing of the scour valve at a ceremony on 6th February 1975. In this picture are (left to right) Barry Gooding (Hydrologist), Harry Crowe (Reservoir Manager), Roland Field (Chief Scientist), Frank Knights (Reservoir Engineer), George Oglanby (Divisional Engineer), John Tindall (Finance Officer), and Peter Langford (Divisional Manager), all Anglian Water Authority employees*
(Brian & Elizabeth Nicholls Photography)

*Right: Dennis Howell switching on the Wansford, Tinwell and Empingham pumps at what is now Howells Inlet near Normanton on 15th September 1975*
(Brian & Elizabeth Nicholls Photography)
*Below: Aerial view of Rutland Water looking north-east towards the dam and Empingham in 2006*
(John Nowell, Zodiac Publishing)