The Mersey Estuary Pollution Alleviation Scheme: Liverpool interceptor sewers

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This paper describes the planning, design and construction of the principal Liverpool elements of the Mersey Estuary Pollution Alleviation Scheme. It excludes the primary wastewater treatment works at Salford Dock which were separately designed and managed by North West Water (NWW). The planning of the project was originally undertaken by Liverpool City Engineer as agent for NWW, and includes major tunnels, combined sewer overflows/storm storage chambers, outfall penstock chambers, and a reactive real time control system. The design and construction cover a period of major management and technological change within the water industry.

Keywords: environment; sewers & drains; tunnels & tunnelling

Background and early planning

The history of the Liverpool drainage systems, and the initial planning options for this project, have been summarized in an associated paper.1 The project addresses the former continuous discharge of raw sewage to the Mersey from a large part of the Liverpool conurbation.2 The minimum overall scheme objectives were to

(a) ensure that the estuary water should at all times contain a sufficient level of oxygen to obviate odour nuisance
(b) obviate the fouling of the estuary foreshore and beaches by crude sewage or solids or fats from industrial effluents.2

1 In 1974, it was concluded that the objectives could be achieved with primary treatment,3 and with efficient stormwater overflows passing forward modified formula A flows to interceptor sewers.4

2 In 1981, agreement was reached with the Mersey Docks and Harbour Company (MDHC) and with the planning authority that a treatment works site at Salford Dock would be acceptable. A 15-year programme was initiated, with detailed design work for the tunnels, storm sewage overflows and outfall penstock chambers commencing in 1984.

Geology

5. The solid geology of the east bank of the Mersey is composed of Sherwood sandstone. This is overlain by glacial sand and gravel, glacial till, marine and estuarine alluvium and, finally, made ground, mostly associated with the construction of the dock system, but including major former waste disposal sites, Mersey Tunnel construction arisings, and the landscaping for the International Garden Festival.

6. The sandstone is typically reddish-brown, but sometimes white, yellow or light grey, varying in strength from zero to approximately 50 MN/m². The origin of the rockhead surface is believed to be glacial erosion by glaciers travelling from north-west to south-east in an ice way following roughly the line of the present Mersey estuary rather than by preglacial fluvial action. The rockhead surface is irregular and the line of the main interceptor tunnel is crossed by a number of buried valleys causing the rock boundary to drop below the crown of the tunnel and thus presenting mixed face tunnelling conditions (Figs 1 and 2).

7. The upper layers of the sandstone are frequently weathered, forming a transition zone between competent rock and unconsolidated sand. The overlying material is glacial sand and gravel and/or till, both of which contain boulders, many of igneous origin. The till is typically ‘stiff’ or ‘very stiff’ silty clay (‘boulder clay’).

8. The Sherwood sandstone is a well-established aquifer, and groundwater levels are generally above tunnel level, having risen in recent years due to reduced abstraction. In addition, there are perched water tables in the made ground above the glacial till.

Site Investigations

9. Some investigations were carried out for Liverpool in 1978/79 in connection with a proposal to carry out tunnelling work in advance of inner ring road construction. In 1983, a further investigation was undertaken.

10. Stage-specific investigations were carried out progressively between 1985 and 1991 under the auspices of a geotechnical consultant. The main objectives were to establish rockhead levels, rock strength properties,
groundwater conditions, and the nature of the overlying glacial till material. Interpretive reports were produced advising on the nature of the ground expected in the tunnelling works and on the likely requirements for excavation support and de-watering for the major structures. Predictions for tunnel settlement were also produced.

Overall design considerations
11. The site investigations were complemented by an overall investigation into the sewer routes, including historical dock, tunnel and wartime records.

Tunnels
12. The investigations highlighted several problem areas, including old dock temporary back-drain systems used during the deepening of docks by underpinning, old ventilation headings above the underground railway (constructed with a Beaumont-English machine) (Fig. 3), and the constructional details of Stanley Dock Passage.

13. An early decision was made to preclude the use of compressed air (unless its use was essential) when groundwater levels were found at or about 10 m above the proposed tunnel level. There was the possibility of the back-drain connections providing a leakage path between tunnel level strata and both dry and wet docks, and major cost and health implications if pressures above 1 bar were needed.

14. The interceptor sewer tunnel route is shown in Fig. 1, plan, and Fig. 2, section. The flows to be conveyed were based on overflow settings using modified formula A and water and population projections to 2002. As that date approaches, it has proved possible to recalculate the settings using formula A with current consumption figures.

Combined sewer overflows (CSOs)
15. The CSOs are designed to separate out any visible solids and floating material that would otherwise pass to the river during storms. Fig. 4 shows an isometric view of a typical rectangular CSO and outfall penstock chamber arrangement, with a control gate and calibrated vortex connection to the tunnel.

16. In 1975, a literature survey was undertaken concerning the design of storm overflows. This survey, together with subsequent research, led to the conclusion that a new approach should be adopted for the design of CSOs for the Mersey Estuary Pollution Abatement Scheme (MEPAS) project, where the interceptor sewers would in some cases be at a considerable depth relative to certain outfalls. Additional head losses caused by the construction of the CSOs were also to be minimized so as not to increase the risk of flooding. The CSOs are designed to pass the set flow to the interceptor via a calibrated vortex controlling the CSO gate. Once the setting is reached, the CSO starts to fill, and the hydraulically powered gate opening reduces under the increasing head.

17. Modelling work was undertaken at Liverpool University, leading to the development of two types of no weir CSO (circular shaft and box shaped). The modelling was undertaken using the Sharp–Kirkbride stilling pond as a standard against which efficiencies were judged. The resulting designs were considerably more efficient than previous designs.
at removing and detaining both solids and floating material, and also had sufficient capacity to meet the calculated first flush volumes.

2. The deep circular CSO is designed for coalesced sites with a depth to the interceptor varying construction by underpinning with precast segments. The hydraulic design principles are similar to the rectangular type, but it has an inclined section to the main baffle, together with a second closely spaced baffle to create a long path for re-entrained floating material. A second floating material dead zone improves performance even further (Figs 5(a) and (b)).

Efficient CSOs obviate the need for static screens, reducing the additional head loss on the outfalls.

3. Modelling work was undertaken by Liverpool John Moores University to develop the method of controlling the pass-forward flow from the CSOs; in some cases the head with the deeper chambers fluctuates by as much as 10 m depending upon storm and tidal conditions. It was found that vortex drops could be calibrated with an almost linear relationship between depth and flow, but that a sifting chamber was required immediately downstream of the gate to be controlled in order to avoid hydraulic jumps that did not occur in the vortex approach. See (a) and (b).

1. CSO sizes range up to 12 m wide x 15 m deep x 25 m long. Referring to Figs 4, 5(a) and (b), dry weather flow leaves both CSO designs via normally open control gate, and proceeds through open channel flow within a culvert to the sewer connection to the tunnel. During storms, flow rates approaching the set pass-forward flow are detected at the vortex, and the control gate begins to close to limit the flow. This results in a rise in the level within the CSO, and the detention of floating material at the rear of the rectangular type of CSO, or in the first and second zones of the circular type. Material with a specific gravity greater than 1 may preferentially to the controlled outlet rather than the outfall (with varying efficiency depending upon the rate of storm flow). As flows subside at the end of the storm, floating material trapped in the chamber is passed to the controlled outlet.

Interceptor sewer tunnels

2. To minimize pumping costs at Saxon, the minimum depth at the approach to the inlet works (15 m) was determined by the ability to intercept all outfalls between Runcorn and Runcorn by gravity, and the depth required to cross Stanley Dock Passage.

2. The original maximum design flow for Station Dock is 11 m³/s, with the tunnels being able to deliver slightly in excess of that figure as required in the future. The largest tunnels

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**Fig. 2. MBPAS location, route, stages and values**

**Fig. 3. The Beaumont-English smooth bore tunnel (c. 1883) with local lining for MBPAS tunnel crossing**
each side of the works are 2.44 m internal diameter at gradients of 1 in 1000, with subsequent sections reducing to between 2:1 and 1:8 m, at gradients between 1 in 1500 and 1 in 2000.

24. Very accurate construction was required adjoining Sandon Dock in view of the fact that the inlet pumping station was designed and modelled without a sump. Taking into account critical depth, backwater and drawdown conditions, depths of flow are measured within the tunnel approaches, and variable speed pumps automatically respond to any tendency for flows to rise or fall, with depths being controlled in a predetermined band above critical depth.

25. In 1984, with an initial commitment to stage 1 only, there could have been a considerable future period where relatively low flows were present, with an attendant risk of hydrogen sulphide attack. Taking all these factors into account, it was decided to preclude unlined pipejacking as a method of construction for the first phases. The tunnel lining was to be watertight, capable of accurate construction, with a secondary lining.

26. On stage 1, the primary lining was specified as 185 mm thick segmental rings comprising five segments and a wedge-shaped key with synthetic rubber gaskets to resist external water pressure and high temporary installation loads. Two types of ring were specified: one straight and one tapered to permit corrections to line and level and negotiation of curves without the use of packers. The original intention was to use a standard 600 mm long ring, but the contractor for this section proposed 1 m long segments with two types of tapered ring (mirror image) as part of the proposal to use a full-faced slurry tunneling machine, and this was accepted. Cast-iron segments were specified beneath Stanley Dock Passage to resist internal surcharge pressures should the dock be empty.

27. An unreinforced secondary lining of 150 mm thickness provided the final hydraulic surface to the required tolerances and also a means by which repairs could be undertaken in the long term without affecting the primary structure.

28. Considerable investigation went into predicting settlements and possible effects on adjoining buildings. The tunnel was aligned so that any risk to buildings and dock structures was minimized.

Outfall penstock chambers

29. To prevent ingress of tidal water into the CSOs and interceptor sewer, outfall penstock gates were installed in outfall penstock chambers on the river wall, computer controlled...
to be normally closed and to open when storm flow levels exceed the tide.

30. Consideration had been given to the use of passive tide flaps, but this approach was rejected due to the risk of downstream siltation and the impossibility of providing high-level emergency outlets that would not themselves add to the risk of major tidal ingress problems. At many locations, the outfalls are below river bed level, with the continuous dry weather flow cutting a channel in the bed. Discontinuation of this flow after commissioning would leave any new tide flaps liable to become buried in the river bed, and incapable of functioning. Experience was also gained of large plastic-faced tide flaps installed by Merseydye Development Corporation on the rebuilt Gower Street/Kings Dock outfall. Silt regularly accumulated in front of the storm-only part of the twin-pipe system, and river swell caused continuous opening and closing (resulting in later hinge failure).

31. The robustness and watertightness of tapered cast ductile iron gates made them the favoured solution, with duplication and frame flushing to further reduce risk of failure or blockage. Both the majority of existing outfalls and the proposed interceptor sewer were well below or within the tidal range of the Mersey, necessitating positive tidal exclusion.

32. The majority of outfalls through the Dock Estate incorporate inverted siphons which in future would convey only storm flows.

33. The best technical course of action was to agree sites for the chambers giving protection to the MDHC system as well as the public sewers. In the event that problems arose with sewage trapped for long periods in the siphons, consideration would be given to back-flushing with sea water. At the termination of each outfall, a chamber was designed with twin hydraulically powered gates in parallel. These gates, normally closed to exclude the tide, would respond to storm/tide conditions. Separate hydraulic power circuits provided security against mechanical and electrical failure. To eliminate the risk of flooding due to total failure, the gates were to finally fail-safe open, with the flow control penstock in the CSO communicating with the interceptor sewer ultimately closing to exclude tidal water from the tunnel.

34. Each penstock gate frame has a high-pressure water jet system built into it, fed from a reservoir and pump within the chamber. The water jets operate automatically on each gate movement, so as to loosen and clear silt which may accumulate during periods with limited storm discharges. The gates are of ductile iron construction with phosphor bronze seatings and stainless-steel hydraulic cylinder rods.

Fig. 5. Circular deep shaft overflow. (a) diagrammatic representation; and (b) photograph of model
Control devices
35. The CSOs required a reliable means of moving the modulating control penstock; it was generally not practicable to position a penstock motor at ground level. This, together with a desire to minimize electrical work beneath ground, reduce the risks in an explosive atmosphere, and the need to move the gates to fail-safe position in the event of certain storm/tide events following an electrical power failure, resulted in a decision to specify hydraulic power with pumps and accumulators housed remotely above ground. The use of the modulating penstock in the CSO meant that with computer control, the pass-forward settings could be remotely reset at any time to any value up to the maximum capacity of the calibrated vortex connection.

36. The calibrated vortex is used in preference to the conventional flume due to its larger equivalent dimensions making blockage less likely; an important consideration for inaccessible underground locations. The vortex also provides an energy-dissipating vertical connection to the interceptor sewer (Fig. 6).

Flow management
37. To operate all gates, a flow management control system was proposed. This would limit the flow to the interceptor to a predetermined figure and would facilitate the discharge of excess flows to the river while at the same time limiting such discharges by mobilizing available storage. Various ultrasonic sensors were included to control the gates, with an appropriate level of redundancy, measuring water levels in the structures, river, and calibrated vortices. Generally, failure of any level measurement device results in an alarm signal and the automatic substitution of the nearest upstream alternative level measurement. Failure of a tide sensor results in substitution by a reading from the sensor at the nearest adjacent outfall.

38. Further sensors measure gate positions, and limit switches confirm total closure or opening. In addition, to guard against total sensor failure at the vortices, gate sensors were included to facilitate movement to predetermined intermediate ‘fixed’ positions.

39. In order to control the penstock gates and monitor the mechanical and electrical plant, GEC Gem 80 programmable logic controllers were selected, and situated in local control buildings with the hydraulic power, electrical and ventilation equipment. These buildings had to be robust both in practice and appearance to survive abuse within the heavily trafficked docks, and elsewhere to blend with listed buildings in the city centre. It was also recognised that they would be the only visible parts of the completed project (Fig. 7).

Control strategy
40. As storm flow entering the CSO builds up, the software detects a rise in flow rate. When the flow at the vortex approaches its set value, the CSO penstock gate throttles down to limit the flow to the set value. To prevent hunting with small flow variations, a routine for damping is incorporated in the software.

41. Once the throttling process commences, stormwater storage also begins. The water level is allowed to rise until it reaches a trigger level for opening the penstock gates at the river. This is set at a high level to cause increased surcharging of the inlet pipe to the CSO so as to improve floating material retention. A further benefit is that it also increases the total storage

Fig. 6. Smaller type of vortex within tunnel shaft (larger types are in separate shafts)

Fig. 7. Control room at pierhead, Liverpool
available. The overspill trigger levels also take account of the existing system's ability to tolerate surcharge, and ensures that the flooding risk is no higher than when each outfall was open to the river. An ultimate opening level also ensures that the gates can function during storms coinciding with abnormally high tides.

42. Once the overspill trigger level has been reached, the level of the river is checked and, providing that a head sufficient to allow flow through the outfall is present, the outfall gates will open. When the level within the CSO has fallen by a preact amount (normally 500 mm), or to a preset lower level, the outfall gates will close, with simultaneous frame flushing.

Telemetry system

43. A telemetry system has been installed to provide communication between the pairs of controllers at the CSO and outfall penstock chamber sites, and also to connect each outfall's control system to a central monitoring system. The former telemetry link is intended to transfer operational data between CSO and outfall pairs (Fig. 4) while the latter is intended to provide current and historical alarms and information to operations personnel responsible for the interceptor sewer.

44. The central monitoring system is located within the control building closest to Sandon Dock, and comprises a large programmable logic controller with multiple communications outlets. Each CSO programmable controller is interfaced with this system via a modem link using multi-screened cables which run in a duct in the sofit of the interceptor sewer. Since the sewer will not normally run under surcharge conditions, the chosen location for the cables was considered to be of lower cost and risk of damage than in a separate duct at highway level.

45. The central monitoring system feeds information to various operational terminals including the Sandon Dock wastewater treatment works control room where alarms are announced.

Programme, contract strategy and outcomes

46. The starting point for construction was a section adjacent to the new treatment works at Sandon. This relatively short length of interceptor sewer on either side of Sandon Dock, a total length of 2.3 km, intercepted 40% of the flows from the whole scheme and was therefore very cost-effective.

47. For construction purposes, the project was divided into five stages in Liverpool, and two in Sefton. Stages 1-4 in Liverpool and stage 1 in Sefton all comprise a length of tunnel together with overflow and outfall structures.

48. Liverpool stage 5 and Sefton stage 2 involved pumping stations and long mains; in the former case this was a change from the originally planned tunnelling option, and enabled construction to be kept entirely outside the boundary of the recently redeveloped Liverpool Airport terminal and apron areas.


Liverpool stage 1 strategy and outcome

50. On Liverpool stage 1 contract, attempts were made to improve the tender assessment process by adopting a two-stage procedure involving a technical appraisal prior to consideration of the fully priced tender. Great care was taken to make methods contractual, but amendments were made to clauses 12 and 14 of the ICE 5th edition with a view to limiting the client's liabilities under clause 12 in the event of method changes by the contractor. Deposit of the contractor's tender breakdown in a bank was also stipulated as a possible aid to claims resolution.

51. Liverpool stage 1 encountered tunnelling difficulties as described later. A major claims situation became complicated by performance payments being withheld from the tunnel machine manufacturer by the contractor, the manufacturer suing for payment, and a high court judge deciding that he should hear, together, all the ground-related evidence, including the notified contract claims. Thus, the normal contract procedures were circumvented. An out-of-court settlement was reached without recourse to the provisions of the special contract clauses, and without inspection of the tender breakdown. (The fact that a settlement was reached without agreement on the precise causes of the difficulties precludes further discussion.)

Liverpool stage 2 strategy and outcome

52. By 1990, when the first stage was substantially complete, contract strategies for North West Water tunnelling contracts moved towards target contracts under the IChemE 'Green Book', based on a percentage fee plus a possible variable bonus related to a tender target cost. Liverpool stage 2 was the first major contract to successfully use this approach. A full bill of quantities had already been prepared for adenrurement, and this assisted with the rapid bidding for fees and bonus. The selected bidder then negotiated the detailed tender target cost. This approach led to greater cooperation between the designer and contractor over the choice of tunnelling equipment and method.

53. Liverpool stage 2 did not suffer any major disputes, and excellent progress was made. When the contractor went into receivership (due to group problems), the form of contract and the standard of the site records facilitated the rapid novation of the contract. The contract was completed within its original
budget despite the need to make ex gratia payments for the continuation of certain key subcontractors whose work was at a critical stage and who had not been paid by the main contractor or the receiver.

**Sefton stage 1 strategy and outcome**

54. Sefton stage 1 was let under ICE 5th edition, but took the form of 50% reimbursement through admeasurement, and 50% against a target, sharing the client/contractor risks associated with each separate method of reimbursement.

55. The contract was cumbersome to manage in that it embodied two systems of reimbursement. After a delayed start (while revised access requirements were agreed with MHGC), the contract was completed within budget and without major dispute.

**Other stages**

56. Sefton stage 2 followed a traditional ICE 5th edition approach, as did the Liverpool Airport Enterprise Zone tunnel. The latter was constructed oversized for its original purpose in the 1980s (for runway crossing and airport purposes). It was aligned so that it could become part of the Mersey Estuary Scheme (see Tables 1 and 2 footnotes concerning final stages).

**Construction**

**Tunnelling**

57. Although the greater part of the interceptor tunnel could be driven entirely in rock, substantial parts of Liverpool stage 1 (L1) and Sefton stage 1 (S1) were in mixed-face conditions. It was recognized that proposals for dealing with these conditions might include the use of compressed air, a situation which the project was anxious to avoid for health, safety, and cost/risk reasons. A clause was included in the L1 specification to the effect that compressed air could only be used if considered 'essential' by both the contractor and the engineer.

58. Four tenders were received for L1. Three proposed the use of open-faced roadheader shields (i.e. shield-mounted booms), with compressed air up to 1 bar, while the fourth was based on the use of a full-faced slurry shield. This tender was accepted, being both fully compliant and demonstrating that the use of compressed air was not essential. The tunnel boring machine (TBM) proposals were subject to an independent consultant's appraisal for North West Water prior to tender acceptance.

59. During construction, the TBM ran into difficulties at an early stage, having trouble with large cobbles at the face, and difficulty in maintaining look-up, particularly when overcutting to facilitate steering to a contractor-introduced 400 m radius horizontal curve. The TBM, a long machine lacking articulation, was removed after driving only 730 m (Fig. 8).

60. The contractor then proposed the use of a system comprising an articulated shield with boom cutter and a built-in bulkhead, using the same slurry system as the previous machine, but followed by a pipejacking system rather than segments (Fig. 9). Pipejacking had been prohibited in the original specification due to tolerances being incompatible with the required gradients, and the need to finish at precise positions at the Sandon inlet works. The Sandon inlet shaft was constructed as part of a separate contract, and had not been available for tunnelling purposes at the commencement of stage 1. It later became available, permitting
driving of the second TBM away from the fixed Sandon positions. The secondary lining within
the oversized pipejack allowed for fine adjustment of finished levels, providing the specified
secondary lining for long-term maintenance
(and to resist hydrogen sulphide attack if
subsequent stages were delayed), and also
sealed the inner joints so as to protect the mild
steel pipejack collars from long-term corrosion.
This system was used to drive the remainder of
the mixed face stage 1 tunnel, in three sections
of 560, 250 and 350 m, the middle section being
curved to 250 m radius, negotiated with tapered
pipes to avoid the use of packing.
61. A short section of tunnel in competent
rock at the south end of this stage was carried
out by drill-and-blast methods using a conven-
tional shield, culminating in a drive with cast-
iron segments under the Stanley Dock Passage
with less than 2 m of cover to the dock bottom,
using hand jiggers only (Fig. 10).
62. The Liverpool stage 2 works included
the longest section of tunnel on an individual
stage (4 km, later extended to 5 km), which was
entirely driven in rock apart from a short
section through the original 'Pool' at Canning
Place. The choice of machine fell quickly into
the field of open-faced shield-mounted boom/
road headers (of the boom type successfully
used on the Liverpool Loop and Link rail
 tunnels). The chosen TBM was fitted with a
profile cutting facility into which a prede-
termined cutting sequence could be programmed
(Fig. 11). This was believed to be a first
application to a shield-mounted roadheader and
greatly aided the accurate cutting of the face,
particularly in the invert. Removal of material
was by chain and then belt conveyor to rail-
mounted skips. To ensure that this machine
could negotiate the mixed ground at the 'Pool' it
was fitted with an extendable hood and face
rams and also with a back-acter as a replace-
ment for the boom (Fig. 12).
63. Stage L2 involved many curves, some at
250 m radius, in order that shafts could be
positioned in the city centre with regard to
traffic requirements. Segmental construction
was therefore essential, and a single 750 mm
long tapered (7.75 mm) ring of six trapezoidal
segments was adopted (Fig. 13). Line and level
were adjusted by relative rotation of the rings.
The overbreak was filled with Lytag blown-in
pellets, followed by cement grout. Shafts were
serviced from overhead straddling rail-mounted
gartries (Fig. 14). This system of tunnelling
proved very successful and consistent rates of
advance between 100 and 110 rings per week
were achieved, with the tunnelling being fin-
ished well ahead of programme, and an addi-
tional 1 km section from the third stage in
similar ground being added.
64. The S1 tunnel was driven northwards
from the Liverpool boundary at Canada Dock in
mixed ground using a full-faced earth balance machine with an oversized pipejack with secondary lining. This commenced, as L2, in 1990. The machine had some difficulty in cutting clay, requiring a change in cutting head, and had minor level control problems, but was generally very successful.

65. Liverpool stage 3 (L3) represented a departure to separate tunnel and structure contracts, both under IChemE Green Book. From this point, a one-pass design was accepted to reduce costs, the criterion of critical tolerances and hydrogen sulphide risk of L1, and the numerous curves of L2, no longer applying.

66. On the contracts with groundwater at 10 m above the tunnel, man-access for maintenance and pick replacement was a concern with respect to the possible need for compressed air. The original stage L1 machine had a one-man airlock that was found to be too small when tested by simulating a rescue, and needed a tunnel airlock; the replacement machine had an acceptable large double bulkhead airlock. Compressed air was not used for any L1/L2/S1 tunnelling operations other than a precautionary pressure of 0.5 bar over 125 m in the vicinity of the 'Pool'.

67. No observable settlement occurred over the tunnels in rock. In mixed ground on stage L1 there were two local areas of road settlement associated with support failures at the tunnel face.

CSO construction

68. The CSO structures are of reinforced concrete with the emphasis on long-term durability, using pulverized fuel ash cement replacement, low water cement ratios and 75 mm cover.

69. With the exception of Battery Lane and Kings/Gower, where temporary diversions facilitated on-line construction, all CSOs were built off-line. Sheet pile cofferdams were generally used for excavations, with deep well dewatering where necessary. The circular Dingle CSO used lined segments (Fig. 15). Live loads of 60 kN/m² (all over) in Mersey Dock areas resulted in very heavy construction, with heavy in situ roof slabs or composite construction of pre-stressed bridge beams with in situ topping.

Outfall penstock chamber construction

70. The chambers were generally constructed as concrete segmental ring shafts sunk by underpinning direct onto the existing live outfalls at the river wall. Temporary flumes were used, followed by stainless-steel hinged plates for finishing while flow was overpumped. The stainless-steel plates are retained in each chamber for long-term maintenance of the penstock gates.

Commissioning

71. Liverpool stage 1 and Sandon Dock were simultaneously commissioned during 1991. Problems arose due to the nature of the discharge from the northern outfall CSO which had been brought on-line with the existing outfall sewer (left outfalling to the river) some days in advance of flow transfer to Sandon. The difficulties were in fact a consequence of the efficiency with which the CSO removed and concentrated solids from the flow, and affected the Sandon inlet screens. A recommissioning, using dock water into which the sewage was gradually introduced, successfully overcame the problem.
Principal participants

72. The principal designers, contractors and consultants are summarized in Table 1. The tunnel linings and machines used on each stage are summarized in Table 2.

Performance and conclusions

73. A twelve-month period of performance was reviewed in 1994/95 to determine the number of actual discharges to the river from those outfalls that are intercepted. Table 3 summarizes the total rainfall events, estimated and actual discharges for the central Liverpool outfalls. Incomplete data only are available for the Sefton outfalls, but performance is similar to the Liverpool section with the exception of the Crosby Northern outfall which has a pumping station without the equivalent of a CSO, and a discharge via a pre-existing tank and screen.

74. Visual beach inspections at Crosby and Waterloo, although subjective, demonstrate a dramatic post-commissioning elimination of sewage solids deposits. The control strategy results in relatively small overspills as opposed to fewer long duration spills.

75. The largest storm event experienced during the twelve-month record examined was 24 mm over 12.5 h. During this event there were 72 individual overspills, with a cumulative duration of 25 h. Several low-intensity storms just caused overspilling, with a cumulative duration of less than 15 min.

76. Table 3 also includes predicted hours of overflow calculated in the early planning stages, and based on the approach of Davidson and Ganesan.1 The dramatic reduction from these predictions to the actual discharges can be attributed to the fact that the original estimates did not take account of the ability of the control system to maximize storage, and the effects of tide levels on storage.

77. Computerized control has resulted in a precise flow being delivered to the treatment works under all storm conditions, full mobilization of storage, and the positive exclusion of the tide from the system (Fig. 16). The summary in Table 3 demonstrates that over the twelve months records examined, control has reduced discharges to 0.25% of the previous continuous discharge and 5.36% of the original post-commissioning prediction. There is scope for further improvement through moving to a predictive real-time control approach.

78. Further monitoring and research may enable comparisons to be made with current overflow design approaches, but there will inevitably be limitations in the application of designs intended to exploit a situation where greater depths exist between outfall pipes and the pass-forward controlled outlet than the usual situation with all pipes at similar invert levels. The CSO designs are more likely to lend themselves to adaptation elsewhere to combined CSO/storage tanks with pumped returns within existing drainage systems, especially if efficiencies can be shown to exceed those of screened CSOs outfalling via simple storage tanks with pumped returns.

79. Later research (for stage L3) has

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**Table 1. Principal contractors, designers and consultants**

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<th>Contractor</th>
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<tr>
<td>Norwest Holst</td>
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<td>Lilley Construction</td>
<td>L2</td>
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<tr>
<td>Amec</td>
<td>L2 completion, L3 tunnel*</td>
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<td>Miller Construction</td>
<td>S1, L3 structures, L4</td>
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<tr>
<td>Birt</td>
<td>S2</td>
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<tr>
<td>Dew</td>
<td>L5†</td>
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<td>Mowlem</td>
<td>Enterprise Zone</td>
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**Principal designers**

- Liverpool City Engineer
- Sefton MBC
- North West Water Engineering
- Bechtel Water†

**Consultants to principal designers**

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<th>Consultant</th>
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<td>CI linings, and early tunnelling appraisals</td>
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<td>Mott Hay and Anderson</td>
<td>Stage L1 Independent TBM appraisals for NW Water</td>
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<tr>
<td>Tweeds</td>
<td>Target adjustment</td>
</tr>
</tbody>
</table>

*Stage L3 tunnel was subject to separate management by NW Water tunnelling section.
†Stage L4/S construction took place after the presentation of this paper under new partnership arrangements.
Table 2. Tunneling details

<table>
<thead>
<tr>
<th>Stage</th>
<th>Length approx. m</th>
<th>THM</th>
<th>Lining primary</th>
<th>Lining secondary</th>
<th>Int. dia. m</th>
<th>Start date</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>2-3</td>
<td>FCB full-faced slurry</td>
<td>Conc. seg.</td>
<td>150 conc.</td>
<td>2.44</td>
<td>09/87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deby's hybrid boom/slurry</td>
<td>Pipejack</td>
<td>150 conc.</td>
<td>2.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clarke shield</td>
<td>CI</td>
<td>150 conc.</td>
<td>2.44</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>5-1</td>
<td>Decon-Dosco boom cutter</td>
<td>Conc. seg.</td>
<td>150 conc.</td>
<td>2.44</td>
<td>04/90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lovat BB</td>
<td>Pipejack</td>
<td>None</td>
<td>2.13</td>
<td>02/93</td>
</tr>
<tr>
<td>L3*</td>
<td>2-2</td>
<td>Decon-Dosco boom cutter</td>
<td>Pipejack</td>
<td>None</td>
<td>2.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lovat BB</td>
<td>Smooth seg.</td>
<td>None</td>
<td>2.13</td>
<td></td>
</tr>
<tr>
<td>L4†</td>
<td>3-3</td>
<td>Lovat BB</td>
<td>Pipejack</td>
<td>None</td>
<td>2.13</td>
<td>11/95</td>
</tr>
<tr>
<td>L5†</td>
<td></td>
<td>No tunnelling</td>
<td>Pipejack</td>
<td>None</td>
<td>1.80</td>
<td>11/95</td>
</tr>
<tr>
<td>S1</td>
<td>2-3</td>
<td>Lovat BB</td>
<td>Pipejack</td>
<td>None</td>
<td>1.80</td>
<td>04/90</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>No tunnelling</td>
<td>Pipejack</td>
<td>None</td>
<td>1.80</td>
<td>04/92</td>
</tr>
<tr>
<td>E. Zone</td>
<td>2-0</td>
<td>Decker full-face slurry</td>
<td>Mini-tunnel</td>
<td>None</td>
<td>1.80</td>
<td>1982</td>
</tr>
</tbody>
</table>

The project also included considerable auxiliary tunnel lengths in addition to the above. For example, at St Nicholas outfall, 409 m of local diversion tunnels were driven by hand above the main interceptor sewer tunnel.

*Stage L3 tunnel was subject to separate management by NWWE tunnelling section.
†Stage L4/S construction took place after the presentation of this paper under new partnership arrangements.

Table 3. Rainfall events and storm performance, central Liverpool outfalls, 1994-95

<table>
<thead>
<tr>
<th>Outfall</th>
<th>Of 192 rainfall events recorded</th>
<th>No. causing discharge</th>
<th>Storm spills</th>
<th>Total actual hours</th>
<th>Calculated/predicted hours</th>
<th>Pre-commissioning hours: 12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No. during event</td>
<td>Post event</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1 Northern</td>
<td></td>
<td>39</td>
<td>88</td>
<td>19</td>
<td>95</td>
<td>332</td>
</tr>
<tr>
<td>L2 Bankhall</td>
<td></td>
<td>4</td>
<td>63</td>
<td>12</td>
<td>13</td>
<td>357</td>
</tr>
<tr>
<td>L3 Sandhills</td>
<td></td>
<td>29</td>
<td>141</td>
<td>13</td>
<td>16</td>
<td>471</td>
</tr>
<tr>
<td>L4 Beacon G.</td>
<td></td>
<td>17</td>
<td>51</td>
<td>27</td>
<td>10</td>
<td>453</td>
</tr>
<tr>
<td>L5 Battery Ln†</td>
<td></td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>7</td>
<td>211</td>
</tr>
<tr>
<td>L6 St Nicholas</td>
<td></td>
<td>30</td>
<td>61</td>
<td>6</td>
<td>19</td>
<td>614</td>
</tr>
<tr>
<td>L7/8 Gower</td>
<td></td>
<td>8</td>
<td>17</td>
<td>11</td>
<td>11</td>
<td>480</td>
</tr>
<tr>
<td>L9 Park St†</td>
<td></td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>334</td>
</tr>
<tr>
<td>Total hours for year</td>
<td>(A) 173</td>
<td>(B) 3215</td>
<td>(C) 70880</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A as %C = 92.5%, B as %C = 4.8%, A as %B = 5.36%. (That is, actual improvement is 92.75% on previous continuous discharge in terms of time. Local polluting loads will reduce by a similar approximate amount (disregarding first flush capture, variation of polluting load with time, and the effects of the post-treatment discharge quality achieved at Sandon Dock).)

*Battery Lane, like many existing outfalls, loses an element of captured flow lying below the CSO outlet invert level on the next OPC gate opening. The post-event discharges, in this case, are caused by routine maintenance gate movements and/or the release of accumulated infiltration.
†Park Street outfall is a new replacement, designed to run uphill from the CSO to the river outfall penstock chamber (OPC). Thus all flows captured or held by the OPC gates are returned to the interceptor sewer; this is reflected in the performance above.

optimized the CSO floor self-cleansing arrangements.18

Acknowledgement

90. The authors wish to express their thanks to North West Water Engineering for permission to present this paper to the Mersey-side Branch of the ICR, and for subsequent publication. The paper is a necessarily brief summary of a project involving a major team effort by NWW and their contractors, together with that of Liverpool and Sefton Councils who let the first contracts and continue in monitoring and maintenance roles.

Fig. 16. Typical control system display of tide level (broken line) and level in CSO (solid line) during 10h storm
Note

61. Since the presentation of this paper and the commissioning of the project, North West Water and the Environment Agency have been reviewing overflow settings in the context of the secondary treatment provision at the Sandon Dock.

References


2. Scheme Objectives: Terms of Reference. Steering Committee on Pollution of the Mersey Estuary, 7 July 1972, items (d) (i) and (ii).


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London SW1P 3AA.