The Bristol regional foul water drainage scheme

P. H. STEEL

Mr P. H. Steel

Some lessons have been learnt from the commissioning of the first stages of the scheme and one of the advantages of development in stages is that it is possible to effect improvements in the light of experience. Trouble has been caused at the works by fibrous material blocking pumps and other equipment, despite the installation of comminutors. Consideration is now being given to the installation of screens after the comminutors, with apertures wide enough to permit comminuted solids to pass. It is hoped by this arrangement to intercept a large proportion of the shredded fibrous content without retaining faecal or similar material. The screenings would then be incinerated.

69. Another aspect deserving more attention is the maintenance of plant without closing down the works. It has been necessary to empty digestion tanks to improve mixing arrangements and this has proved to be a difficult and lengthy operation. The next group of digestion tanks to be constructed will therefore include a number of improvements but the design of the tanks has otherwise proved to be satisfactory.

70. Since providing a screening chamber at the Black Rocks Quarry Temporary Pumping Station (§ 58) operation has been generally satisfactory. The screenings are lifted to a level above the soffit of the main trunk sewer and are flushed into it, thus by-passing the main pumps.

71. Improvement in the condition of the River Avon has already become noticeable and in 1967 only 88 tons of chlorine were used instead of the 200–300 tons previously required.

Mr R. G. Armytage, A. E. Farr, Ltd

A. E. Farr, Ltd were the main contractors on the tunnel works. These tunnels were based on target contracts. The general basis of the target contract is that tenders are invited in the normal way with a bill of quantities. The tenders are received and the contract is let to the lowest tender subject to the usual proviso. The figure accepted is then called the target figure. The contractor is paid the costs plus a fee. If the costs are less or more than the target figure the contractor is paid a bonus or suffers a loss. This saving or loss is shared by the employer and contractor in a proportion set out in the contract.

73. The benefit to the Corporation was that there were several risks involved which could be foreseen but not estimated. For example, the effect of blasting upon property. In the case of a fixed price contract a tender figure would have been put in to allow for these unknown quantities and the tender sum would have been larger. If these conditions did not arise then there would be a saving to the Corporation.

74. Although there is a chance that the contractor may lose, in the same way as with any other contract, he has a bonus to aim for, and the contractor and the engineer are working in the same interest. This arrangement leads to a very harmonious relationship between the employer and the contractor.

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75. In the siphon upflow shaft precast units were adopted for the lining. This was decided at a site meeting. The water in the lower part of the shaft was such that the cast in situ lining which was originally intended would not have been feasible and might have been a very costly operation.

76. The units were 3 ft 4 in. high, so that 6 units gave a 20 ft lift, which was the spacing for the landings. Eight units generally formed a complete circle. The units weighed about 2 tons each.

77. They were bedded when level and in position, determined by plumb bob, and the back of the units was filled in with 2-3 in. stones and sand/cement grout, maintaining a colloidal mixture on the top. The grouting kept the water to the rock face and the shaft itself was virtually sealed off. This process was repeated up the shaft at the rate of about a lift (3 ft 4 in.) a day. This was quite comparable with in situ lining. The cost was perhaps a little more than in situ lining, but in the circumstances much cheaper than the original plan.

Mr J. M. Haseldine, John Taylor & Sons

My firm was engaged by the Bristol Corporation to design the aeration plant to produce the water supply for the Imperial Smelting Corporation. The Imperial Smelting Corporation require an effluent of Royal Commission Standard namely, 30 ppm of suspended solids and 20 ppm BOD. The effluent is used as a water supply and the plant operates at a uniform rate of flow. This is rare in what is essentially a sewage treatment process.

79. The Imperial Smelting Corporation require 5 million gallons of water a day. This is a small proportion of the dry weather flow coming through to the main primary treatment works; the water is bled off from the outlet from the primary sedimentation tanks at a uniform rate of flow throughout the day, and therefore there is no need to cater for peak rates of flow which tend to wash the sludge out or reduce the quantity of activated sludge in the aeration unit and concentrate it in the sedimentation unit.

80. The installation is a surface aeration plant with high intensity cones and two independent channels with a total capacity of 1 million gallons, giving 4.8 h retention. There are six aeration pockets in each channel and each cone is driven by its own 25 hp electric motor with its own reduction gear, thus minimizing the effect of a motor failure.

81. This gives a total installed horse power of 300 and it is expected that under normal running 200 hp will be absorbed. A spare motor and gear box are kept in store in case of breakdown.

82. The final sedimentation tanks are circular with a sloping floor and centre sludge draw-off. They are 85 ft in diameter, with a capacity of 673 000 gallons, equivalent to 3.2 h retention. This gives an upward velocity of just under 3 ft/h and a weir overflow rate of 18 720 gal/day per ft of weir. The return sludge is lifted by two Archimedian screw-type pumps. The total output of 7.5 mgd is $1\frac{1}{2}$ times the flow rate. There is also a chlorination plant.

83. The capacity of the units is considerably less than a normal sewage treatment plant which has to be designed to take peak flows of at least three times the dry weather flow, but it was not reduced as much as was theoretically possible since the maintenance of the standard of the effluent in this case was considered very important.

84. The plant was producing a Royal Commission effluent 26 months after the date that we were instructed to prepare the designs and the construction period was just over a year. The cost was between £200 000 and £250 000. The plant has now been producing for nine months 5 mgd of effluent at a standard considerably better than that required. This is largely due to the incoming sewage at present containing an undue proportion of infiltration water, so that the effluent from the primary settlement tanks has a BOD well below 100.

Mr M. G. Healey, London Borough of Croydon

In § 39 it is stated that the main pumping station was conceived as being fully automatic but in his introduction Mr Steel mentioned a problem with rag at pumping stations. Will the Author tell us if automatic operation has been achieved in practice; also if the comminutors have given adequate protection to the variable speed pumps? The fixed speed pumps are not easy of access, being suspended in the wet wells and I would like to know how they are maintained. How often are the wet wells drained down and is grit or debris a problem in these? What is the average spacing of manholes or access points on the main trunk sewers?

86. In § 58 the difficulties at Black Rocks Quarry are mentioned and I should like to know more about the specification of the pumps. Are these in fact true sewage pumps? What are their speeds and what size spheres will they pass? If the Author had an opportunity of redesigning the scheme would he use a different type of pump, perhaps centrifugal pump in this instance, would he install screens or would he do both?

87. The sewage works appear to be operating well. May we know a little more about the analyses being obtained, particularly of the primary treatment works? What is the unit cost of electricity at this stage?

88. This scheme incorporated several novel features and I would like to know how the bubble gun is functioning in the digestion plant and how well the rotating inlet of the primary tanks is working.

Mr M. F. G. Archer, Howard Humphreys & Sons

Bristol has only recently benefited by a modern system of sewage disposal. There are many good reasons for this. In the early days of Bristol's existence the river system on which it was situated was capable of receiving, without nuisance the foul run-off which existed at that time. More recent plans were shelved due to the Second World War. Since then a certain amount was done to alleviate conditions but the ultimate solution was never finally tackled, and it would be interesting to know the factors which influenced this pattern of progress.

90. Bearing in mind the state in which the rivers of the area appear to have been, the effects of the present scheme are dramatic—for example—the immediate improvement in the River Frome (§ 15). No doubt many complaints were received and it would be interesting to know if an equal number of letters of congratulation and thanks were received when the river was restored to a healthy condition.

91. It is praiseworthy to note that the areas outside the Bristol City boundary were not forgotten and that the planning has been carried out on a regional basis. Paragraph 12 gives the impression that this policy nearly foundered in respect of the Frome Valley area, where the greater capital cost of linking with Bristol was almost the deciding factor until the Bristol Avon River Board, very rightly stressed the overall advantage of eliminating the various individual treatment works in the area. Apart from the reason given by the River Board one can think of others. One is that the operation of smaller works is becoming more difficult due to the problem of recruiting manpower. Also, no doubt in due course at these works it would have been necessary to add extensive tertiary treatment to raise the standard of effluent, and sludge disposal would be an ever-increasing problem. Lastly, the opportunity of re-using the effluent from these small works may have been lost.

92. Adjoining authorities are also due for some praise for their part in this regional scheme. For example, in addition to its proportionate contribution to the capital cost of one of the Bristol trunk sewers, the Kingswood and Warmley Joint Sewerage Committee is currently spending some £800 000 on the extension of this trunk sewer into its own area—a distance of some $5\frac{1}{2}$ miles.

93. The capacity of all sewers, including the main trunk sewer, appears to have been based on a factor of six times the dry weather flow. This is common practice

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but since the peak dry weather flows in the larger trunk sewers are not likely to reach more than 1.5 times the average dry weather flow, would Mr Steel please give his views on the logic of maintaining the factor of six so far downstream in a scheme with such long times of concentration? The answer is probably that it is based on the river authority's requirements in respect of overflow settings. Could Mr Steel also say what peak dry weather flows have been reaching the main pumping station, expressed as a multiple of the average dry weather flow?

94. Figure 2 shows that the main trunk sewer changes from a gradient of 1 in 1667 to 1 in 3500 downstream. Is this because of the drawdown effect?

95. Do the 3 ft and 5 ft concrete pipes of the main inverted siphon have Ogee joints? If so, was a sealer included in the joint? There is a substantial concrete surround but this would not necessarily ensure watertightness as indifferent placing and compaction and shrinkage cracking could permit leakage. Such leakage did occur in one place in the Kingswood and Warmley trunk sewer where Ogee jointed pipes in heading with a concrete surround had been used, necessitating grouting. This was successful. A joint sealer had in fact been used at all joints but even this did not prevent leakage in this one particular spot where there was a large amount of water.

96. The idea of allowing groundwater to drain into the stormleg of the siphon is very ingenious. Is the amount controlled, and if not would not there be danger of excessive amounts of groundwater entering, especially if there is a breakthrough from a fissure at some later date?

97. The rising pipes of the siphon are vertical and very deep. With velocities of 4–5 ft/s there is a likelihood of the heavier particles not being carried up the pipe. If this siphon has been in use, would Mr Steel please say if any difficulties have been experienced with settlement?

98. What is the spacing of manholes and what percentage of the cost of the trunk sewers do these represent? What methods of ventilation are used, and has any system of odour control, such as activated carbon filters, been used in conjunction with any ventilators which have been installed?

99. In § 57 reference is made to the Clifton high level sewer, which ramps down some 150 ft at a gradient of 1 in 2. It would be of interest to know more details of this such as its proportions, material, and the extent of erosion in it; also how the energy of the falling sewage is dealt with. It would also be interesting to hear of the condition of the old sewers in Bristol.

100. I understand that vortex drops have been considered on this scheme. Have any been constructed and operated, if so, were there any construction difficulties and do they operate successfully?

101. I understand that if the product of part of a sewage treatment works is sold then that part becomes a factory and is subject to the Factories Act. Presumably if the effluent is sold then the whole works becomes a factory for the purpose of the Act and therefore comes within the jurisdiction of the Factories Inspector. This could have important repercussions and I should be pleased if Mr Steel would comment on this.

Mr E. W. Bates, A. E. Farr, Ltd

I endorse the remarks made by Mr Armytage concerning target based contracts. On six target contracts I have known a very happy relationship to exist between contractor and engineer; such a relationship is seldom found on a normal contract.

103. Turning to the construction of the sewage treatment works and the industrial water installation Fig. 17 shows the detritus channels. There are eight channels 125 ft long constructed with steel shutters 25 ft long. The canopy was precast, erected and concreted into the main wall.

104. Figure 18 shows one of the six settlement tanks. The method of construction used was to construct the core and the leg containing the 36 in. cast-iron entry

Fig. 17. Bristol sewage treatment works constant velocity detritus channels

Fig. 18. Construction of the 150 ft dia. radial flow sedimentation tanks. Concrete sub base and pile reinforcement before floor construction

Fig. 19. Sedimentation tank floor and wall construction showing the wall shutter

Fig. 20. Sedimentation tank approaching completion

pipe in a sheet piled cofferdam. The vertical legs supporting the dam were precast, were positioned by means of a jig, and the slab cast on top. This view shows the excavation of the tank almost completed. It was carried out with a drag line and a 3 in. blinding concrete was placed over the whole site.

105. Figure 19 shows the greater part of the floor completed, the first of the wall lifts concreted, and the travelling shutter being moved into position for the second pour.

106. Figure 20 shows the near-completed tank. A section of precast weir and an in situ make-up piece forming the outlet have yet to be constructed.

107. The tank floor was 18 in. thick, doubly reinforced, and provided with a smooth surface in one operation. This was done using power floats. The fall to the centre was 6°. This compared with a fall to the centre of about 20° on the secondary treatment tanks where the floor was 15 in. thick. This was constructed with a tamped finish and followed by a 2 in. thick screed of $\frac{3}{4}$ in. concrete, with a light mesh reinforcement.

108. I should be glad to have your observations on the merits of these two schemes.

109. The weirs were painted with an epoxy resin paint. I should like to know how it has withstood the test of nine months' wear

Mr D. H. Hughes, J. D. & D. M. Watson

Mr Steel had explained that initially a brick lining was provided for the lower part of the walls and the invert in the main tunnel. Later for the invert only, and subsequently no brick lining was provided at all. He gave as the reason for eliminating the lining that the bricks were being pushed in by water pressure from behind the concrete. I should like to know if this pressure water is, in fact, being kept out by not having the brick work. I assume this is not so and that it must still find its way in from behind the concrete. However, I should also like to question the wisdom of having a lining only of concrete.

111. The flow velocities quoted are a maximum of 4 ft/s and a minimum of $2\frac{1}{2}$ ft/s. This suggests that there is no danger of erosion from the movement of sewage through this large tunnel, so there would not seem to be a need for a brick lining on this account.

112. However, I would think there is a need for protecting the concrete above the water line, where attack on the concrete is usually most prevalent. This does not appear to have been provided even in the original design. Was this considered? Could Mr Steel say what type of concrete has been used and whether any surface treatment has been given as a protection against corrosive attack?

113. The tradition of providing a Class A engineering brickwork lining to structures of this sort purely as protection against the effect of septic sewage gases is very expensive and it would be better perhaps to be able to coat the concrete with some membrane to achieve the same effect.

114. Was any provision made in the rising mains for measurement of flow from the pumps, and has any check been made on whether the main pumps do, in fact, pump the quantities for which they are designed?

Mr P. C. Edwards, W. S. Atkins & Partners

It is interesting to notice that there have been changes of design and re-examinations of assumptions, especially with regard to maintenance of pumping stations. I think that re-examination of design assumptions is overdue for sewage treatment works plant. It seems to take a long time to get some of this plant to work, possibly because initial planning and design is based on standard items sold by commercial firms and there is not much money for development.

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116. I should like to ask Mr Steel why water retaining code requirements were necessary for an outfall. There is room for improvement on outfall designs, too; I am pleased to see that Bristol are studying the effects of the outfall.

117. In three instances major changes in design were found to be necessary, particularly during the construction of the tunnels. It is commendable when engineers and contractors are prepared to agree quickly on a change in the design when difficulties are encountered. It would appear that such changes, often unpopular or impossible on other types of civil engineering contracts, can be made much more easily under a target contract.

Mr D. A. H. Everett, London Borough of Croydon

From § 25 the design velocities seem to be low, the self-cleansing velocities only occurring during peak daily flows. This suggests that deposition occurs over much of the day, and may not be flushed away at this $1\frac{1}{2}$ dwf rate of $2\frac{1}{2}$ ft/s. Have there been any adverse effects due to the design?

119. What arrangements are made for cleaning the siphon (§ 43), for emptying it, and what safety precautions are provided? It appears that there might be some risk to the maintenance men on removal of the covers both from gas and possibly flooding. There is no indication in the Paper as to how the contents of the siphon are first removed.

120. Did Mr Steel consider mechanical aids to maintenance, and how is the accumulated silt removed from the bottom of the shaft?

121. In view of the very high vertical leg and the velocities quoted of only 4 or 5 ft/s, there could be substantial deposition at the foot of the leg. Is there a routine for cleaning this siphon at fortnightly or monthly intervals and has it been necessary to review this?

122. Could Mr Steel elaborate on the legal and financial implications of the industrial water installation?

123. The City Council has a statutory liability to treat sewage to at least the primary stage; they are now making a charge for this to the industrial user. Croydon have for 30 years provided effluent to the CEGB free of charge. Originally the Electricity Board was the local authority's electricity undertaking, and this effluent was provided free by the Sewage Works Committee. In the early days, we were providing a few hundred thousand gallons a day but for the last 16 years they have been taking 3 mgd.

Mr J. T. Calvert, Chairman

In § 63, Mr Steel says that his salary costs were 3% of the cost of the works but to this I presume overhead and supervisory charges should be added. I think that this is in line and possibly higher than consulting engineers' salary costs. If it is merely the salaries of people working on the job then it does not compete with the consulting engineer.

125. I think that a minimum velocity of 4 ft is rather high and I feel sure it would be safe to lay sewers with velocities flowing full of the order of $2\frac{1}{2}$ –3 ft/s. A sewer carrying six times the dry weather flow with a velocity of 4 ft/s, when carrying $1\frac{1}{2}$ times the dry weather flow, namely a quarter of the volumetric would have a velocity of between 3 and $3\frac{1}{2}$ ft/s which is greater than is necessary to keep them clean.

126. Mr Steel (§ 46) says that experiments are to be carried out on the five siphons in the system. Has any progress been made with these experiments, and if so are they successful? I would suspect that too much gas would be released to make a siphon really reliable under all conditions.

Written contributions:

Mr M. Lansdell, Torbay CBC

The scheme is indeed a bold one and all connected with its design and construction are to be congratulated.

128. Two of the storm sewage overflows the Author mentions are described in Mr B. Smisson's paper read and discussed at the symposium on storm sewage overflows in May of last year. It is unfortunate that this design of vortex overflow was not tested by the hydraulics research laboratory. I think that this fact has not been fully appreciated by designers.

129. I think that the main inverted siphon in this scheme will prove difficult to muck out by the method stated on account of the difficulty in ventilating the 36 in. siphon in which men will have to work, owing to the release of methane and hydrogen sulphide when the silt is stirred up. Presumably a submersible pump would be lowered down the siphon to be emptied. I would have suggested the provision of a sump at the base of the upflow shaft and in vertical alignment with it. An 'orange-peel' type grab could be lowered down the shaft through the sewage to dredge the sump into which material would be washed during periods of high flow. This would avoid diverting the dry weather flow.

130. The provision of a coarse screen (9 in.-12 in. centres) in the inlet chamber of the siphons would catch contractors' plant and materials and even personnel which get washed down by sudden rainfall during maintenance operations.

131. I was interested to read about true siphons for sewage and shall be pleased to hear how sewage balances under 28 ft wg of vacuum.

Mr A. W. Shilston, Consulting Engineer

Would the Author say which of the classical discharge formulae was used to determine the sizes of the sewers in this regional scheme and whether the choice was a preference based on past custom in Bristol or otherwise?

133. Could the range of the seasonal subsoil water movements under the rising main and the effluent culvert be stated: also whether artesian and tidal influences were observed? I am interested in the presence of peat in the sub-soil (Fig. 2) and would like to ask Mr Steel whether normal ground water movements or the temporary effects of sub-soil dewatering during construction gave rise to ground surface movements under the rising main. If so was that linked in the Author's mind with the behaviour of the peat?

134. By inference the Author approves of target contracts. This is reassuring because it is a form of contract which deserves to be more widely used. One gains the vague impression from hearing of other instances in which this form of contract has been adopted that the experiences were far from being happy ones.

135. Could the Author contrast the staff requirements called for to administer a target contract with a normal measure and value contract? Was the City Treasurer continuously involved in the checking of wages and invoices or was this done by the Resident Engineer's staff? Some remarks on the 'office' and audit side of the contract administration would be of value.

136. Pooling of ideas was understood to be an integral part of the process. How is the pricing datum to support the target price defined to allow variations to be agreed and authorized thereby putting the target up or bringing it down as the case may be? Some comments on arrangements made for the purchase and disposal of plant and joint insurances would also be helpful.

137. With the experience gained over several years in the tunnel driving one would expect that increasing efficiency and perhaps greater mechanization would partly offset the usual inflationary cost spiral. Was such a trend discernible in the labour/plant relationship?

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138. Could some indication be given of the tunnel costs so that overall price per cu. yd of rock blasted could be derived? Reference to the blasting and mucking sequences eventually established and the explosive requirements would also be of interest.

139. Finally had operating experiences to date at the sewage treatment works indicated any disadvantages in the choice of primary sedimentation tanks of 150 ft dia?

Mr P. H. Steel

I must first thank all those who have contributed to the discussion and I propose to reply in the order in which topics appear in the Paper.

141. Mr Archer commented on the delay in taking action on the various schemes proposed during the last 100 years. One of the principal reasons was connected with development of land at Avonmouth for dock purposes, in particular since the turn of the century. Early schemes depended on using land possibly required for dock extensions and it was not until the thirties that the present extent of the port was defined. World War II intervened and immediately afterwards serious flooding problems required priority treatment. The improvement in the condition of the rivers has not gone unnoticed by the public and the reappearance of fish is occasionally commented on in the press. It is not yet possible to assess peak flows in the system owing to the fact that the main trunk sewer is used at present as a tank sewer and pumping is carried out to suit generating station preferences and to ensure that the industrial water plant always has enough flow.

142. The use of the factor of six times the dry weather flow in sewer design was to give as great a margin as could be justified to allow for future increases in flow. An increase in dry weather flow of 50% would still leave a capacity of four times dwf in the system, thus ensuring adequacy for many years.

143. The main trunk sewer gradient changes from 1 in 1667 to 1 in 3500 further downstream purely for the physical reasons of passing over a storm culvert at the upper end and under the River Trym at the change point. Drawdown was taken into account and the backwater curve was calculated to give the overflow weir level at the upstream end of the steeper section.

144. In reply to Mr Shilston's query about flow formulae, the brick lined portions of the sewers were designed using Barne's formula for hard, well pointed brick culverts:

$$v = 92.19m^{0.602}i^{0.486}$$

145. The concrete lined culverts were based on Manning's formula:

$$v = \frac{1.486}{n} m^{2/3} i^{1/2} \text{ using } n = 0.012$$

146. Recently, the Hydraulic Research Station flow tables based on the Colebrook White formula have been used.

147. Concerning subsoil water levels in the Avonmouth marsh area, only a small variation occurs seasonally, 2-3 ft. Tidal effect was only noticeable near the outfall, almost entirely due to seepage through recent filling used in land reclamation. The subsoil is substantially waterproof and dewatering of excavations did not affect adjacent areas. The peat is in patches occurring at different levels, often 15-20 ft below ground level and is usually stronger than the very weak alluvium occurring above and below.

148. Mr Edwards queried the use of water retaining code requirements for the outfall. This was done to achieve durability in an exposed position by restricting steel stresses, providing a reasonably generous cover to reinforcement and a good thickness of concrete.

149. Mr Healey refers to the main pumping station which has been generally satisfactory in operation. The comminutors effectively protect the 33 in. dia. mixed flow variable speed pumps which have required no repair except the replacement of

gland packings. The variable speed motors have, however, required rewiring due to overheating, the cost being recovered through insurance. In time of storm excessive quantities of rag have arrived and as the screen rakings are flushed to the comminutors, cases have arisen where these have been overloaded and blocked. This trouble with rag may be due to the relatively low dry weather flow received at present which may result in rags being stranded and flushed down in time of storm. It is hoped that as flow increases, this problem will disappear.

150. It has not been necessary to empty sumps and no maintenance has been required on the suspended pumps. Without doubt sludge and grit accumulate in the wells but when a pump is run for a few hours the accumulations are scoured away.

151. Concerning the main sewers, as a general rule manhole spacing is approximately 100 times the sewer diameter. However, if the sewer is very deep the spacing is increased on the assumption that a very deep manhole is of little use for access. An extreme example is the 8 ft x 8 ft 3 in. southern interceptor upstream of the main inverted siphon. In a length of 1 mile there is only one intermediate shaft. The sewer is up to 300 ft in depth and most of the ground surface is heavily wooded, rocky and inaccessible. The one shaft provided is alongside a footpath in the steep-sided Nightingale Valley at which the depth reduced to 60 ft. It is ruled that any working parties must be equipped with breathing apparatus in these sewers.

152. The manholes cost approximately 6% of the main sewers.

153. Ventilation of the main sewers is provided at all pumping stations and manholes where no offence will be caused. Branch sewers are provided with ventilating columns at the upper ends and house connexions are not required to have interceptors. The situation is kept under review and further measures may be necessary in the light of experience.

154. Opinions appear to differ on self-cleansing velocities, Mr Everett considering the ones adopted too low and Mr Calvert too high. It has not yet been possible to fully check whether deposition of solids will occur because present flows are much below the design flows. As previously mentioned the main trunk sewer has, in dry weather, been used as a tank sewer, being substantially emptied at intervals. An inspection after one such emptying did not reveal any deposition of silt but the increase in sludge, grit and rag arriving at the sewage treatment works in time of storm indicates that under present operating conditions, some deposition is taking place. As dry weather flows will increase as the scheme proceeds, free flow conditions can be operated at all times and it will be possible to verify whether or not self-cleansing conditions are present. Experience elsewhere in Bristol indicates that the velocities used in design will be satisfactory.

155. Mr Archer raised the question of the condition of the old brick sewers constructed a century ago. These have withstood the corrosive environment remarkably well, re-pointing often being the only repair required. In some cases new pre-cast concrete inverts have been provided where erosion of the brickwork was marked. The Clifton high level sewer ramp was recently inspected after 113 years' service. This sewer drops about 150 ft in level with portions at a gradient of 1 in 2. The size is 48 in. dia. and construction is 9 in. brickwork. The upper lengths were in very good condition with only some joint erosion but towards the bottom severe erosion had occurred and repairs had obviously been carried out. A portion had been replaced with concrete pipes, probably 20 years ago and since then erosion of the pipes had occurred to a depth of about 1½ in. The ramp now only serves as a storm sewage overflow sewer and after repair should last many years in that role.

156. The durability of the old brick sewers was the reason why brick lining was originally included in the trunk sewer invert and sides to above dry weather flow level, where, as Mr Hughes states, corrosion is most liable to happen through the action of sulphate reducing bacteria. A number of considerations led to the abandoning of the brick lining:

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- (a) a thick concrete lining has more strength and stability to resist external pressures than a thin brick skin;
- (b) erosion or corrosion of joints would involve a very difficult task of repair because of the large flow involved. Most of the old sewers requiring repair were combined and dry weather flow was manageable;
- (c) the first sign of trouble would probably be the arrival of bricks at the main pumping station or even blockage of the main sewers due to material forming dams with displaced bricks;
- (d) the main inverted siphon was considered particularly vulnerable in the event of bricks being displaced;
- (e) corrosion of concrete could proceed at a slow rate for a very long time without causing difficulties;
- (f) self-cleansing velocities in ventilated sewers should keep the sewage in a fresh condition and so minimize the formation of hydrogen sulphide;
- (g) omission of the brickwork was obviously a considerable economy.

157. Tunnel construction details requested by Mr Shilston are as follows.

Sewer size	Cu. yd excavation per yd	Average explosive per round	Average pull per round	Cost per lin. yd (1963 tender)
11 ft × 9 ft 3 in. main trunk sewer . . .	17	140–150 lb polar ammon gelignite	7 ft to 7 ft 6 in.	Excavation £167 Lining £73 Total £240
8 ft 10 in. × 8 ft 3 in. southern interceptor . . .	12	100–200 lb	6 ft to 6 ft 6 in.	Excavation £126 Lining £51 Total £177

158. Work was normally carried out 5½ days a week in two shifts of 12 h and the cycle of drilling, blasting and mucking out normally took 6 h. The average excavation length per week in the southern interceptor was 95 ft and the best week's output in rock not requiring support was 136 ft.

159. The concrete consisted of ¾ in. to 1 in. limestone aggregate, Bristol Channel sand and Portland Cement (600 lb cement per cu. yd concrete). Minimum test cube strengths at seven days were specified as 3000 lb/sq. in. Placing behind the 75 ft long steel shutter was achieved using a pneumatic placer, the resulting impact consolidating the concrete, assisted also by poker vibrators operated through ports in the shutter. The finish of the concrete was good.

160. Several members commented on the main inverted siphon, the design of which posed many problems. The 3 and 5 ft dia. pipes were OG jointed, using cement mortar. After the tunnel had been filled solid with concrete some joints were found to leak and grouting was used to bring this down to a reasonable level. When in service any slight leakage would be quite harmless at this location below the river.

161. The 9 in. dia. siphon flush pipe is a mile in length at a gradient of 1 in 2500 so the quantity delivered is not likely to be excessive. When last inspected, it was running about ¼ full and from its location under the invert of the southern interceptor it seems improbable that a break through from a fissure will occur.

162. The siphon will not be used until the Ashton Avenue Pumping Station is commissioned in 1970 as it would be imprudent to do so with only the small flow available at present.

163. Maintenance arrangements for the siphon were influenced by experience of existing inverted siphons, at least six of which are over 100 years old and require virtually no maintenance. It is anticipated that the procedure to be adopted will be as follows:

- (a) Inspect the inlet chamber at peak dry weather flow time. If the flow is all passing through the 3 ft pipe, no action is necessary. On previous experience this may be all the checking required for a very long time, perhaps 50 years.
- (b) If overflow is taking place into the 5 ft pipe at peak dwf partial blockage must have occurred. The 3 ft pipe would be closed at each end using the stop log grooves for securing the dams.
- (c) The contents of the 3 ft pipe would be removed by a submersible pump lowered down the upflow leg. This leg is carried above the outlet to a platform above flood level for this purpose.
- (d) The bolted iron cover would be removed after dewatering the access shaft. A sump in the bottom of the shaft permits a small head pump to operate in the 3 ft pipe.
- (e) Manual cleaning out would proceed, if necessary, with breathing apparatus. It is appreciated that this is a difficult job, but it is expected to be very infrequent.

164. Mr Lansdell's idea of providing a sump was considered but not adopted for the reason that it would certainly have accumulated material that would otherwise have been carried through, so requiring frequent maintenance.

165. Similarly, any form of screen at the inlet would require probably daily cleaning. This chamber is in a quarry a mile from the nearest road along a towpath and any maintenance must be kept to a minimum. Safety chains are provided at all access points for use when men are working in the sewer.

166. I regret that the experimental work on true siphons has not yet been carried out. The apparatus is almost complete and is in course of erection at the main pumping station. It consists of a 6 in. dia. siphon from the storm sewage sump at one end of the station to the sump at the opposite end, vacuum pump, flow meter and level measuring rods. It is proposed to carry out the experiments during the warmest part of the year because these will probably be the worst conditions.

167. Mr Shilston refers to the target based contracts, which have advantages where a large proportion of unknown risks are involved. Including a large storm-water tunnelling scheme, six of these contracts have been executed in Bristol at a total value exceeding £5 million. The results have been very satisfactory to both the Corporation and the contractor and the administration has involved little more than the normal measured contract. Checking of wage sheets, invoices, etc., was carried out by the Resident Engineer's staff consisting of one senior clerk, one assistant, one junior clerk and a typist, who dealt with up to four target and about four normal contracts proceeding simultaneously. Auditing was carried out by City Treasurer's staff.

168. A list of basic prices of materials was included in the tender documents and variations to the target were defined by comparison with actual prices paid. Plant was normally purchased for the contract and sold by independent auction at the end, thus defining its cost. Insurances were effected by the contractor, the premiums of course forming part of the cost of works.

169. Sewage received at the treatment works from the areas served at present is weak and well below the strength expected from sampling of outfalls. As further sewer interceptions are made it is expected that the overall strength will increase.

DISCUSSION

170. Average analysis results at present are:

Test			Crude sewage	Sediment tank effluent	Final effluent
Five-day solids	BOD	suspended	123 ppm 160 ppm	75 ppm 59 ppm	6 ppm 9 ppm

171. The 150 ft dia. primary sedimentation tanks are operating satisfactorily and although this part of the plant is only receiving some $\frac{2}{3}$ of the design loading at present, a good performance is anticipated at higher loadings.

172. Preliminary comparative tests with two different experimental inlets have so far proved inconclusive and the simple vertical tapered pipe inlets on three of the tanks give virtually as good a result as the experimental inlets.

173. It must be admitted, however, that the rotating inlet described by Mr G. M. Richards has not yet been made to work as designed.

174. Some difficulties have been experienced with the sludge digestion plant, partly due to a failure of mixing aggravated by accumulation of rags. Larger 'bubble guns' are being installed and at present these seem to be operating very satisfactorily.

175. The cost of power generated, charging the gas utilized as equivalent to fuel oil, is 1.36d/kWh. This is expected to drop to not more than 1.25d as power demand increases.

176. At Black Rocks Quarry temporary pumping station referred to by Mr Healey, the pumps were specified as being capable of dealing with unscreened sewage. The pumps actually installed are vertical inlet bowl mixed flow pumps, details being:

Size, in.	No.	Speed, rpm	bhp	Max. size of sphere passed, in.	Static head, ft	Output, cusecs
15	2	960	58	4	18	15
24	2	720	105	4	18	30

177. These pumps are now operating satisfactorily on screened sewage after modifications had been made on parts which tended to catch rags. Inlet guides are now fixed to the sump floor and these have cured the excessive turbulence and power demand that previously existed. If the station was being designed again, similar pumps would be acceptable, being appropriate to the duty, with screen protection due to the importance of the installation which serves a population of 140 000. The main improvement would be to provide more space and facilities for maintenance but as the station is only expected to serve for 15 years, capital cost was minimized.

178. The pump deliveries at the main pumping station are provided with flow meters and also the internal pumping station of the sewage treatment works. As a general rule, subsidiary pumping stations are not provided with measuring instruments. Performance checks at the main pumping station showed a higher output and current than specified, probably due to the newness of the pipework resulting in lower friction losses than allowed for in the design.

179. At the sewage treatment works two types of tank floor finish are described by Mr Bates. The solid concrete floor with a power float finish gives a very durable job but the screeded finish also appears to be satisfactory and may be more suitable

for steeply sloping floors. The final tank weirs were painted with white epoxy resin paint to discourage algal growth. The finish is attractive and still intact, but brushing is still necessary to dislodge alga. The smooth finish does, however, facilitate this operation.

180. Mr Archer's supposition about the jurisdiction of the Factories Inspector over the secondary treatment plant is correct as far as I am aware. The sludge digestion plant and generating station have been visited and if the Inspector has any comments about the remainder of the plant, these will be seriously considered.

181. Concerning the charge of 6d per thousand gallons for industrial water discussed by Mr Everett, it was felt that the charge should reflect the intrinsic value of the primary tank effluent. The Corporation have expended millions of pounds in bringing the water to the works and treating it to the required standard. The value of a product depends to some extent on what it can fetch in an open competitive market and is not necessarily the cost of production. There are other potential users in the vicinity and the present agreement is, therefore a precedent. It was an agreement freely entered into by both parties with the approval of the statutory water undertaking.

182. In reply to Mr Calvert, the salaries figure of 3% of the cost of the work includes both design and site supervision. The direct employment of staff by the local authority for a long term project such as this one is very appropriate and brings many benefits such as the day-to-day contact between design and operating staff. The cost of staff has varied from below 1% for large tunnelled sewers to 6-8% for pumping stations, the latter figure applying to the main pumping station which had to be extensively redesigned following model tests. As the scale of main sewerage decreases upstream, the very low costs of staff salaries can be expected to increase.