Walthamstow Reservoirs No. 4 & No. 5 embankment protection

C.B. PECK, Thames Water RWE, UK

SYNOPSIS.
Walthamstow reservoirs Nos. 2, 3, 4 and 5 are situated in the Lee Valley, north-east London. Reservoirs Nos. 4 and 5 fall within the provisions of the Reservoirs Act 1975, have a common top water level and share a common embankment with Reservoir Nos. 2 and 3 which lie at a lower level. No. 2 and 3 reservoirs are used as settlement lagoons for wash water from the nearby Coppermills water treatment works and were in danger of becoming "silt" bound. The reservoirs are also within a Site of Special Scientific Interest and support fish, birds and wildfowl, including migratory species.

An inspection of the common embankments in 1998, revealed a general lack of protection, including evidence of wave action undercutting the lower toe. Recommendations were made to provide protection to the whole length of the embankment, namely the shore of Reservoir Nos. 2 and 3.

The project involved sinking a chain of timber stakes 3m from the lower toe. A geo-mesh lining was then secured to contain "silt" dredged from Reservoir No. 3. Reeds were then planted in the "silt" to consolidate the protection and enhance the environment. Timber platforms were provided for anglers.

BACKGROUND

Walthamstow reservoirs Nos. 2, 3, 4 and 5 are a chain of reservoirs situated in the Lee Valley, north-east London (Fig. 1). Reservoirs Nos. 2 and 3 were constructed in 1863 and Nos. 4 and 5 in 1866, under the powers of the East London Act of 1853. The two sets of reservoirs share a common embankment.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

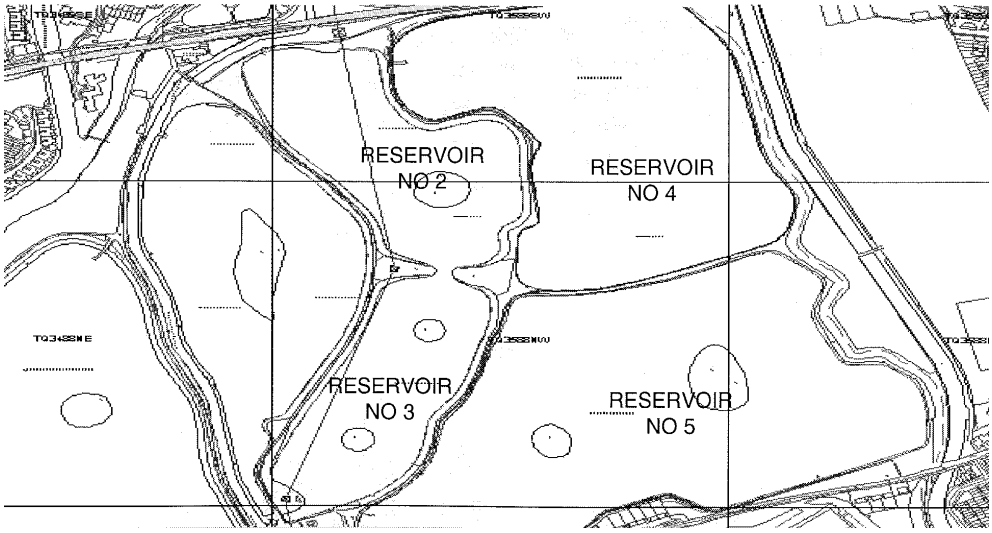

Fig. 1 Location plan of Reservoirs Nos. 2,3,4 & 5
Reproduced from Ordnance Survey mapping on behalf of The Controller of Her Majesty's Stationery Office © Crown Copyright 100042062

Reservoirs Nos. 4 and 5 are statutory reservoirs, falling within the provisions of the Reservoirs Act 1975, and have a common top water level and share a common embankment with Reservoirs Nos. 2 and 3, which lie at a lower level (Fig. 2). Reservoirs Nos. 4 and 5 are operated as raw water storage reservoirs and provide a key supply route for stored water to Coppermills water treatment works, as the final two reservoirs in the gravity chain. Reservoirs Nos. 2 and 3 are used as settlement lagoons for washwater from Coppermills water treatment works and are not classified as statutory reservoirs due to the volumes they hold. These two lagoons were in danger of becoming "silt" bound.

All the Walthamstow reservoirs form part of a designated site of special scientific interest (SSSI), which has also been designated as a special protection area under the EU Birds Directive. This SSSI supports a wide variety of fish, birds and waterfowl, including migratory species. In particular they provide a habitat for a colony of herons, which have bred at the reservoirs since 1928. The environmental management and development of the site is work in conjunction with English Nature, who act as guardians of the environmental legalisation. The reservoirs are also used by anglers

and birdwatchers as part of the recreational facilities managed by Thames Water Utilities.

Fig. 2 General view of Reservoir No. 2 next to Reservoir No. 4

Over the past 15 years, three separate incidents have occurred at Walthamstow Reservoirs Nos. 4 and 5, which have affected reservoir safety. The incidents were a downstream embankment slip in 1988, crest settlement between 1986 to 1992 and seepage through the embankment in 1996. Remedial works have been carried out to solve the problems caused by the incidents.

Hydrographic surveys carried out in 1994 and 1998 on Reservoirs Nos. 2 and 3 showed them to be heavily "silted, with a significant increase in "silt" **1* levels between the surveys, as a result of washwater discharge from a newly constructed granulated activated carbon (GAC) / sand separation plant. At the time of the project the inlet to Reservoir/Lagoon No 3 was almost completely blocked with sand and "silt" (Fig. 3). Reprofiling of these reservoirs was identified as being required in the immediate future to maintain their effective use. Issues concerning contamination within the "silt", drying out, transportation and special landfill requirements, ruled out the option of removing the "silt" from site.

**1 the term "silt" referred to in the paper is a general term covering the sediment found in the reservoirs*

View Synopsis

Fig. 3 Silted inlet of Reservoir (Lagoon) No. 3

During the statutory inspection dated 20th November 1998 of reservoirs Nos. 4 and 5, recommendations were made to inspect the outer embankments. The subsequent inspection, carried out at water level, revealed a general lack of suitable protection including evidence of wave action undercutting the lower toe. The final inspection report recommended that all areas where erosion had taken place, were to be reinstated and erosion protection provided to the whole length of the external bank of Reservoirs Nos. 4 and 5. This is the internal bank to Reservoir (Lagoons) Nos. 2 and 3. This protection was required around the top water level in Reservoirs (Lagoons) Nos. 2 and 3, whose water level is usually constant at around 7.81m above ordnance datum Newlyn (AODN). A project was initiated in September 1999 for the design and construction of 830 metres of bank protection works.

SCOPE OF WORK

Three options were considered, two of which addressed embankment protection only, and one of which addressed embankment protection and washwater treatment as a secondary output.

Option 1: Removal of "silt" from Reservoir No. 3, placing and stabilising it along the external banks of Reservoirs Nos. 4 and 5.

The protection to the external banks in this option, would be provided by dredging the "silt" from Reservoir No. 3 and placing it on the banks to form a "silt" shelf, in which reed beds would be planted. When established, the reed beds will help to keep the "silt" in place and will also provide an environmental enhancement to the area. The length of embankment protected by the reeded "silt" shelf can be identified in Figure 1.

Option 2: Installation of a 2m wide layer of crushed rocks along the external banks of Reservoirs Nos. 4 and 5.

Option 3: Installation of precast concrete mats along the external banks of Reservoirs Nos. 4 and 5.

Options 2 and 3 only addressed the matter of protection of the existing reservoir banks and were unlikely to be favourable from an environmental point of view to English Nature, whose approval was required for any works carried out on these reservoirs.

Option 1 was chosen as it was the only option that, as well as meeting the primary objective of providing protection to the external embankments of the statutory reservoirs, also provided other benefits. Dredging the shallowest part of Reservoir No. 3, will help to maintain the effective use of the reservoirs as settling lagoons for the treatment of the washwater from Coppermills advance water treatment plant. Other benefits included not having to import permanent works materials, which would have created an impact of additional traffic on the restricted local roads leading up to the site. Finally the chosen option was more likely to receive the required environmental approval for the works from English Nature, which in due course was attained. The reed beds provide a new facility for birds such as herons, who already use the site, and also attract new species of birds, and they have also provided biodiversity enhancements to the SSSI.

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

SURVEYS & TESTING

Hydrographic Surveys

Hydrographic surveys were carried out on Reservoirs Nos. 2 and 3 to determine the levels and volumes of "silt" in the reservoirs. The hydrographic survey carried out in 1994 covered all of Reservoir No. 3, but only part of Reservoir No 2 and therefore did not provide a figure for the volume of "silt" in Reservoir No. 2. The survey revealed that there was approximately 50,000m3 of "silt" in Reservoir No. 3, which was equivalent to 73% of its volume.

The later survey in 1998 covered Reservoir No. 2 as well as No. 3 and took measurements of the top and bottom levels of the "silt", which enabled the depth of "silt" to be calculated. In Reservoir No. 2 the "silt" depth varied up to a maximum depth of 1.1m, and in Reservoir No. 3 up to 2.1m. Topographical/hydrographic CAD drawings were produced by Thames Water's Survey Group, which were then used to estimate the volumes of "silt" in the two reservoirs, which are shown in Table 1.

Table 1 Results of Hydrographic Survey in 1998 for Reservoirs Nos. 2 and 3

Reservoir	Reservoir Capacity at Design TWL (m3)	Volume of "Silt" in Reservoir (m3)	Percentage of "Silt" in Reservoir (%)
Walthamstow No 2	77,000	31,020	40
Walthamstow No 3	68,000	59,400	87

The output from the hydrographic survey carried out in 1998, was primarily to give an indication of the rate and pattern of the build up of "silt" in Reservoirs Nos. 2 and 3, but it was also used to determine where best to dredge the "silt", which was used to form the "silt" shelf.

"Silt" Testing

To provide information on the nature of the "silt" at the base of the reservoirs to the Contractor Land and Water, several disturbed samples were recovered using 'grab' sampling techniques from eight separate locations in Reservoirs Nos. 2 and 3. The results from particle size distribution analyses and Atterberg Limits indicated that the material fell into two distinct groups. Two samples contained no fines, one being sand and the other gravel. The remaining six samples had a fines content varying from between 95 and 99% and liquid limits varying between 135 and 285%. All the samples, bar one, had a liquid limit of 262% or greater and organic contents around 20%. By a combination of test results and visual description these samples were classified as organic "silt"/clay of extremely high plasticity.

The results from the hydrographic surveys and the "silt" testing were used by the Contractor Land and Water and Thames Water, to determine where best to dredge the "silt", that was used to form the "silt" shelf.

DESIGN & CONSTRUCTION

Access to Reservoir Embankments

As there have been minor slips along the external embankments of Reservoirs Nos. 2 and 3 in the past, there was a need to avoid moving any heavy plant along the top or on the embankments, to reduce the risk of causing any further slips. The Contractor was able to carry out all the works from the water using floating craft/machinery (see Fig. 4), with only Land Rovers and small vans being used along the top of the embankments when carrying out the planting of the reed beds.

Fig. 4 Placing of "silt" shelf using machinery on floating craft

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

Dredging of "Silt"

The Contractor carried out pre and post dredging hydrographic surveys. This information was used to estimate the amount of "silt" dredged and where in Reservoir No. 3 it was dredged from.

The dredging of the "silt" from the reservoirs was carried out using a hydraulic excavator floated on a barge. 3750m3 of "silt" was dredged from Reservoir No. 3, firstly from the area around the outlet from the culvert that brings the washwater into Reservoir No. 3, as this is the location where the larger heavier sand/gravel particles settle out first and had formed banks that were visible above top water level (see Fig. 3). Removing the material from around the outlet helped clear a path for the washwater, creating a more distributed settlement pattern through Reservoirs Nos. 2 and 3. These more coarse particles were a better material for forming the protection shelf being built up all along the 800m length being protected. When the material around the outlet had been exhausted, further "silt" material was dredged from the deepest areas of "silt", identified from the hydrographic survey of Reservoir No. 3. The chemistry of silt samples from Reservoir No. 3 indicated the expected organic rich conditions and elevated sulphide, ammonia, zinc and copper.

There was some existing concrete "rip-rap" embankments protection around the water level on the internal embankments of Reservoirs Nos. 2 and 3. This existing protection was left in place and the new protection shelf formed over the top of the "rip-rap".

"Silt" Shelf Retaining System

A "nicospan" revetment system supplied by MMG, retained the "silt", which formed the 3m wide dredged "silt" planting shelf for the reed beds on the reservoir embankments. The retaining system utilised a geo-mesh lining retained by sinking a chain of timber stakes 3m from the lower toe. "Nicospan" is a prefabricated, double weave revetment fabric made from strong UV stabilized monofilament yarns that are heat sealed to form a series of open pockets each having a width of 220mm, so that posts can be placed into them. The geo-mesh was selected to allow water to pass through but retain the "silt" (Fig. 5).

The posts for the "nicospan" revetment were driven in using a small piling hammer, converted for 100mm posts, mounted on an excavator. The posts were driven, at 500mm centres, into individual pockets of the "nicospan" to progressively "tighten" the revetment. The line of the revetment was agreed with Thames Water's site staff to offer maximum toe restraint to the embankment, but also offer the most ecological benefit. Anchor poles were

driven to the rear of the “nicospan” at 100mm centres and, wired to the “nicospan” using galvanized fending wire. The excavator, used to install the retaining system, was secured to a floating pontoon (Fig. 5).

Fig. 5 View of revetment system being placed

The Contractor designed the form and retaining system for the “silt” shelf (see Fig. 6) and Thames Water’s Geotechnics Group checked whether the new shelf would affect the stability of the reservoir embankments. The analyses were undertaken for slope angles of 1 in 2 and 1 in 3 using the methodology suggested by Morgenstern and Price (1965) and conservative soil parameters (c' = 0kPa and phi = 37 degrees for the gravels and c' = 3kPa and phi = 20 degrees for the London Clay). The results for failure surfaces

within the gravels and the London Clay both with and without the silt shelf are summarised in Table 2

Table 2 FOS Results for failure surfaces within gravels and London Clay with and without the silt shelf

1 in 3 Slope				1 in 2 Slope			
Failure in London Clay		Failure in Gravels		Failure in London Clay		Failure in Gravels	
A	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1.92	1.80	2.22	2.08	1.36	1.27	1.53	1.40

(Case A FOS without silt shelf and Case B FOS with silt shelf)

The conclusion was that the effect of the "silt" shelf on FOS was minimal and that even with the most onerous combination of a steeper slope and with the failure surface entirely in the London Clay, an acceptable FOS was obtained.

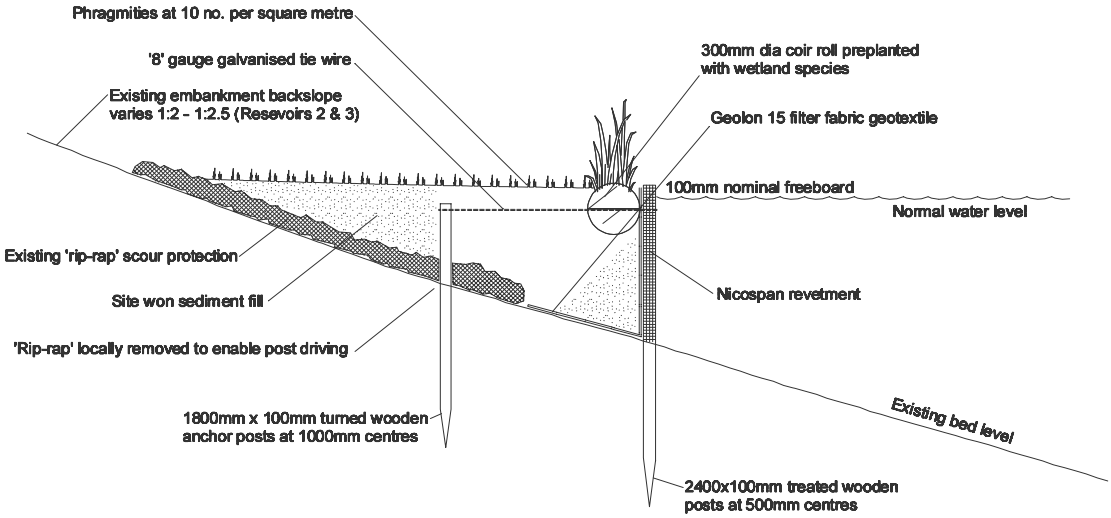

Fig. 6 – Section of "silt" shelf

At the start of the construction period the Contractor formed a short section of the proposed "silt" shelf, which demonstrated the effectiveness of the design, before progressing with the rest of the required 800m length.

After the "silt" shelf was completed (see Fig. 7), reed beds were planted during late spring 2000, which was the best time of the year for their establishment. The reed beds were planted in the "silt" to consolidate the protection and enhance the environment. Timber platforms were constructed at intervals to provide "swims" for the anglers that use the reservoirs.

Fig. 7 View of placed “silt” shelf

Reed Beds

The depth that the reed beds sit in the water was important to their surviving and maturing, and the Contractor formed the “silt” shelf to a level of 8.00m AOD, which allowed for 0.20m settlement of the “silt” shelf. This level ensured that the roots of the plants were always submerged. The finished level of the “nicospan” revetment was 50mm above the top water level. The density of the reed beds planted was ten plants per square metre. The reed beds were planted during May, which was the best time of year for their establishment (Fig. 8). Also the Contractor’s design included the use of pre-planted reed “coir” rolls and mattresses, which minimised the chances of die back or natural waste of the reeds.

As these rolls were placed at the front of the shelf and the reeds in the rolls were established, they prevented erosion of the “silt” shelf whilst it consolidated and the planted reeds behind established themselves.

Fig. 8 Planting of reed beds

There is a thriving bird life on the Walthamstow Reservoirs, and the newly planted reeds would be susceptible to damage by the birds, therefore to minimise the damage, netting was placed over the reeds as protection. This type of netting is proven to deter wildfowl interest.

Fishing Platforms ("Swims")

There were ten wooden platforms built out into Reservoirs Nos. 2 and 3 along the 800m of the "silt" shelf and they were approximately 2m long by 3m wide. The swims provided a new safer access to the waterside, and the reed beds either side helped to conceal the outline of the fishermen to the fish. A plan and section of a platform is shown in Fig. 9.

ENVIRONMENTAL ISSUES WITH CONSTRUCTION

There were a few environmental issues identified at the early stages of the project, which were dealt with by the Contractor in a responsible way. There was a need for the Contractor, whilst dredging, to prevent disturbed suspended solids from passing further downstream and into the River Lea. This was done by erecting a geofabric boom sediment curtain at the outlet

from Reservoir No. 2, for the extent of the construction period. This boom curtain was designed by the Contractor.

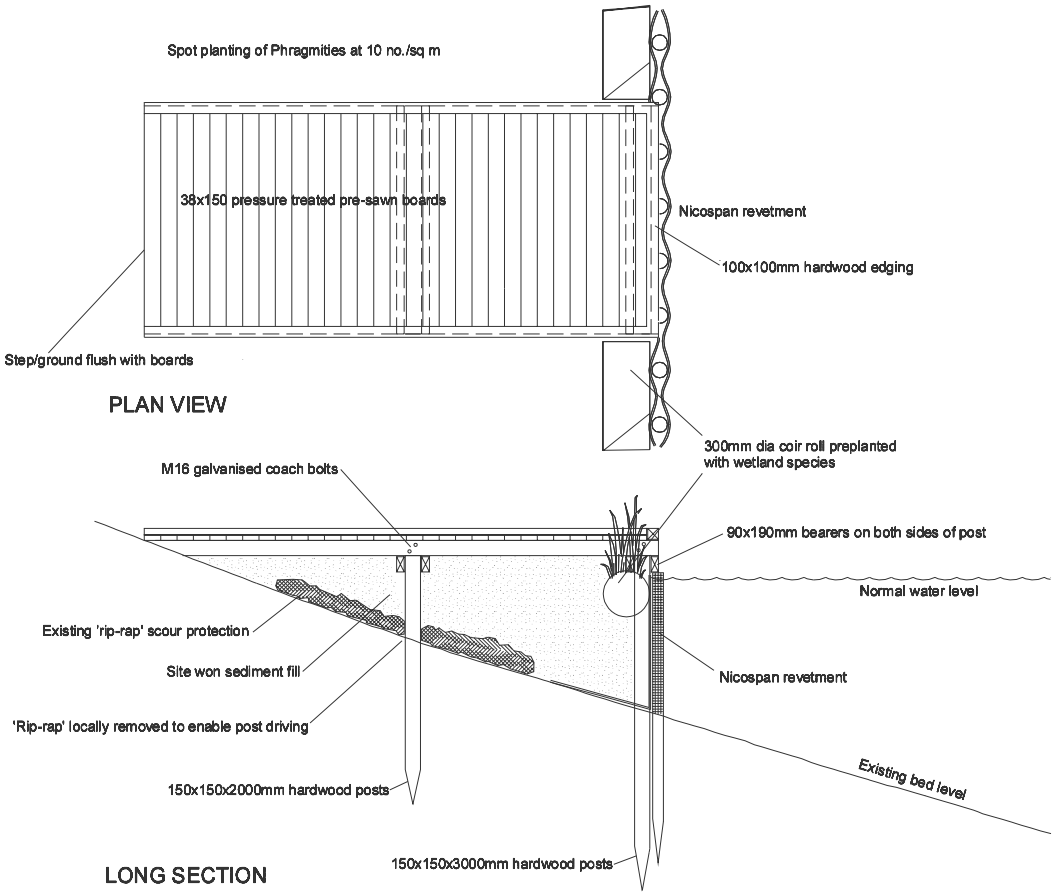

Fig. 9 Section of fishing platform

There are fish and other aquatic life within the reservoirs on the site and the Contractor monitored the dissolved oxygen and ammonia levels in Reservoirs Nos. 2 and 3 at least twice a day during the dredging. If the levels fell dramatically this would be likely to affect the fish and so the Contractor had on site emergency aeration equipment that could be immediately deployed to improve the water quality. The aeration was from a blower feeding a 1m diameter diffuser ring, but this equipment was not actually required to be used.

CONCLUSION

The “silt” shelf and reed beds were completed in May 2000, taking six months to complete, and apart from some minor secondary planting of reeds in early 2001, the reed beds are fully established and along with the “silt” shelf are fulfilling their function of protecting the embankments of the statutory reservoirs and providing biodiversity enhancements to the SSSI.

ACKNOWLEDMENTS

The support of John Harris and Jon Green of Thames Water and James Maclean of Land and Water in preparing this paper is gratefully acknowledged.

REFERENCES

Green J - Walthamstow No.4 and No.5 Reservoirs – A Recent History

Institution of Civil Engineers (2000). A Guide to the Reservoirs Act 1975

Morgenstern, N.R., and Price, V.E., (1965). "The analysis of the stability of general slip surfaces", Géotechnique 15, pp.79-93