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Woolston New Weir and River Mersey Diversion

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The Woolston Weir and River Mersey Diversion project involved provision of a new hydraulic control structure, diversion channel and ancillary works on the River Mersey, near Warrington, for the Manchester Ship Canal Company. The weir is a substantial structure, nearly 80 m wide. It includes the largest low-head, air-regulated siphon weir to date in the UK, with nine bays, each 4 m width, plus 17·8 m wide 'ogee'-type weirs either side, and a fishpass. Design involved extensive physical and numerical modelling. The weir was built in dewatered open cut in difficult ground, within a new channel some 600 m length cutting across an ancient loop in the Mersey. The scheme has provided an economic means of closely controlling a wide range of flows, for flood and navigation purposes, consistent with a pleasant river environment.

1. INTRODUCTION

The River Mersey/Manchester Ship Canal system provides drainage to a large area of the North West of England. The upper Mersey joins the Ship Canal south of Manchester and separates again at Rixton Junction, some 6 km upstream of Woolston (Fig. 1). Woolston Weir controls water levels in both the upper Mersey and Ship Canal. Flows of typically 20–40 cumecs, but up to 200 cumecs in flood, pass down the Mersey. Flows in excess of 140 cumecs are routed mainly down the Ship Canal, controlled by parallel operation of sluices at Latchford Locks and Woolston Weir. The systems are integrated to maintain satisfactory water levels in the Ship Canal for navigational requirements and flood control, under the range of flows.

The 'Old Woolston Weir' was constructed in the 1890s as part of the Manchester Ship Canal works, engineered by Sir Edward Leader Williams.[1] It had 16 gates, mechanically operated to control upstream water levels. This required full time staffing, with quite complex procedures to respond to notice of floods from upstream stations to lower or raise gates accordingly and to liaise with operations at Latchford Locks.

By the 1980s, the weir was nearing the end of its life. Reconstruction or replacement in situ while maintaining operations would have been extremely difficult and expensive. The Ship Canal Company considered this with HR Wallingford, resulting in the proposal for a new 'automated' control structure, using low-head, air-regulated siphons. Several such structures had been constructed (Table 1), including a three-bay siphon on the River Lee at Ware,[2–6] but nothing on the present scale, in the UK. A hydraulic feasibility study, including modelling, showed that it was practical and economic to pass the required flows with a minimal rise in upstream level.

An engineering feasibility study was carried out in 1990–91. The best option was to construct the new weir in the dry, in a channel across an existing loop in the River Mersey. Preparatory works were carried out in 1992. The main construction was carried out during 1993–94, with completion in time to celebrate the centenary of the Manchester Ship Canal.

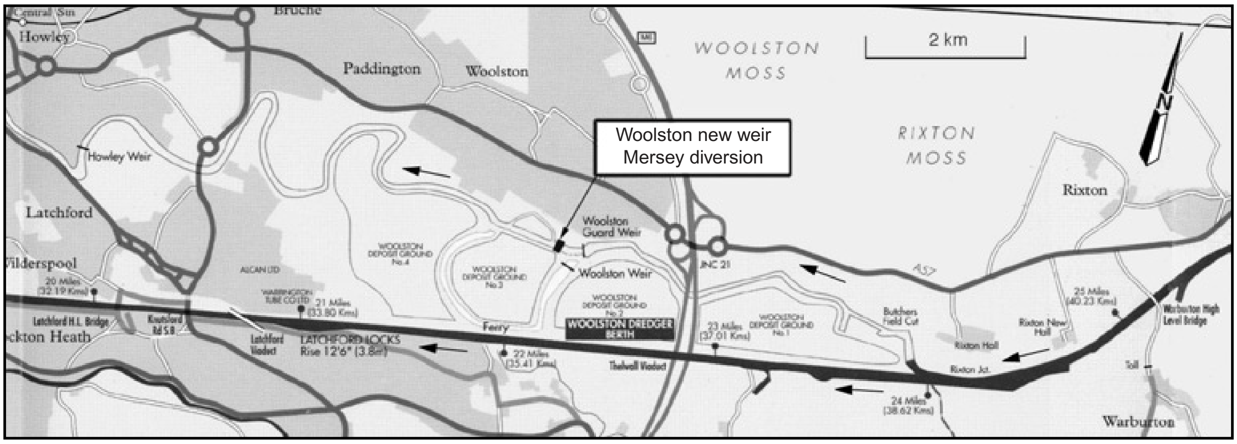

Fig. 1. Plan showing the Manchester Ship Canal, River Mersey and Woolston Weir

Location	Date	No. bays	Dimensions: m	Max. head: m	Peak flow: m^3/s	Material	Comments
Low-head river siphons							
Wessex Sherborne Lake	1975	3	3·7 × 1·2	2·1	(113)	Concrete	Flood control for lake
River Ouse, Barcombe Mills					45		
River Cray, Hall Place	1970	3			40		
River Bourne, Little Mill	1959	2	1·8 × 0·9	0·8	13		
Anglia, River Welland	1968	2	1·8 × 0·9	0·9		Steel	Reported stress failures
River Gwash, Newstead Mill	1966	1	1·8 × 0·9	0·9		Concrete	
River Welland, Gretton	1970	2	1·8 × 0·9	0·9		Steel	Reported stress failures
River Welland, Tinwell	1970	5	1·8 × 0·9	0·9		Steel	
River Nene, Barnwell	1967	5	1·8 × 0·9	0·9		Steel	Reported stress failures
River Nene, Denford	1968	4	1·8 × 0·9	0·9		Steel	Stress failures lead to collapse. Materials replaced in 1992–93?
East and West Glen Rivers, Flotlado Mill Syphon	1974	1	1·8 × 1·5			Steel	Problems with trash
River Welland, Newborough Syphon	1977	3	2·0 × 1·2			Steel	
River Welland, Four Mile Bar Syphons	1976	3	2·0 × 1·2			Steel	
NRA Thames							
River Lee, Ware Weir	1976	1	3·0 × 1·2	1·1	12·9	Concrete	Reference 4
River Lee, Ware Lock	1977	3	3·3 × 1·2	1·9	63	Concrete	Noise, back venting under hood (van Beesten[2,3])
River Beane, Sele Mill Siphon	1979	1	3·0 × 1·2	0·6	10	Concrete	
Reservoir siphons							
NW Water Jumbles Reservoir	1967–71	24	1·5 × 0·8			Concrete	Gives large flow surges downstream
Yorkshire Water Mixenden Reservoir	1987	2	2·3 × 0·9	2·13	11·2	Concrete	
Eyebrook Reservoir	1940					Concrete	
Shin Diversion Dam, Scotland	1957	3 × 2	1·8 × 0·9	≈4	85	Concrete	
Dunalastair	1930	2 2	1·8 × 0·9 2·4 × 1·2			Concrete	Modified in 1970s
Lubreoch	1958	2	1·2 × 3·8	17	68	Concrete	Priming controlled by valves
Ericht	1953	3 × 2	1·7 × 1·1		102	Concrete	Priming controlled by air valve. Siphons not operated up to 1975

Table 1. Details of some UK air-regulated siphons

2. HYDRAULIC DESIGN

The proposed structure had to accommodate flows from typically 20–140 cumecs, to over 200 cumecs in extreme situations (Tables 2, 3 and 4) with minimal rise in the upstream water level. Advances in hydraulic engineering have led to the development of ‘low-head, air-regulated siphons’ which can smoothly pass a wide range of flows with little variation in upstream head. The hydraulics of the new structure, stilling basin and overall system were studied in considerable detail by HR Wallingford.[7] The eventual system consisted of an ‘ogee’ weir each side of a bank of siphon weirs (Figs 2 and 3) designed to match the earlier flow regime, but with improved behaviour (i.e. slightly lower water levels) under flood conditions.

River diversion		Upstream	Downstream
Length		80 m	490 m
Bed level		5·98 m AOD	2·25 m AOD
Low water level	20 m^3/s	8·1 m AOD	5·5 m AOD
High water level	140 m^3/s	8·3 m AOD	6·0 m AOD
Max. flood level	240 m^3/s	9·3 m AOD	8·3 m AOD
Flood banks to		9·8 m AOD	8·8 m AOD
Channel width		50–60 m	50–80 m
Section	Trapezoidal with 1-in-2 slopes		
Weir and stilling basin			
Overall width	76·5 m		
Side ‘ogee’ spillways	2 No. × 17·75 m wide with crest at 7·97 m AOD		
Siphons	9 No. 4 m wide, 1·2 m deep with crest at 8·12 m AOD		

Table 2. Summary of principal hydraulic design requirements

The hydraulic studies included tests using various scaled physical models. A ‘vertical-slice’ model (i.e. section) was used to study siphon behaviour under the range of flows, varying the detailed geometry to obtain the required hydraulic characteristics. The hydraulic behaviour of siphon weirs is

Return period: years	Mean daily flow: m^3/s
0·25	218
0·5	267
1	304
2	378
5	486
10	583
20	636
50	≈750
100	≈820

Table 3. Manchester Ship Canal/Mersey system at Woolston/Latchford. Flows and return periods

extremely complex, with the rate of air entrainment serving to control the discharge. Design remains beyond the scope of hydraulic theory. Physical modelling is the only reliable means of determining this behaviour and hence of developing a structure design to meet project requirements.

The siphon weir flow passes through four distinct phases: ordinary weir flow, sub-atmospheric weir flow, air-partialised flow and blackwater flow. Fig. 4 shows the siphon model in action (sub-atmospheric weir flow), with the step serving to entrain air which feeds and maintains the siphonic action and hence the flow characteristics. The siphonic nature of the flow results in rapidly increasing discharge for quite small rises in upstream water level. Key features that affect the performance include

(*a*) the inlet shape, throat width and level (relative to crest)
(*b*) the underside of the roof/hood profile
(*c*) the step, which is critical to priming and the air entrainment process
(*d*) the extent of the downstream hood.

Van Beesten[2,3] has drawn attention to 'gulping' causing

Year	Mersey at Woolston Weir*: m^3/s			MSC Latchford sluices open†	Combined: m^3/s		Combined peak: m^3/s
	>25	>50	>100		>200	>300	
1986	183	92	63	14	11	4	140 + 420 = 560
1987	365	206	97	14	15	0	
1988	138	91	61	20	12	1	140 + 230 = 370
1989	273	86	42	13	2	0	
1990	365	145	81	21	2	0	
1991	90	31	19	2	0	0	

*No. of days showing flows exceeding 25, 50 and 100 cumecs.
†No. of days on which Latchford sluices opened for flood control.

Table 4. Analysis of prior flows in the Mersey and Manchester Ship Canal

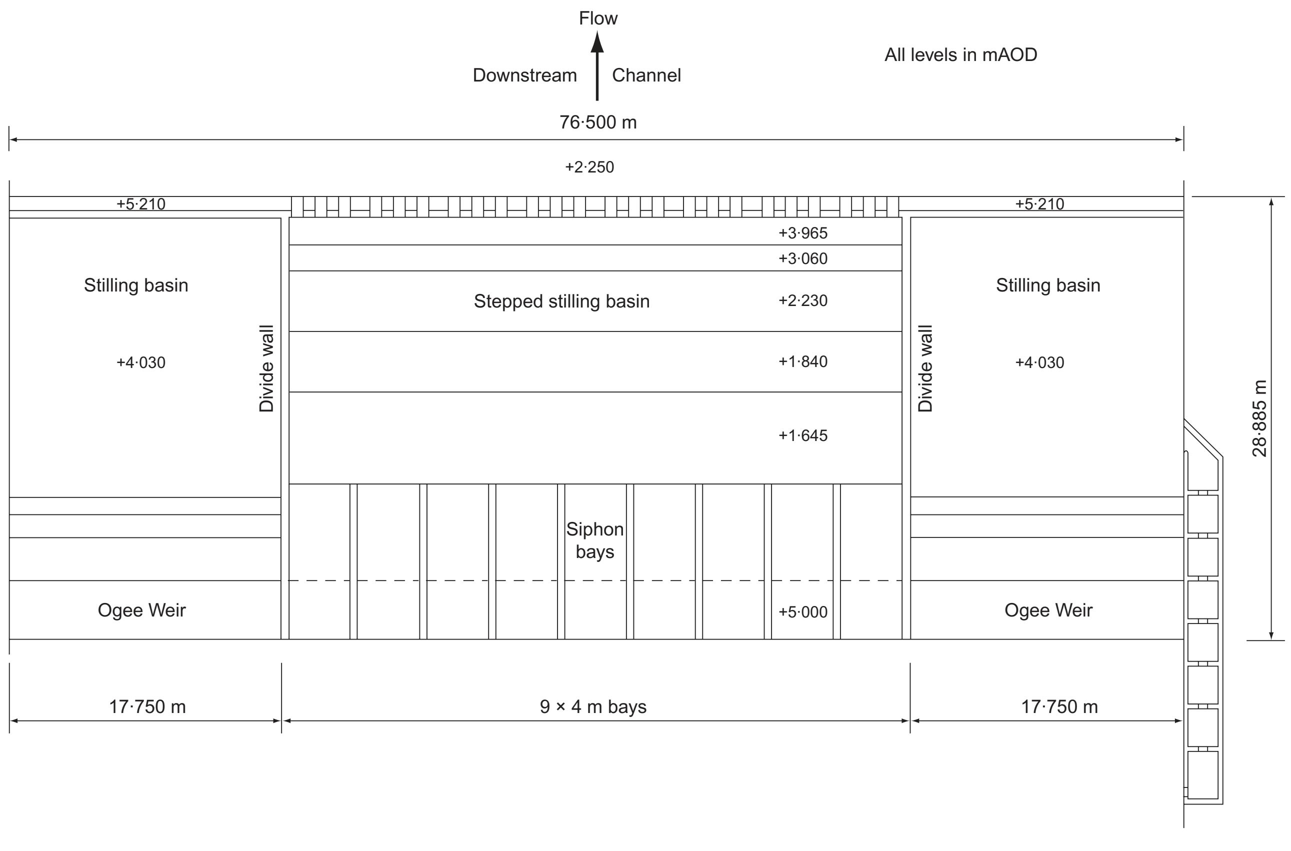

Fig. 2. Plan of siphon and stilling basin

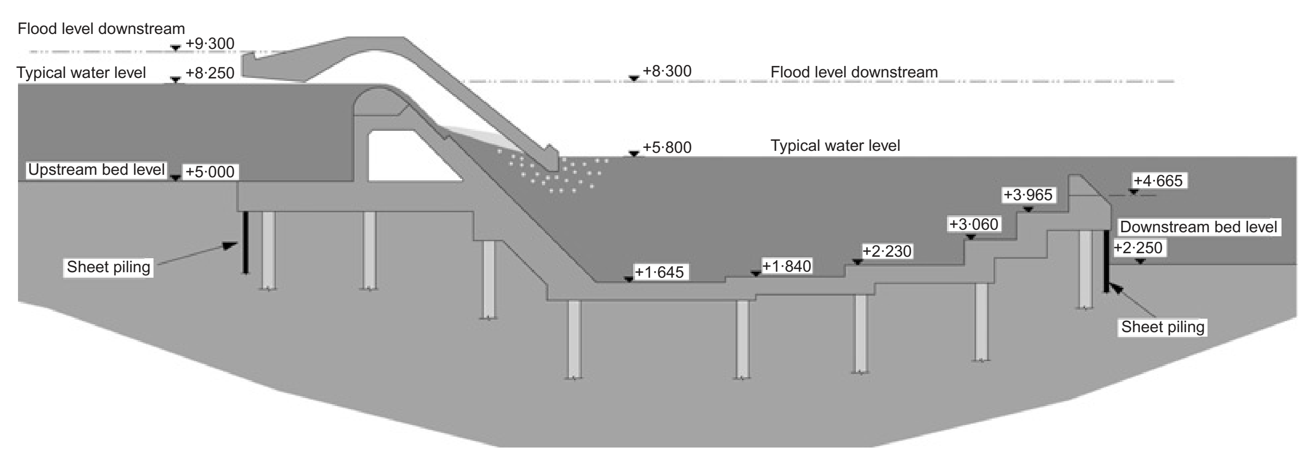

Fig. 3. Section through siphon and stilling basin

Fig. 4. Photo of vertical-slice model in operation

audible bangs and waves upstream as well as downstream in the three-bay siphon weir at Ware, attributed to air entering the siphon from downstream. The present modelling confirmed that the downstream hood must extend sufficiently for the nappe to be well drowned out under all conditions to prevent this.

At blackwater (full siphon action) and above, air entrainment does not occur. Siphon flow can then be calculated from equation (1), i.e. flow proportional to the square root of the head

$$Q = C_d BH\sqrt{(2gh)} \tag{1}$$

where Q is flow (m^3/s), C_d is coefficient of discharge, B is crest width (m), H is siphon throat depth (m) and h is head (m) across the structure (i.e. headwater–tailwater). Upstream levels then rise quite rapidly, also with an increase in downstream level. Under these conditions the ogee weirs are of particular importance with flow proportional to head to the power 3/2 (equation (2))

$$Q = C_d\ B\ h^{3/2} \tag{2}$$

Downstream tidal effects could have significant influence on siphonic action and particularly the 'priming' under some circumstances. This required modelling and design for a complex downstream tidal and surge regime which, in the extreme, could drown out the stilling basin.

Figure 5 shows the horizontal model of siphon, weir, stilling basin and channel used to optimise behaviour of the system including layout, flow mixing, control and erosion protection aspects. This led also to the design of the detailed geometry for the new channel.

A stage discharge curve (S/D) is shown in Fig. 6, extending the modelling results to 36 m total siphon width to match the required conditions and including the adjacent ogee weirs. The weir crests were set to maintain statutory water level in the Ship Canal for 'normal flow'. Note the very small increase in upstream level as flow increases from 20 to 200 cumecs, with steadily developing siphonic action. This can be compared with the curves for previous operations—the required water levels having to be controlled by progressive gate operation.

It was important to establish the impact of the proposed structure on the overall behaviour of the canal system. The information from the physical models was incorporated into a computational model (SALMON-F), and calibrated with flow and level data from the canal and River Mersey. In parallel, the Manchester Ship Canal Company was embarking on a project to automate the operation of the sluice gates adjacent to the lock

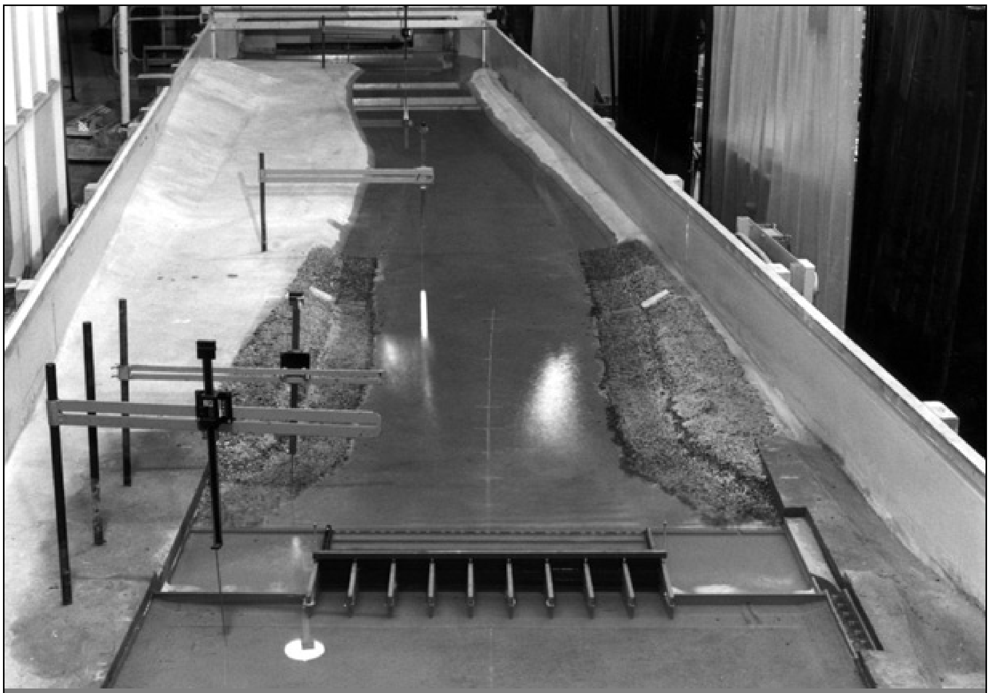

Fig. 5. Photo of plan model viewed from upstream

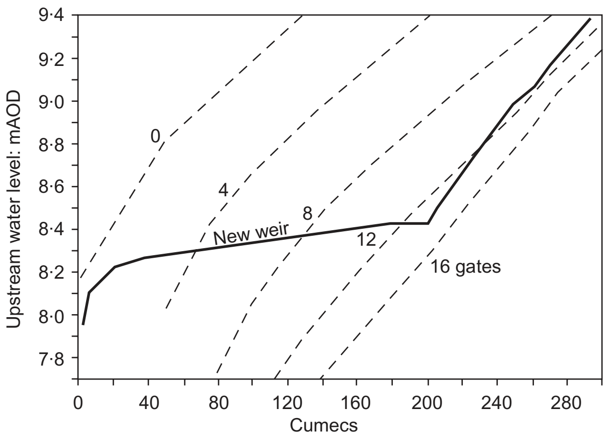

Fig. 6. Stage discharge curves for new system compared to old weir with zero—16 gates open

structures. The hydraulic studies at Woolston assisted with the automation of the control systems, particularly at Latchford Locks.

Downstream of the weir, considerable energy is dissipated with significant erosion potential. Various designs of stilling basin were modelled. The final design creates complex interactions through different flow conditions, but essentially there is always a stable centralised main flow leaving the basin without creating 'rollers'. Even in extremes, downstream velocities do not exceed 2 m/s in the centre channel and 0·8 m/s at the bed and bank. These studies enabled sizeable savings in erosion protection.

3. FISHPASS

Water quality in the Ship Canal and River Mersey Basin is being steadily improved by a wide variety of measures. Fish are now present in this stretch of the Mersey and numbers are increasing. They would not, however, have been able to pass the old gated weir. The National Rivers Authority (NRA, now part of the Environment Agency) requested, and the Manchester Ship Canal Company happily agreed to the provision of a pass for fish and eels.

Studies included hydraulic modelling to assess interaction of flows from the pass with those from the main weir system. The resultant 'pool-and-notch'-type pass will allow fish to climb some 2·5–3 m and provides an interesting feature to the works.

4. GEOTECHNICS AND GROUND CONDITIONS

The ground conditions were fairly difficult. The site lies within the Glacial Mersey Valley, where underlying rocks have been scoured out to more than 40 m depth in places. Site investigations included conventional boring, and in situ and laboratory testing. These revealed extensive loose, water-bearing silts and sands, with significant hydraulic heads. Piezocones were particularly useful for assessing the soft and permeable strata. Dense sands and glacial clay suitable for founding piles were typically at 8–10 m depth, with sandstone at 10 to >20 m. Geophysical and hydrographic surveys were carried out for the river closure works.

Stability of the channel slopes and adjacent embankments was critical, under the range of construction and permanent conditions (Fig. 7). Numerous stability analyses were carried out. Design parameters for the various soils are given in Table 5. Crucial to this were the groundwater conditions, including the effects of dewatering, 'rapid drawdown' and subsequently flooding of the new channel. Many piezometers were installed for monitoring and control during construction. The stability of the nearby lagoon embankment was already critical and strengthening measures had to be carried out prior to formation of the channel. The main works were designed to further improve this, with a toe drainage blanket and stabilising berm.

Selection and control of excavated materials for re-use in the various flood protection bunds and closure banks was the key to economic earthworks. Table 6 gives a summary of the main quantities. Some excavated material was used to raise the adjacent deposit ground bank over very weak dredgings using geotextile reinforcement to assist short-term stability—a technique successfully developed for Manchester Ship Canal dredgings elsewhere.[8]

5. WELLPOINTING AND TRIALS

Dewatering for the diversion channel was identified as a key

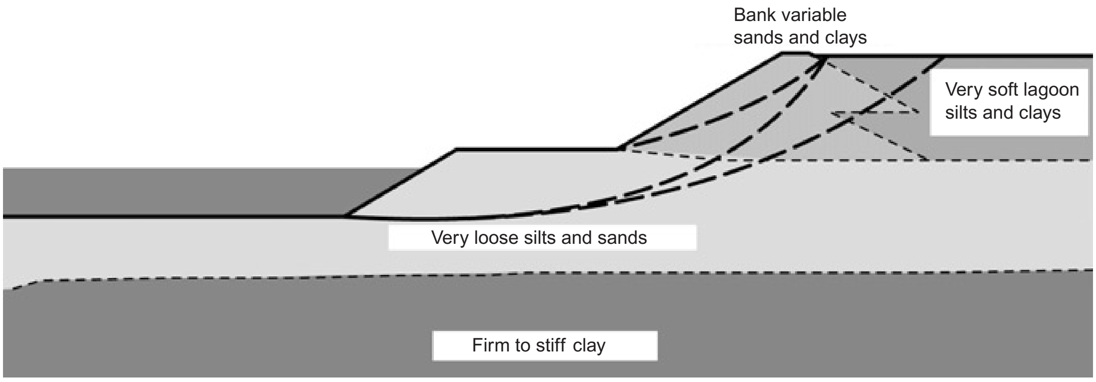

Fig. 7. Cross-section showing typical ground conditions affecting stability

Material	Density	C_u: kN/m^3	c': kN/m^2	ϕ': kN/m^2	Comments
Foundation silts and clays	18	20 = 0·25po'	0	28	Existing with consolidation
Foundation silty sands—loose	18	—	0	28	
Foundation sands—m. dense	18	—	0	32	
Dredgings (general soft silts and clays)	16	10 = 0·25po'	0	28	Existing C_u with consolidation
Existing bank materials	18	—	0	28	
Sand fill S	17	—	0	36	
General fill S-F, SF	16	—	0	32	

Table 5. Summary of soil design parameters

Excavations	Length: m	Bed: m AOD	Depth: m	Area: m^2	Volume: m^3	Sand: m^3	Gen. fill: m^3
Upstream	80	6·0	2·5	140	12 500	0	12 500
Weir and basin	25	1·0 min.	6·5	540	12 500	6500	6000
Downstream	475	2·25	5·5	330	180 000	60 000	120 000
Total	580				205 000	66 500	138 500
Fills							
Bunds							
Upstream north	110	9·8	2·0	13	1400	1400	
Upstream south	75	9·8	2·0	13	1000	1000	
Downstream north	520	8·8	1·5	9	3700	3700	
Downstream south	455	8·8	1·5	40	57 700	57 700	
W closure D/S	210	8·8	1·3	7	1400	1400	
Total	1370				65 200	65 200	
Closure bunds							
East closure	85	9·8	9	240	14 000	12 000	2000
West closure	75	8·8	6·5	160	8000	6000	2000
Raising no. 3 bank	445	22·0	5·5	83	52 000	13 000	39 000

Table 6. Summary of main earthworks quantities

risk factor. Groundwater had to be lowered from near-surface to about 6 m depth, over an area some 600 m long by 50–80 m wide. There would be considerable delays and costs if draw-downs could not be quickly established. Complex adjacent groundwater sources included the river at either end, a raised lagoon to the south and an ancient navigation canal to the north.

A wellpointing trial was instigated, with a 40 m square of wellpoints at 2 m centres, to 7 m depth operated with various pumping combinations over three months. Extensive monitoring confirmed that single lines of wellpoints on either side of the excavation were practical and economic, and draw-downs would not have significant influence outside the site boundary. The wellpoints were suitably located for the main works and handed to the contractor, so that the cost of the trial was defrayed. As a result, the difficult construction dewatering was economic and without significant problems or delays.

6. STRUCTURAL DESIGN

The weirs and stilling basin are surrounded by substantial permanent sheet pile walls, taken down to cut-off in the boulder clay, designed to also provide temporary support to the excavation during construction. Larssen 32 W sheet piles were used to meet the substantial bending moments. They were propped off the base slabs. At the crest, permanent tie-backs were taken via the reinforced concrete slabs to short anchor sheet piles behind.

Structural design of the siphon and hood was dominated by complex dynamic pressures. Model testing with transducers showed large pressure variations on both the crest and the hood, from about 3 m (30 kPa) positive head to –5 m (–50 kPa) suction, varying over microseconds. Very random behaviour was found, without scope to set up natural frequencies or patterns of oscillations on the rigid concrete structure. Computer analyses assessed the reinforced concrete under the range of operational forces. There were reports that a steel siphon weir had shaken itself to destruction (see Table 1). The analyses indicated that the natural frequency of such a structure in steel could well be within the frequencies to be expected, whereas for this concrete structure they were of a different order of magnitude.

The weir profiles required some complex curved shapes to tight tolerances (±6 mm) dictated by hydraulic requirements, with difficult upper surfaces. It was concluded that the required quality was best achieved by precast units cast inverted, designed to be fixed in place, to very tight tolerances. The system involved final shimming into exact position, then grouting up, with large bolts (M11s) taken through to the voids below. The main body of the siphon weir was therefore designed hollow to allow access for securing the crest units and also to reduce loadings (Fig. 3). Precasting was also considered for the complex shapes of the siphon structure roof. However, moment continuity was desirable for rigidity and damping against the dynamic stresses. The aesthetics of the structure were also given much attention. Fluted concrete faces were specified to mimic the sheet piling profile. Dytap panels were chosen for the siphon roof, to match nearby erosion protection.

Piling was required to support the weir and stilling basin loadings. This also proved more economical than increasing the dead-weight to withstand uplift. Conventional 275 mm square precast concrete piles were used, with 60 tonne working loads, driven to set at around 10 m below the base of the stilling basin and verified by static and dynamic testing.

7. CONSTRUCTION

The works were carried out under a conventional ICE 6th Edition Contract for a tender sum of around £2m with a contract period of 62 weeks. Tables 7 and 8 summarise the costs and programme, respectively, for the main items of work. Fig. 8 shows the works during construction in the summer of 1993, with the weir and stilling basin in dewatered excavation around 6 m deep and the newly excavated channel a few months before flooding. In the foreground is the upstream River Mersey, guard weir and the old Woolston Weir evidenced by turbulence downstream. The Manchester Ship Canal (top-left corner) runs nearly parallel to the Mersey.

	Cost: £k
Site investigations and studies	80
Preliminary works, drainage and dewatering trial	50
Site preparation and prelims	50
Wellpoint dewatering.	180
Earthworks 200 000 m^3 (including bunds, disposal and re-use)	570
Deposit ground no. 3 general fill	130
Stilling basin concrete	300
Weirs concrete	260
Piling	40
Sheet piling	280
Temporary works including dewatering	100
Erosion protection	220
Monitoring	30
Drainage	40
Roads, footpath, fencing, services, etc.	20
Miscellaneous/other	90
Total	£2·1m

Table 7. Summary of main costs

Although before the advent of CDM, considerable attention was given to health and safety in design as well as construction. The client had extensive in-house experience as owner and operator of the many Ship Canal structures and also as the navigation authority. Risks were designed out where possible. In particular, the siphon structure avoids the need for the inherently risky manual operations and maintenance of gates. Construction in a dewatered cut avoided most of the risks of over-water working. The weir was designed with as clean and simple operations as

Task	Commenced	Duration
Feasibility studies	1989–90	1 year
Consultations	1990	4 years
Preliminary designs	February 1991	5 months
Site investigations	March 1991	3 months
Hydraulic physical and computer modelling	March 1991	18 months
Wellpoint trials	May 1992	8 weeks
Detailed design	March 1992	8 months
Tenders issued	18th December 1992	6 weeks
Construction programme	March 1993 to May 1994	62 weeks
Preparatory earthworks mounds etc.	22nd March	4 weeks
Sheet piling	19th April	5 weeks
Wellpointing structure	17th May	3 weeks
D/S channel wellpointing, rip/rap, etc.	17th May	9 weeks
Guard weir refurbishment, footbridge	16th June	4 weeks
Precast piling	18th June	4 weeks
Central stilling basin slab	27th July	7 weeks
Fishpass	1st August	8 weeks
Central stilling basin slope	4th August	6 weeks
N/S walls/basins	6th September	5 weeks
U/S channel wellpoints rip/rap etc.	8th September	9 weeks
Weir precast blocks	19th October	2 weeks
Siphon hood	22nd October	12 weeks
Planting	1st November	3 weeks
Upstream and downstream breakthroughs	4th May 1994	8 weeks

Table 8. Main design and construction activities

Fig. 8. Aerial view of the works during construction (from upstream)

hydraulic requirements allowed. Considerable emphasis was placed on safety during the construction stage and the contractor's procedures were commendable.

Figures 9–12 show the siphon during construction and operation. Fig. 9 gives an impression of the massive downstream face, prior to the hood being formed, with some precast crest units in place. The concreting sequence was quite involved, with nine similar bays for the siphon weir. The critical path ran through these activities, which had to be well advanced before water could be allowed into the new channel adjacent to the structure. Logistics of the steel-fixing, formwork, pours and striking times for the siphons, plus many other sections of weir, stilling basin and fish-pass proved quite demanding. Reinforcement was heavy in places, particularly in the more difficult areas of siphon walls and roof. The construction programme involved over 100 pours up to 140 m^3, many of complex shapes, with a total of over 5000 m^3 of concrete.

A high-quality, geotextile-formed (Zemdrain) concrete finish was specified for the weir concrete, giving decreased water–cement ratio and improved durability. The awkward curved profiles were novel, but after some experimentation with trial panels (then used as quality standards) an impressive concrete surface quality was achieved. The step in the lower face was made of stainless steel, in view of the fairly harsh environment and difficulty of replacement.

In the downstream channel, erosion protection was provided by vegetation where possible, including shallow water margins formed just below water level, planted with reeds. Rip-rap, where necessary, was placed on geotextiles, typically 2 mm thick, 600 g/m^2. In erosion-sensitive areas reinforced grass was used, pre-sown close to operating water levels. Adjacent to the weir, 150 mm thick Dytap panels were specified, consisting of stone in concrete blocks, 410 kg/m^2, with continuous stainless steel cable ties, formed into flexible articulated panels. A reddish-brown colouration was chosen to match the sandstone of the Mersey Valley. The downstream channel was broken through to the existing river in October 1993 and the channel left to 'bed down' over winter.

8. BREAKTHROUGH AND OPERATIONS

In early summer of 1994 the upstream channel was broken through. Mersey flows were controlled over the next year by operation of the old weir and guard weir to allow the new system to settle and vegetation to become established on the banks, before running the siphon up to blackwater flows.

Fig. 9. Siphon during construction, viewed from stilling basin before formation of hood

Fig. 10. Fishpass, construction near complete

The weir has now been operating satisfactorily for over five years and gives a good match with design expectations. As expected, there is some 'lapping' noise from the upstream openings, reflecting the prime/break cycles, but this is not excessive and is well screened. There are also perceptible 'reflection' waves travelling upstream from the openings. Each bay acts slightly differently in this, due to minor construction and natural variations. With a wind shear gradient on the upstream surface the higher side tends to prime first. These details are considered desirable as they give interference and damping of the pressure effects.

9. ENVIRONMENTAL AND COMMUNITY ASPECTS

The site lies in a pleasant local amenity area used by the local population for walking and bird watching, with a nearby SSSI managed by a conservation group. The Mersey Valley and river water quality are being steadily improved; environmental considerations have featured accordingly. The new weir and fishpass provide interesting features. Landscaping bunds were formed at the start of the works to screen construction from nearby housing. An 'environmental channel' approach^9 was taken to design, with an ancient meandering channel rehabilitated to create an island for wildlife, areas of wetlands and water margins planted with reeds.

The works necessarily involved consultation with the NRA, the local authority and the community generally. A noise assessment was carried out with consultations before construction, with suitable controls on piling and some other operations. The client, contractor and consultant cooperated in keeping the local community well informed, including a display and explanatory video, resulting in good relationships throughout the works.

A wide range of planting was specified, including screening between footpaths and wildlife/bird-watching areas and elsewhere wildflower mixes, designed to promote species diversity. The final scheme has created a pleasant amenity area with space for nature and leisure, in harmony with important flood control works.

10. CONCLUSIONS

The new Woolston Weir provides modern, effective flood control measures on the Manchester Ship Canal/Upper River Mersey system. The weir automatically controls flows of up to 140 cumecs, with less than a 200 mm rise in upstream water level. Higher flows, up to 700 cumecs or more, are passed in combination with the adjacent Ship Canal sluices, automated by telemetry, tuned in accordance with the computer and physical modelling.

The scheme has proved economic and effective and is a tribute to the many who worked hard on its design and construction. It was constructed on time and within budget and entailed

Fig. 11. View of weir from the south, near complete. Upstream erosion protection in progress

Fig. 12. Weir in operation

interesting and innovative work for all the main parties involved.

The weir is performing well and in line with the design expectations. It is also an attractive structure, blending well with the area and contributing as a feature.

11. ACKNOWLEDGEMENTS

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