*Discussion on Paper No. 6613**

An investigation into the effects of warmed water from Marchwood power station into Southampton Water

by

J. P. M. Pannell, *M.B.E.*, M.I.C.E., M.I.Mech.E.

A. E. Johnson, B.Sc.(Eng.), A.M.I.C.E.

and

J. E. G. Raymont, A.M., D.Sc.

Mr R. H. Coates (Deputy Regional Director, Central Electricity Generating Board) said it was very pleasant to find the Institution receiving a Paper in which three Authors from widely different spheres had collaborated. The collaboration which was illustrated by the presentation of the Paper, and which was referred to in § 14 as a 'friendly arrangement', was in itself something of importance, irrespective of what it produced. The Harbour Board as part of its normal responsibilities, in addition to its day-to-day activities, would naturally consider the long-term ecology of the harbour; the University naturally recognized the long-term problems, and the electricity supply industry, as the largest industrial user of the harbour waters, had been glad to take its long-term part in the exercise. The last sentence in § 14 described the direct interests of the Generating Board, but in addition the Board was conscious that their stations and the staff operating them were part of the neighbourhood in which the station was found. Work of the nature described in the Paper, which was of general value to Southampton and elsewhere, was not likely to be so successful without that element of good neighbourliness.

64. It had been said that 'a little fellow feeling makes us wondrous kind'. About the year 1950 somebody brought him the rudder of a little boat which he owned, unpleasantly eaten by the gribble. There was some evidence from ports in the southern half of the British Isles that, as Professor Raymont had indicated, occasional outbreaks, very similar to outbreaks of diseases in cities, could be triggered off by unusual occurrences of temperature, importation or local change in environment. It seemed probable that those areas primarily affected needed a permanent monitoring of the conditions in harbours of the kind in question.

65. The Paper described a considerable advance in the knowledge of temperature phenomena in tidal estuaries, particularly where fresh water and salt water mixed, or rather did not mix, and there might be a temptation to feel that the job had been nearly completed. The present results, however, were hardly what the original investigation had anticipated, and he hoped that the exercise would continue indefinitely, because the further useful results which were likely to arise might equally well not be anticipated at the present time and there was still a danger of reaching premature conclusions.

66. Some support for that was to be found in the fact that the Authors in § 56 referred to 'the limited time available for survey and office work'. He was very conscious of the calls on the time of senior staff in all three participating bodies and the natural tendency of technical and professional personnel to concentrate on doing the

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* *Proc. Instn civ. Engrs*, vol. 23, September 1962, pp. 35–62.

job rather than writing up the results. The Paper was evidence of the determination of the Authors to overcome those difficulties and in congratulating them he expressed the hope that further information would be provided in future in a similar way.

Mr A. T. McDonald (Engineer, Hampshire River Board) congratulated the Authors on an interesting piece of research and expressed the hope that they would carry on with it, because it was of the greatest importance to the fishery authority. In that connexion he drew attention to a statement in the Paper that the Southampton Harbour Board was responsible for the well-being of fish in the estuary, including salmon, and pointed out that the Hampshire River Board was the responsible authority for salmon and migratory fish in the whole of their area, which included the Test and Southampton Water.

68. His remarks would be mainly concerned with the effects on fish of heating the estuary. In § 8 the summer flow of the River Test was given as 250 cusecs and the winter flow as 1000 cusecs. He did not know what was the Authors' idea of the time when summer arrived in this country, but in fact the flow of the Test was at its lowest in November and at its highest in March. The figures quoted were very nearly extreme flows and more normal figures would be 300 cusecs in November and 700 in March. The flow of the Test, because of the nature of its catchment area, was remarkably constant and the hydrograph of one year corresponded almost exactly with that of the next.

69. In § 51 it was stated that in recent years there had been a high rate of run-off from the Test which brought down nutritive substances such as phosphates, and in the next paragraph the Authors attributed the increase in the number of barnacle larvae to the nutrients thus brought down. The River Test derived its flow almost entirely from springs, and spring water, of course, contained phosphates. The phosphate content of the water was increased by sewage and other effluents. The catchment area of the Test was roughly 80% upper chalk coming to the surface. In that area there were practically no surface streams, and no artificial fertilizers containing phosphates were drained into the Test. So far as was known, the phosphate content of the springs remained constant. There had been no change of significance in the flow of the Test at any time in the past ten years, and so far as was known there had been no significant change in the volume or composition of any effluent. It seemed, therefore, that the growth of barnacle larvae must be due to something other than an increase in the phosphates coming down the river. If the Authors had measured any increase the River Board would be extremely interested.

70. There had been a very large increase in the number of mullet that came to the upper estuary, and these wretched animals made salmon fishing very difficult. It seemed to the River Board that this increase must be due to an increase in the food supply of mullet. Could this be due to the heating effect of the water discharged from Marchwood generating station?

71. In § 36 it was stated that recirculation of the hot water at Marchwood had occurred on only one occasion. It seemed, however, that the whole body of the Marchwood basin had been raised in temperature by 2°F, so that it seemed that constant recirculation must take place. Perhaps the Authors would comment on that.

72. Finally, in § 56 it was stated that the temperature of the water near the intake continued to rise. Up to the present the rise in the temperature of the estuary had had no effect on the number of salmon reaching the upper reaches of the river, but all salmon and migratory trout must as adult or as young fish pass through the estuary and it was of great importance that they should be able to do so without any hindrance from hot water. Perhaps the Authors could say what the ultimate temperature would be when equilibrium was reached.

Captain J. Andrew (Harbour Master, Southampton Harbour Board) thanked the President for the opportunity of listening to and taking part in what had been a very interesting discussion. His own interest, he said, was mainly concerned with shipping and navigation. There seemed to be a problem here which had been mentioned but not solved. No explanation has been given for the variation of the temperature of the water from year to year. He suggested that, if it had not already been done, an investigation should be made to see whether or not the variation in temperature was in any way related to the variation in volume of water entering and leaving Southampton Water due to the change in the height of spring and neap tides which were not consistent throughout the year or from one year to another. It took approximately 19 years to complete the cycle of tides.[4] One year there would be a very high spring tide and another year, not so high. This also applied to neap tides. This particular problem might be solved by comparing the variations in yearly temperatures with the yearly variations of the volume of water entering and leaving Southampton Water.

74. Mr Pannell had mentioned the removal of wrecks. Within the Port of Southampton there was approximately 44 miles of shore line and it included the Rivers Test, Itchen and Hamble. There was no mention of this investigation being carried out in the Rivers Itchen and Hamble. In the River Hamble a large number of yachts were accommodated during the summer months and the numbers would probably increase with the increase of pile mooring facilities which were being provided by the Board at the approximate cost of £10 000 so that a greater number of yachts could be accommodated in the same area without resorting to dredging. The yachts in the port area would, in future, number from 1000 upwards, a few made of steel and plastic but the majority being of wood.

75. The Harbour Board had removed a few derelicts close to the Marchwood cooling-water outfall but there were the remains of a large number of derelicts around the shore line and in addition a large quantity of driftwood had collected over the years. Whenever there was a very high spring tide, Southampton Water was covered with driftwood which varied from large planks to small pieces of wood which might be contaminated and possibly be deposited on adjoining foreshores. The Board's Salvage Department, which was small, had only removed a few of the derelicts but could not possibly undertake the task of clearing all derelicts and driftwood and, as the work was subject to tidal conditions, would probably be very expensive. There was also the question of the financial responsibility. The problem was a difficult one and would increase. It might well be a question of 'a stitch in time saves nine'.

Mr C. E. C. Townsend (Divisional Engineer, Port of London Authority) said that on the Thames there was the problem of heated discharges, because there were 25 existing generating stations, all but three of which belonged to the Central Electricity Generating Board, which had a maximum output at the moment of 5600 MW. Two more were under construction, of 1300 and 1400 MW respectively. In future all of these stations, producing 8300 MW, would require cooling water at the rate of 333 m.g.h. during winter peaks, but the fresh water flow coming over Teddington weir, which averaged 50 m.g.h. throughout the year, might be as low, during a cold but dry March, as $12\frac{1}{2}$ m.g.h., so that the total consumption of cooling water would be roughly 27 times the fresh water flow.

77. Their main concern at present, however, was that when there was only a little oxygen dissolved in the Thames water any discharge of heat which would accelerate biochemical activity might lead to the consumption of all the available oxygen, in which case sulphate, of which there was much in the water, would be reduced bacterially to sulphide, with undesirable results. Recently they had made it a condition for new heated discharges that oxygen should be introduced into the water to offset any unpleasant effects which might otherwise result. The Central Electricity Generating Board had co-operated with them most whole-heartedly and at their Belvedere power station, officially opened on 12 October, 1962, they had installed a most successful aeration plant which fully complied with the Authority's requirements.

78. Throughout the last 40 years the temperature of the Thames had been rising. That was not due simply to the discharge from the power stations; there were heated

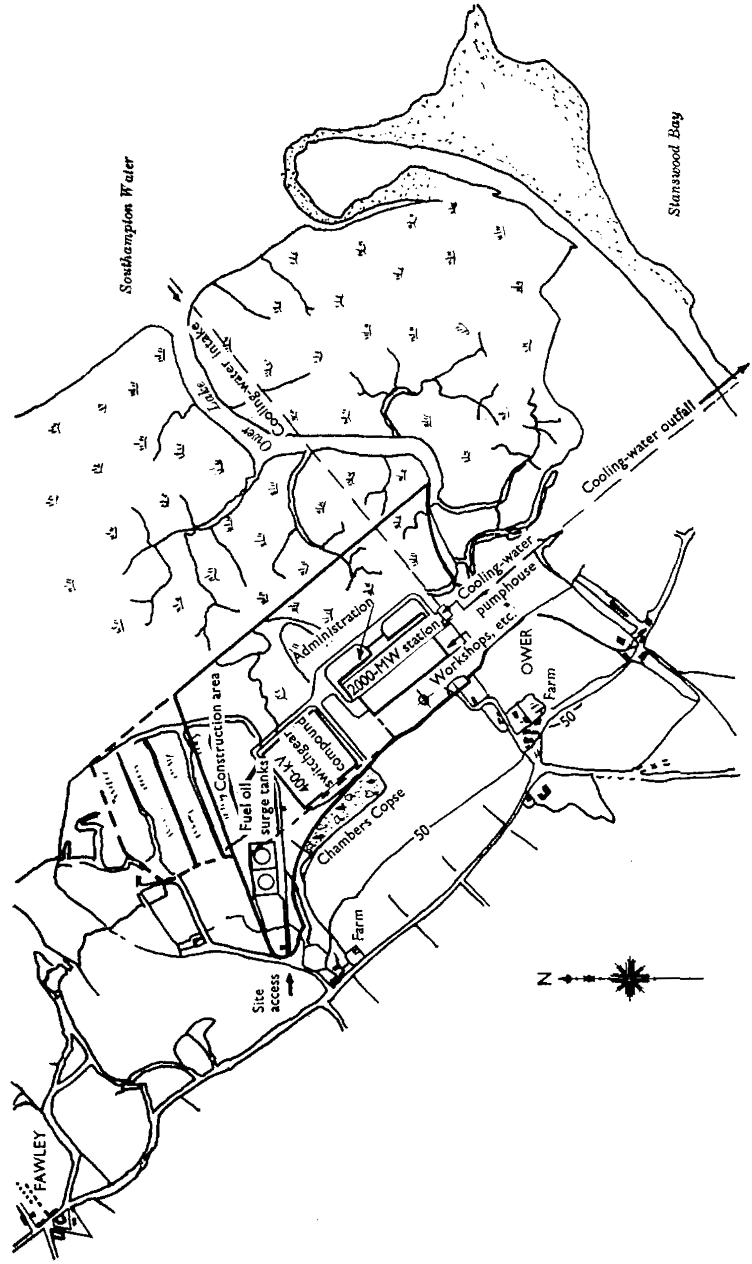

FIG. 18: FAWLEY: TENTATIVE LAYOUT

discharges from sewage works as well. The total temperature rise had been about 3½°C in that period. The Authority and others concerned had to consider what was going to be the effect in the lower reaches of the Thames when the two new giant power stations were commissioned. If and when the quality of the river water improved, would the animal activity in that part of the river increase undesirably?

79. The programme of temperature measurement used by the Authors seemed to him to be extremely thorough and would no doubt be of considerable interest to others faced with recirculation problems in a similar type of estuary; but it was surprising to find that so little attention had been paid to the effect of wind, which by disturbing the surface must very largely contribute to the removal of heat from the water. The investigation had certainly shown that the theory of the cooling of heated discharges in coastal waters could not be applied directly to partially mixed estuaries, where the density currents due to varying salinity had naturally a much stronger effect that those due to temperature gradients.

Mr G. E. Tuck (Senior Assistant Engineer, Central Electricity Generating Board), as a member of the Planning Department of the C.E.G.B. concerned in siting power stations in the south west of the country, thought it might be helpful to describe how the work referred to in the Paper had assisted in planning the Fawley power station and particularly in the siting of the circulating-water system. Before doing so, however, he said he was glad to have the opportunity of contributing to the discussion because he had a personal interest in the investigation described. He had at one time worked in the Southern Division of the Board and had taken part in some of the hydrographic surveys. He had been delighted to read in § 19 that 'Early surveys were carried out using a single thermistor coupled to a direct-reading scale' and also that 'the warmed water was not behaving as had been forecast'. This had been the first occasion on which the very sensitive thermistors had been used, and it had been a considerable time before it was appreciated that it was the warmed water which was not behaving as forecast and not the thermistors!

81. He welcomed the opportunity of speaking also because it enabled him to congratulate the Authors on bringing their work to fruition. They were particularly to be congratulated on the way in which a large mass of material collected over a number of years had been brought together in such a small compass.

82. The problems at Fawley could be very simply stated as:

(*i*) Where should the circulating-water outfall be sited?
(*ii*) What effect would the effluent have?
(*iii*) Would anybody mind?

In the light of what had been said so far in the discussion, it would be appreciated that these were very real problems. Every aspect of the work described in the Paper had been of tremendous help in answering those questions. He proposed to deal with each of them in turn, after showing where the Fawley power station was and what the possibilities were.

83. The possibilities were to put a deep intake into the station at the point on Fig. 18 marked by an arrow and to discharge into Stanswood Bay, or, retaining the intake in that position, to dredge a channel out through the mud and discharge the water down the channel, some degree of separation between the intake and outfall being effected by a baffle wall in the position shown.

84. Together with their consultants, they first did a paper exercise. Their prime considerations were the same as those given in § 14 for Marchwood, but in a different order. They were primarily concerned with the effect of recirculation which would affect the efficiency of the station, and also warmed water from the power station could affect the efficiency of the refinery upstream, and thereby possibly reduce the throughput. There were also all the biological effects which had been referred to in the discussion.

85. Fawley had a capacity of about 2000 MW as compared with Marchwood's

480 MW, but the heat rejection was not proportionate to the capacity, and in fact Fawley would discharge 65 m.g.h. of warmed water at 15–16°F as compared with Marchwood's 26 m.g.h. at about 12°F above ambient.

86. The arrangements necessary for discharging into the dredged channel would be relatively cheap, but there was a risk of recirculation and some of the undesirable side effects. In Stanswood Bay a high cost penalty (perhaps hundreds of thousands of pounds) would have to be met. It had been obvious that the problem of making the choice needed close attention.

87. If a direct comparison was made between the water flowing past Calshot Spit and up Southampton Water and filling the whole tidal volume of the estuary with the discharge from Fawley, and between the similar volume of water above the Marchwood outfall with the Marchwood discharge, it was found that the comparison was favourable to Fawley; in other words, the total heat rejected to the total mass of water flowing was less at Fawley than at Marchwood. Also, since Fawley was at the end of Southampton Water, it seemed that the water flowing out of the estuary on the ebb tide would take half the effluent with it and it would not return. That also looked hopeful and could be advantageous as compared with Marchwood, where the warmed water went down on the ebb but tended to come back again and did not escape.

88. Furthermore, as the intakes are sited in a natural deep, it was thought that it might be possible to avoid drawing down the heated water from the surface. The possibilities of discharging successfully at Ower therefore, on inspection, appeared to be quite high.

89. Next, an approach had been made to the University of Southampton to use their hydraulic model from which it had been found that some of the suppositions made had been a little erroneous. It was found, when discharging into the dredged channel, that there was some slight recirculation, particularly during the slack water neap tides, presumably because the pumps drew from all layers of water. It was thought that possibly this effect might be enhanced in nature if similar density variations existed at Fawley to those described in the Paper at Marchwood.

90. Mr Tuck could confirm Mr Johnson's finding that the spread of warmed water after it had come out of the channel remained on the south side of the estuary and did not go up the Hamble, but it did go up to the refinery intakes. Their assumption that half the effluent would escape, however, had been a little awry, because although a large proportion of the water did go past the Spit some of it came back on the following tide.

91. They had used dye in the model to trace the transport of warm water and, although this did not simulate the heat content, there had been some accretion of dye between Calshot and Hythe. It seemed possible that this might have a similar effect in heating up the whole of the estuary to that described at Marchwood, but to a lesser extent.

92. They also found that there was a great pond of warm water formed in the area behind Calshot Spit over the saltings, and they wondered whether or not this would destroy the vegetation. There seemed to be a danger that if the banks were denuded they might erode and change the estuarial régime. On all those grounds the effects, though marginal, gave some cause for concern, because at Fawley they might produce in the whole of Southampton Water the effects which had been described in the Marchwood basin.

93. The Stanswood Bay discharge showed none of those effects, largely because there was a tidal current which set in and took the warmed water down the Solent.

94. The work described in the Paper had been of invaluable assistance concerning the question 'would anybody mind'. The difficulty in these circumstances was firstly to appreciate the size of the problem, then to describe it accurately and finally to know what risks were involved and whether they were justifiable. It would be appreciated that because of their familiarity with the issues involved all those concerned were very much better able to give an opinion and all that part of the work had been made very easy.

95. He wished he could say that they had reached an elegant solution at Fawley, using all the work that the Authors had done and saving themselves some hundreds of thousands of pounds, but they had not been able to do that. Although it had been thought possible to go to Ower Lake it had not seemed wise to do so, and in the circumstances the second-best solution of going to Stanswood Bay was probably soundly based and well justified.

96. He had a few questions to put to the Authors. *Teredo* was rather a dirty word, and perhaps 'gribble' should be. The Board had now inspected several estuaries on the south, east and west coasts and had found *Teredo* present in every case. Was *Teredo* endemic all round the shores of this country? Professor Raymont had seemed to hint that it was. If so, were any cyclic outbreaks occurring in other ports and what was the nature of the cycles in terms of the time when these might occur?

97. It might be useful, in view of Captain Andrew's remarks, to know what protection timber needed to resist settlement and attack by *Teredo* larvae. Was a coat of paint good enough? It was mentioned at the end of § 46 that a piece of driftwood had been found to be discharging actively-swimming larvae at a high rate. Was there any indication of the origin of this driftwood? Had it come from piles somewhere nearby and might the whole area be infested? It would be interesting to have details of the way these animals behaved and whether or not one piece of driftwood would be enough to infest the area.

98. In § 35 it was stated that the Marchwood basin appeared to act as a sump for the warmed water. Had the test-blocks been sited in this sump and had that had any influence on the attack on the samples? Also, when the wreck had been removed the incidence of attack seemed to decline, so that he had drawn the conclusion that the presence of breeding timber was more important than the temperature.

Mr N. B. Webber (Lecturer in Civil Engineering, Southampton University) said that little factual data had hitherto been published on the behaviour and effects of heated water in estuaries, and the Paper therefore represented a welcome addition to our knowledge. This type of cooling-water problem was of considerable complexity, for the process of heat transfer to atmosphere, itself a difficult phenomenon to analyse, was greatly influenced by the complicating hydraulic factors of unsteady flow, density differences, and irregular boundary conditions.

100. The Authors were to be especially commended for their frank information on the conditions as they were expected to exist, since subsequent observations revealed some significant discrepancies, although of course the cooling-water layout might be judged successful in that there had been virtually no recirculation. All too rarely with these estuarine problems had quantitative comparisons been made between predicted and actual behaviour, thereby affording an excellent opportunity for the review and possible improvement of design techniques. It would be of particular interest, therefore, if the Authors could explain the basis of the prediction in § 9, subsection (e).

101. The dispersion of heated water from the Marchwood outfall was undoubtedly influenced more by tidal currents than by gravitational or conduction effects. In these circumstances a very simplified approach to the ascertaining of the upstream and downstream extent of the cooling pond could be made on the basis of estuary volumes, or cubatures, as they were sometimes called. All that was required was a detailed hydrographical chart and tidal curves for a number of representative points. The diagram (Fig. 19) showed the volume curves, high and low water spring and neap tides, for the portion of the estuary in the vicinity of Marchwood. Horizontal lines, drawn as shown between the high and low water curves, indicated the maximum upstream and downstream distances travelled by particles from their point of release, or the approximate lengthwise extent of the relevant cooling pond. No account was taken of the fresh water inflow to the estuary, since on a volumetric basis it was quite insignificant in relation to the tidal prism. Thus it was found that on spring tides the cooling-pond coverage

extended from approximately 5300 ft upstream to 8200 ft downstream and on neap tides from 2500 ft upstream to 3700 ft downstream. These distances appeared to be somewhat less than those encountered in practice (§ 27, p. 46).

102. From this same data the tidal flow-time curves might be derived. These were shown in Fig. 20 with the cooling-water discharge superimposed. The rapid ebb after high water on a spring tide was most marked. For the greater part of the neap tidal cycle, conditions are relatively slack and consequently less favourable for heat dispersion.

103. The principal defect of the method was that it presupposed a uniform velocity distribution, which was in fact far from the truth, both with regard to the vertical and horizontal planes. Also, of course, it did not take into account the stratification associated with fresh river water, which, as the Authors had explained, had a significant effect on the behaviour of the cooling pond.

104. The aid of hydraulic models was often invoked in the study of cooling-water problems and it might be wondered why greater use was not made of the Solent model situated at Southampton University and referred to in § 18. This model was constructed in 1957 by Dr W. Wright, now Professor Wright of Trinity College, Dublin, for the purpose of an investigation into the effects of proposed dredging near Calshot. It embraced the whole of the Solent waterway system and the scales were 1/1250 horizontal and 1/100 vertical, with a consequent vertical exaggeration of 12·5. During 1960 some simple verification tests were carried out in the vicinity of Marchwood. While the broad pattern of behaviour was reasonably reproduced, the degree of conformity was not sufficiently satisfactory to justify proceeding with more elaborate studies. In any event with this particular model it was not practicable to make provision for the important stratification effects.

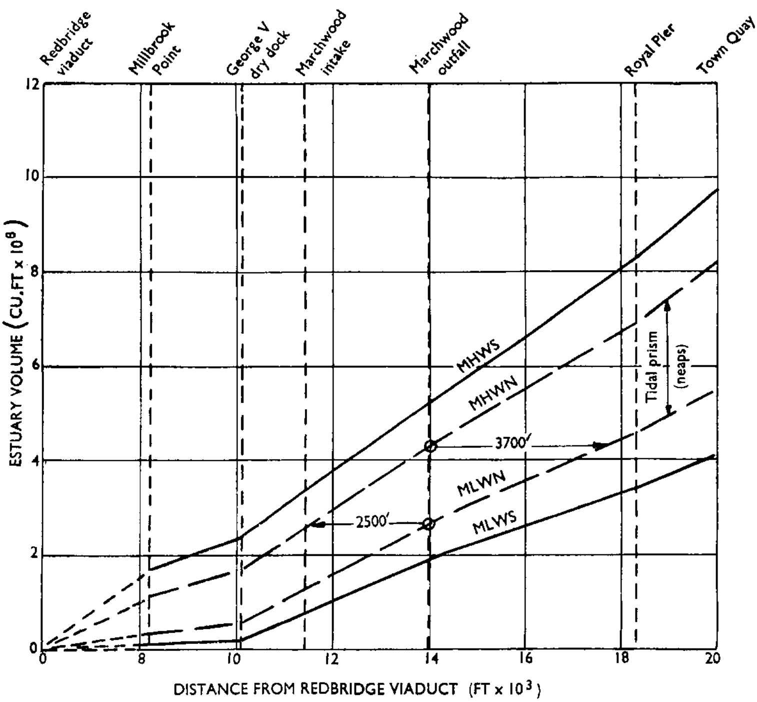

FIG. 19: ESTUARY VOLUME CURVES—RIVER TEST

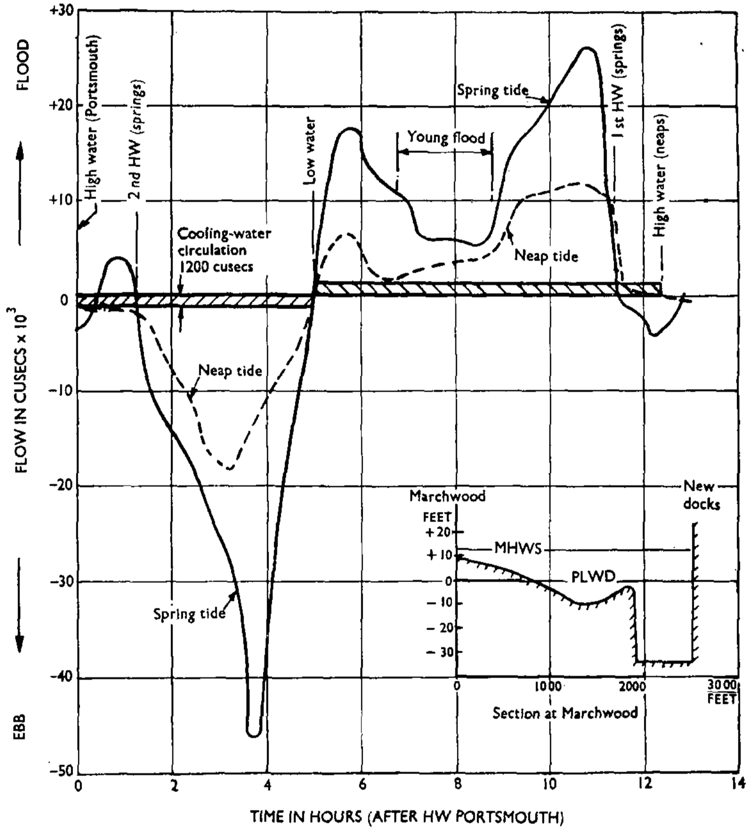

FIG. 20: TIDAL FLOW—TIME CURVES FOR MARCHWOOD

105. These limitations were no reflexion on the performance of the model or its design. It quite adequately fulfilled the task for which it was constructed, but for a study of the present problem it was really unsuited. Hydraulic models in general, and estuary models in particular, do not resemble computers or calculating machines, giving precise answers in accordance with the data fed to them. On the contrary, there were inherent errors and inaccuracies in extrapolating to the prototype, which became larger the smaller the scale. If a model were to be constructed for a study of the present problem, the indications were that the horizontal scale should preferably be three or four times larger than at present though its areal coverage need be no more than Southampton Water.

Mr A. R. Hockley (Department of Zoology, Southampton University) said that most of the observations made on wood-borers had been carried out under his direction, but at the time of the preparation of the Paper he had been abroad and Professor Raymont and Mr Pannell had extracted from his progress reports and from the theses of two Ph.D. students the information necessary for the wood-borer part of the Paper. It might be of interest if he were to bring the report a little more up to date from the period 1958–59, where the Paper ended.

107. There was a suggestion in the Paper that the *Limnoria* attack at Marchwood was in danger of overtaking the attack at Calshot and that the probable reason for the lighter attack at Marchwood in the first instance had been the lower state of the natural population in the neighbourhood. He must report that the reduction shown at Calshot had been a temporary check only and in fact the numbers had since continued to rise at both sites. They did not know why the Calshot numbers continued to rise unless it was attributable to the increased temperature at Calshot which might be due to other sources of warm effluent, such as the Esso refinery.

108. It would be seen from Figs 4A–D, the thermograph charts, that the trace illustrating the temperature change at Calshot had become more irregular with the passage of years. The trace for Calshot, Figs 4A and B, showed greater irregularity, which meant more fluctuations of temperature, in the chart for May 1960 than in that for May 1954. It was not improbable that they were in fact losing Calshot as a reliable base comparison or base-line because of the interference of warm water from other stations. It was a fact that with almost every monthly sample the *Limnoria* attack showed an increase over the corresponding months in previous years and it was still climbing at both sites.

109. With regard to *Teredo* the situation was again somewhat confusing and difficult to explain. It would be seen from the Paper that *Teredo* in 1959 had begun to appear at both sites. The year 1961 had been very bad for *Teredo* and there had been a really serious attack at Calshot, but he was glad to report that this was now back at something like the 1958–59 figures. If he had to guess the reason for increased *Teredo* attack he would blame the proximity of timbers likely to become infected quite as much as the increase in water temperature. When the wreck at Marchwood had been removed there had definitely been an immediate reduction in the number of *Teredo* larvae settling on the battens. They had not been able at Calshot to locate a definite source for the larvae which had caused the great increase in numbers in 1961, but one batten, 5 ft × 2 in. × 1 in., withdrawn after two months' exposure in September, had no fewer than 441 *Teredo* established in it, a very heavy attack indeed. That had probably been due to some local infection, the presence of some infected wood. Only a few weeks ago they had found drawn up above high water on the beach a structure of some size, 10 to 15 ft long, heavily infested with *Teredo* bores. If that had been in the water during 1958–60 it could easily account for the outbreak of *Teredo* suffered in 1961 at Calshot.

110. Mr Tuck had asked for information about the driftwood found at the Town Quay at Southampton. It was a piece of softwood and had been manufactured; it was not the branch of a tree. Mr Hockley hesitated to say what it had been, but it was not the sort of wood which any responsible boat builder would use, so that the most probable explanation was that it was a piece of spare wood thrown over the side of a ship. It was only a few feet in length and no more than 2–3 in. in thickness. Where it had come from he could not say, but it could have been infected from the wreck or derelict vessel at Marchwood, which had been in position at that time.

111. This emphasized the fact that derelict vessels were a very real danger, having even more effect than timber harbour work. During its life the vessel might have picked up small numbers of *Teredo* in some port, and it was when the vessel ceased to be hauled out every year and painted that the *Teredo* got to work and formed a really big breeding population.

112. With regard to the Hamble River and to the planned generating station at Fawley it might be of interest to mention that they had already embarked on a programme of monitoring for *Limnoria* and *Teredo* right up the Hamble estuary and round the Calshot Spit and into the bay beyond. They were already planning the same sort of investigation as had preceded the establishment of Marchwood station and he would fairly soon be able to say what the *Teredo* situation year by year in the Hamble River was. *Teredo* had been found there but in small numbers. Anything that he, personally, found there he would take steps to have removed. As a boat-owner himself, he regarded the menace of derelict boats as a very real one.

Mr I. P. Haigh (Research Engineer, Sir Alexander Gibb & Partners) referred to the statement in § 11 that 'For efficient operating conditions 26 000 000 gallons of circulating water are required per hour' and said that 2·4 cusecs/MW was an unusually large rate of circulation for 60-MW sets. He wondered whether the investigation had covered the question of volume and temperature rise from the point of view of the health and régime of the estuary. It might be that a smaller rate of circulating water, with a corresponding increase in outfall temperature, would have beneficial effects on the estuary, rather than the reverse.

114. He had been very much intrigued by the air photographs of the discharge trace from the outfall which the Authors had shown. It was not always possible to take such photographs, and he wondered whether or not any work had been done on the use of tracers such as fluorescein, in following the path of circulating water from outfalls.

115. He had recently seen a report which dealt with mussel growth in circulating water systems. Marine borers had received a good deal of attention in the Paper and mussels had been mentioned. Could the Authors say anything about the influences of the smoothness of concrete surfaces and of the velocity of the flow of water on the growth of mussels? He had an idea that some velocity was a great help to mussel growth but that there was a certain velocity beyond which growth was inhibited.

116. Finally, was there a difference between the ways in which barnacles and mussels adhered to steel structures, and in particular to coated steel structures? A recent Paper on the subject suggested that barnacles were a serious cause of the breakdown of a paint film, whereas mussels had no such effect.

The following contributions were received in writing:

Mr A. C. Oliver (Research and Development Officer, Timber Research and Development Association) wrote that although the water temperatures showed significant increases in the vicinity of the Marchwood power station, and increases of a lesser amount at Calshot over the levels recorded prior to the commissioning of the Marchwood power station, this should not be taken to mean that the concomitant increase in *Limnoria* spp. breeding and the increase of *Teredo* in Southampton Water would lead to rapid attack and early failure of durable or preserved timber structures in the area.

118. Trials had been carried out by his Association over more than ten years in the locked portion of Shoreham Harbour, Sussex, with the permission of the harbour trustees, to investigate the performance of timber reputed to have natural resistance and timber treated with wood preservatives when exposed to marine borer attack.

119. Temperature data for this area of Shoreham Harbour where the trials were conducted were collected by the harbour authorities daily, and over the period of August 1960 to April 1962, the maximum and minimum temperatures recorded were:

Maximum 20°C (68°F) in August and September
Minimum 9°C (48°F) in January

This harbour also received cooling water from the C.E.G.B. power station.

120. Comparing these data with those in Fig. 5 during the period of April 1959 to December 1961, when the last generator set was commissioned, the following table was derived:

TABLE 5

		Maxima		Minima	
Shoreham	(August 1960 to April 1962)	20°C	68°F	9°C	48°F
Marchwood	(April 1959 to	24·5–27°C	76–80°F	6·5°C	43°F
Calshot	December 1961)	19–22·5°C	66–72°F	5·5°C	42°F

121. In comparing these readings it should be emphasized that the Shoreham data were merely daily readings whereas the Marchwood and Calshot were monthly maxima and minima. It was clear that while the levels in the Marchwood vicinity were higher than those at Shoreham in the summer, the situation was reversed in the winter. It could be argued from the data published by Raymont and his co-workers elsewhere, that as, for example, high winter temperatures enabled all year round breeding and migration of *L. quadripunctata*, Shoreham was a more severe situation than Southampton Water in the vicinity of Marchwood. Conversely, higher summer temperatures at Marchwood might enable quicker establishments of boring and marine animals at this site. However, it was suggested that the hazard of marine borer attack to timber was comparable at the two situations of Marchwood and Shoreham.

122. On the subject of the resistance of timber and preservatives to marine borer attack, Mr Oliver wished to say that from the test data from T.R.A.D.A. trials at Shoreham, it was clear that timbers with high natural resistance or treated adequately with effective wood preservatives could provide a durable long lasting structure in sea water, even at these raised temperatures.

123. The results of these trials were available in various publications of his Association.

Mr Bruce Delve (Management and Industrial Consultant) wrote that he would like to ask the Authors of the Paper if they were able to tell him what possible effects the warm water emitted from the power station would have in respect of the development of Southampton as a major cargo port. For example, what were the existing effects relating to the wharves, where timber piles were in use? Would it be reasonable to suppose that such structures could not now be used but if it was possible to use them should the timber be subjected to any special treatment?

125. Would the *Teredo* have a detrimental effect on the stacking of timber on quays, and if so to what extent would such timber have to be subjected to replacement, i.e. how long could timber be left before it could be expected to suffer from attack?

126. Finally he asked if it was possible to say that the observations made were relevant to the surface and below-water levels, and that the shore of quay lines above water levels at varying heights of tide were held as above attack.

127. In the context above stated, were there any considerations which ought to be included in planning Southampton as a major cargo port, in the sense that the existing effects of warm water would make the reception and storage of specific goods or commodities impossible, or give cause for grave misgivings on the part of potential users? For example, would packing cases have to be treated in a special way if transhipment took place through Southampton?

Mr C. K. Haswell (Partner, Sir William Halcrow & Partners) wrote that the Authors of this Paper had undoubtedly made a valuable contribution to the designer's armoury by patiently recording and presenting their measurements and observations at Marchwood.

129. It was probably known that Sir William Halcrow & Partners were responsible to the Board for the original recommendations as to the suitability of Marchwood for the power station and the forecast quoted in § 9 was virtually that made in 1952. One point which had been omitted, however, was that the quantitative forecasts in § 9(*e*) were based on expected load factors of 0·75 on four 60-MW generating sets in the summer and 0·70 on eight sets in the winter. It would be helpful if the Authors could complete their records by stating the actual output of the station over the relevant period.

130. The double tide at Marchwood combined with a very small contribution of river water in dry weather at first indicated that the water outside the power station would remain almost stationary. That was to say, a particle in the river would run to and fro with the flood and ebb of the tide, but it would only reach the open sea after a

long period. During extensive float tests it was found, however, that there was a differential movement in the surface water—a fact that had to be taken into account when navigating craft with a draught of more than about 7 ft. This phenomenon was mentioned by Cmdr D. F. MacMillan in his book, jointly written with R. C. H. Russell, M.A., called 'Waves and Tides'.[1] The effect, as far as the cooling system was concerned, was that surface layers would progress, in a series of oscillations, to the open sea, within a reasonable time.

131. There was no reason to suppose that this statement was not true but, of course, as the Authors had shown, it was not the warm effluent from the power station which was on the surface. Nevertheless, some mixing obviously took place in a vertical sense; otherwise the temperatures would have been much higher than those actually measured.

132. It was clear that the fact that the density of the water was controlled by its salinity rather than by its temperature was not sufficiently apparent in the early stages and Mr Haswell believed that it was on this alone that the forecast had proved to be partly inadequate. However, at the design stage it was thought that some advantage might accrue by discharging the effluent further downstream and provision was in fact made for this by means of a short stub duct at the existing outfall structure.

133. Mr Haswell would also like to make the suggestion that, in the future, the designer should be given more opportunity to follow up his forecasts in co-operation with those locally interested so that the data obtained, such as that recorded in the Paper, could be compared at once with the design parameters and assumptions: in this way the best use could be made of such data.

Dr D. I. H. Barr (Lecturer in Civil Engineering, The Royal College of Science and Technology, Glasgow) wrote that the statement in § 33, regarding the capacity of 'salinity variations of the order of 1000–2000 p.p.m. are sufficient to set in motion density currents', could be misleading. These salinities corresponded to roughly 780–1560 p.p.m. density difference, and, depending on the conditions, very much smaller density differences could produce recognizable density difference phenomena. Certainly the figures mentioned were of the order of the minimum which appeared to be viable over relatively long periods in estuaries with strong tidal currents.[5] But where currents were less strong it was likely that the effect of very much smaller density differences could not be ignored.

135. In a laboratory study of lock exchange flow,[6] a density difference of 1·8 p.p.m. had been used. This was produced by dissolved potassium permanganate, the colouring effect being just apparent when an 18-in. thickness of the solution was viewed against a white background. With a total depth of just under 6 in. a definite lock exchange flow was set up and the coefficient of proportionality for the initial velocity of the underflow was found to be 0·49 compared with the value of 0·40 which would have been expected.[6] Again using a thermal density difference of 40 p.p.m., a coefficient of proportionality of 0·43 was obtained for the overflow compared with the expected 0·48. At such small density differences control of experiments was difficult and the above variations in no way alter the fact that the normal phenomena took place. Turning to the stabilizing influence of density difference on a turbulent flow in a flume, experiments had recently been described[5] in which thermal density differences down to about 40 p.p.m. were observed to result in variations in behaviour which provided evidence for the relevance of the densimetric Froude number criterion of similarity.

136. Regarding the combined effect of salinity and temperature variation on density difference in the context of heat dissipation, some experiments of this nature had been undertaken during the Kincardine power station model investigation.[7] Unfortunately this was one of the aspects of the studies not reported[8] due to the restriction on the length of papers. The investigation was primarily concerned with low water conditions in a section of the comparatively shallow upper part of the Forth estuary. It was considered that the greatest possible variation in salinity between the circulated water and

the ambient water at the outfall would reverse the density difference effect normally associated with a 15°F temperature increment and fairly high natural water temperature in slightly brackish water. The heated outfall water would then be roughly 1000 p.p.m. more dense than the ambient water. Sufficient saline solution was added to the outfall flow in the model to simulate this, the required model density differences being the same as in the prototype.[5] Three such tests were run and it was found that during the period corresponding to the most prolonged low water stand thought possible the recirculation figures were not materially worse than for the normal fresh water tests. The extremes of density difference gave rise to a warm surface layer on the one hand and a warm saline bottom layer on the other. Since the range of density difference between the tests using salinity and the normal tests was more or less covered by cases of very low basic temperatures, including temperatures just above freezing point and thus well below the point of maximum density, the production of intermediate cases using saline solution was not thought necessary. It was considered that the circumstances which would give rise to a maximum velocity of spread of a body of heated water, formed in the river during a low water stand, towards the intake had been adequately covered. Intermediate density differences would produce lesser rates of spread.

137. In §§ 9 and 25 of the Paper, reference was made to the general expectation, prior to the investigation, 'that the warmed water would spread from the outfall in the form of a thin layer on the surface of the estuary' and that one of the two major modes of elimination of heat from the estuary would be 'the dissipation of heat to the atmosphere through radiation and evaporation'. However no indication was given of what was considered to be a thin layer, nor of the proportion of heat expected to be dissipated to the atmosphere.

138. If a surface layer was formed, the rate of heat loss depended on the differential temperature of the layer and the air. Hence the percentage heat loss in any given time was a function of the depth. The prediction of the rate of heat loss for selected conditions was not difficult—Throne's formula[9] should give reasonably accurate results or a more rigorous approach might be made. The problem was to establish the tendency for the effluent to form 'thin' layers and to predict the persistance of such layers when carried by tidal flows. Although very thin layers could be formed in a laboratory flume, given sufficient time and with various precautions, and although fairly thin warm surface layers were commonly noted during the flooding of a warmed beach, the nature of the spread of a buoyant effluent was such as to make the formation of very thin layers unlikely in full scale circumstances of the type in question. Dr Barr explained the mechanism of this in detail in recently published papers.[10, 11] For the present reference to the fragmentary Keulegan-type congruency diagram for the underflow of lock exchange flow in a wide flume, which he had provided, could illustrate the pronounced scale effects. For a given density difference the densimetric Reynolds number (for consistency this might rather be called the densimetric Froude-Reynolds number, $\overline{F_{\Delta}R} = [(\Delta\rho g/\rho)^{1/2}\, l^{3/2}]/\nu$) varied with the 1·5 power of the depth, ignoring variations in kinematic viscosity which were small. The diagram showed how markedly the capacity for spread decreased with decreasing densimetric Reynolds number. Once the spread velocity had fallen away at the edge of a field, i.e. at the front, the extent of the field behind the front was immaterial as regards its effect on the spread velocity, unless the field was then thickened by a continuing flow of buoyant effluent. In the simple case of a rectangular container the length of the front was constant.

139. If one considered a discharge of heated water (of the order of 1000 cusecs in the present case) into a 'stagnant' pool as an approximation to the presently considered situation at slack water, the perimeter of the field would initially be small and if the natural rate of advance of the front were small, a thickening would occur and would increase the rate of advance. However, as the perimeter increased the constant inflow would have less and less capacity to affect the rate of front advance.

140. The problem was similar to that illustrated in Fig. 6 of a paper on thermal

density currents by Dr Barr.[6] Forced surface density currents in a flume were illustrated at 'capacity' and above and below 'capacity'. In the power station outfall circumstance there was the added complication of increasing front length with extension. At present the model approach to prediction of such occurrences seemed to be the best method of obtaining knowledge prior to the actual operation of a station. But the scales of the model must be carefully chosen. Unfortunately our knowledge of basic occurrences, such as was contained in congruency diagrams and was used in the design of models, was as yet far from sufficient.[5] Nevertheless the problem of model simulation graphically illustrated the improbability of the formation of thin layers. A considerable exaggeration of the vertical scale of a model with a small horizontal scale was necessary to obtain correspondence as between model and prototype in the extent of a spreading buoyant field.[5]

141. Summarizing, two factors appeared to make unlikely the formation of thin layers of slightly heated effluent of the order of say, 6-in. thickness or less, and thus allow the dissipation of a considerable proportion of the heat content to the atmosphere:

(*a*) the pronounced scale effect in the mechanism of spread in stagnant water; and
(*b*) the tendency of a thin surface layer of heated water to suffer erosion and to be eventually mixed into a main tidal flow once the aforesaid flow had commenced.

Mr F. F. Ross (Research Department, Central Electricity Generating Board) wrote that the comments by Mr Hockley on the dangers of unprotected wood were worth emphasizing. Timber in seawater could be satisfactorily protected from *Teredo* and *Limnoria*, either by maintaining in good condition a coat of paint or varnish or by preservative treatment of the wood itself, and the British Wood Preserving Association had been conducting experiments in Shoreham and Poole harbours in collaboration with the Timber Research and Development Association. Wood borers served an important biological function in nature as scavengers of wood that nobody wished to preserve, and it would seem that a slight raising of the temperature enabled them to do their job more quickly.

The Authors, in reply, thanked all those who had contributed to the discussion.

144. The Authors wished to clarify for the benefit of Mr McDonald a possible but unintended misinterpretation of the relative responsibilities of the Harbour Board and the River Board. The Harbour Board as such was the Sea Fisheries Sub-Committee, the Harbour Master being the local Sea Fisheries Officer. The Paper referred to the Harbour Board having an interest in, but that should not be extended to include any responsibility for, migratory salmon and the other creatures for which Mr McDonald was responsible, a responsibility which he exercised so fully.

145. In §§ 74 and 75, Captain Andrew referred to the Rivers Itchen and Hamble being included in the investigation. It had, however, been necessary to confine the survey to areas where the warm water from the power station and refinery were proved to be circulating. Tests were being extended to the Hamble River in view of the construction of a new power station near the junction of that river with Southampton Water. Captain Andrew's remarks had been answered in part by Mr Hockley, and the Authors would have plenty of opportunities of arguing with him in the days to come.

146. The Harbour Authority could not cope with the whole problem of marine borer attack on wooden structures and ships. It should be a responsibility of all owners of such to see that they did not become breeding grounds for *Teredo* or *Limnoria*.

147. In § 99 Mr Tuck raised the question of timber protection, and Mr Ross also discussed this point. Protection was a matter of degree. A painted surface, while it was intact, would protect the timber and so also would chemical injection, but no such

protection could be permanent. The best protection for timber was that built in by nature, and the use of timbers known to be resistant to marine borers was likely to be most economical in the long run. Mr Ross's commendation of marine borers as scavengers would not be likely to receive the support of timber users in ports harassed by the attacks of these creatures. The whole field of timber protection would lend itself very well to more than one paper equal in length to the present one.

148. Mr Bruce Delve in §§ 124–126 appeared to misunderstand the nature of the marine borers. These creatures do not affect any timber above sea level. Generally speaking, the range of attack was from low-water level to a foot or two below high-water level. Cargoes in packing cases or stacks of timber would be quite unaffected.

149. In reply to Mr Coates' most stimulating contribution, the Authors were well aware that the extent of their investigation had only enabled them to explore the parameters of the problem of cooling ponds in estuaries; to do full justice to it would have meant a very large scale operation which would not have been at all economic and therefore had been entirely out of the question. As a result of their exploration they had obtained some useful information, but they knew its limitations and the conclusions drawn at the end of the Paper, so far as temperatures were concerned, were merely the observed results; no theories had been put forward, because it was impossible to draw any conclusions or propound any theories from the information gained.

150. Mr McDonald had referred to the temperature of the estuary in the vicinity of Marchwood being 2°F above ambient. The question of a continued rise in temperature was partly answered by Fig. 21 which amplified Fig. 5A. The temperature did not seem to go beyond 4°F above ambient, but it appeared to fluctuate violently. With the changing pattern of loading at Marchwood, the Authors did not envisage that it would exceed 4°F above ambient during the remainder of the economic life of the station. It would probably repeat the cycle of a rise of up to 4°F above ambient for a number of months, then a sudden drop back and then a rise.

151. The figures quoted in the Paper of 250 cusecs and 1000 cusecs were, as Mr McDonald pointed out, extreme flows. These figures would give the extreme limits for design purposes rather than the average conditions.

152. Recirculation was generally considered to take place when water flowed directly from the outfall to the intake within a period of one to two hours. As stated in the Paper, this had been observed on one occasion only. This was a serious condition since, with continued recycling, the temperature continued to rise above safe levels for marine life and economic levels for operation of plant. The Authors agreed with Mr McDonald that some recirculation did occur, but it was from the mass of warmed water opposite Marchwood rather than the condition noted above.

153. The rise in temperature as noted in § 56 had stopped (see Fig. 21). There now appeared to be some long-term cycling whereby the mass of water might rise to 4°–5° above ambient during the winter months, showing little or no difference in summer. This condition had been observed over the past two years with summer generation only slightly below winter levels. It was unlikely that summer generation at Marchwood in 1963 would approach that of previous years and as was normal in C.E.G.B. practice, would continue to decline with each succeeding year. Since the 4°F rise had had no apparent deleterious effects for the above reasons, Mr McDonald, and all who were interested in salmon and migratory trout, could be reassured that the Marchwood warmed water would not interfere with the passage of these fish through the estuary.

154. The tidal variations suggested by Captain Andrew would have to be considerable to account for the wide temperature fluctuations observed. The variations referred to were of the order 3–4 in. up and down over the tides each year. This would mean that the change in volume of water passing inwards and outwards through the section of the estuary at the outfall would change by 10–15% very roughly, which would not account for the changes in temperature (0°–4°F).

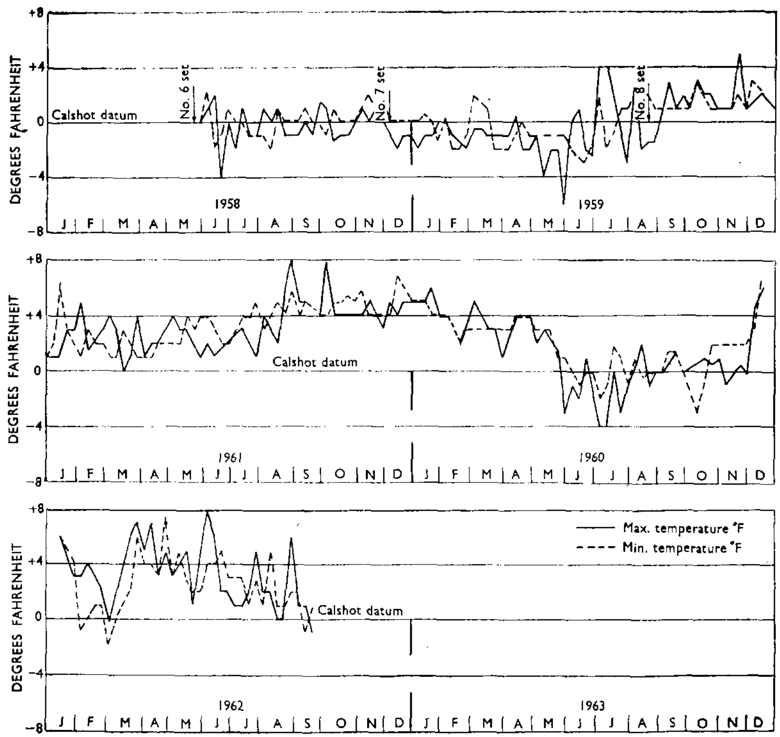

FIG. 21: MARCHWOOD GENERATING STATION—COOLING-WATER INTAKE TEMPERATURES

155. In answer to Mr Townsend, wind speeds and velocities were recorded for all surveys and shown on all charts recording the temperature conditions. In § 36 attention was drawn to the one occasion of recirculation which had been noted and it was quite clear that this was due to a very strong south-east wind. The wind considerably affected the shape of the cooling pond; subsequent surveys had noted the warmed water being moved against the tide. Precise measurements of the rate of cooling had not been made, but it was obvious from the extent of the cooling pond on a windy day compared with a relatively still day that the rate of heat dispersion was very much faster.

156. There had been occasions when the warmed-water discharge had been blown upstream against the ebb tide and downstream against the flood tide. That was remarkable in view of the fact that the tidal streams at Southampton were quite strong, particularly on the ebb and the last part of the flood.

157. The basis of the prediction in § 9(e) was that suggested by Throne,[9] which at the time (1952) was the only published information available on cooling ponds, while little or no practical studies of this problem were recorded.

158. Mr Webber's graphs (Figs 19 and 20), as he stated, were a simplified approach to the problem and could be used to give some idea of the parameters. However, these did not take into account the natural conditions which occurred in the estuary. Russell and Macmillan[1] had noted the variation in current direction and speed

between the surface (0–7 ft) and the bottom, while float runs had shown that the ebb current continued along the Marchwood shore for two hours or so after low water. In addition, the warmed water tended to move in a mass and was in a well defined stream some two miles from the outfall. In similar estuaries with other inflows, such variations from the average must be expected.

159. Mr Hockley was an active participant in the whole of the work, and since the Paper had been written, it had been possible to confirm his suspicion that Calshot as a datum point was no longer unaffected by heat. Recent surveys had shown that warmed water from Fawley Refinery flowed out of the estuary past Calshot in a narrow stream 50–100 ft wide, less that 3 ft in depth, and 1°–2°F above ambient temperature.

160. The limiting condition for the circulating water was a rise of 12°F between intake and outfall (i.e. across condensers, since the drop between these and the outfall was negligible) which was imposed by Southampton Harbour Board in giving consent to the station. This was not unreasonable, since, with river temperatures in excess of 70°F in the summer months, a rise of 12°F meant that the outfall temperature was approaching 84°F which some authorities suggested was the lowest level at which salmon might be killed. In summer months with intake temperatures around 70°F, considerable trouble was experienced in maintaining efficient turbine operation; thus greater temperature rises across the condenser could not be accepted.

161. The use of such tracers as fluorescein had been examined. To dose the system with sufficient to detect would have cost £2000 per hour. This cost, coupled with the fact that Southampton Water was a clean estuary where pollution was prohibited, was sufficient to banish such ideas.

162. Mussel growth in circulating water systems gave considerable trouble and could reduce plant efficiency. At Marchwood after one year's operation, about 100 tons of mussels and marine growth were removed from a culvert about 750 ft in length and 8 ft square. From observations, mussels would adhere to any irregularity in the surface, either artificial, e.g. cracks, fins, etc. or natural, e.g. barnacles becoming established, then mussels. While barnacles would adhere to smooth surfaces, mussels would very quickly build up along cracks, expansion joints, fins, airholes, and barnacles as well. Undoubtedly, a smooth hard surface made attachment more difficult, thus helping to reduce the attack. The problem of barnacle settlement was, however, one meriting attention.

163. There had been a number of velocities suggested beyond which mussels would not adhere to culvert walls. Those given had been average velocities for the whole culvert. It was well known that the velocity distribution was not uniform, the velocity near the walls being approximately zero; thus mussels could settle reasonably easily in a semi-still zone.

164. The figures quoted by Mr A. C. Oliver for Shoreham were interesting. It should be noted that the last set (No. 8) at Marchwood was commissioned in August 1959, not December 1961, as suggested. In comparing Marchwood and Shoreham, there were these differences:

Brighton A power station discharged into the Harbour.

Brighton B power station discharged direct into the Channel.

165. In 1961 the generation output of Brighton A was some 3% of that of Marchwood and probably in the winter months accounted for the higher temperatures at Shoreham. The effect of warming the layers of water over the mud flats in Southampton Water undoubtedly contributed to higher summer water temperatures at Marchwood in addition to heat from the power station.

166. To clarify a point raised by Mr Oliver, the Marchwood temperature records, although plotted as monthly maximum and minimum, were taken from continuous record charts which had been maintained in position for the whole of the investigation.

167. The forecast made in § 9 was quoted so that a comparison could be made

between the predicted behaviour (based on the knowledge then available) and the actual behaviour, and was in no way intended as a criticism as the forecast agreed with that of the C.E.G.B.

168. To answer Mr Haswell, the load factor for Marchwood since the commissioning of No. 8 set had been as follows:

	%
April–September 1959	90·8
October–March 1959–60	92·4
April–September 1960	80·8
October–March 1960–61	91·2
April–September 1961	78·3
October–March 1961–62	81·3
April–September 1962	77·5
October–March 1962–63	85·6

which was considerably in excess of the original forecast.

169. It had been proved that warmed water from Marchwood was dispersed in the estuary by mixing and did not leave the estuary as an identifiable mass, as originally suggested. Dr Barr, in asking what was meant by a thin layer, further suggested that it was unlikely to be 6 in. or less in thickness. This was contrary to what was suggested by Throne[9] and to experience at Poole power station. Here, water was taken from Holes Bay at depth and discharged into the Wareham Channel at mid-tide level. There was little or no fresh water entering these areas, and it was found that after about 500 ft from the outfall the warmed water had spread into a layer not greater than 1 in. thick. Under these conditions, it was affected by the wind to a far greater extent than at Marchwood.

170. The Authors emphasized the difficulties regarding the extent of biological aspects of the investigation. Had sufficient resources been available, not only plankton but fish and bottom faunal changes might all have been used as criteria of the 'health' of the estuary. They had been faced, however, with the prospect of doing something superficial or of concentrating on one aspect on which firm data could be provided. They would very much like to see the investigation continued.

171. Mr McDonald had asked about nutrients, particularly phosphates. A number of samples taken for phosphate analysis, further up the estuary from Marchwood, revealed an increasing amount of phosphate above the generating station site. From the information that Mr McDonald had given, the Authors agreed that this phosphate might not have originated from the River Test normal drainage; pollution was a possible source. A remarkable feature was that the highest concentration of phosphate usually appeared in the uppermost water layer which was of very low salinity.

172. Mr McDonald referred to the increase in mullet. This was not in itself objectionable, since such a density of fish indicated relatively healthy conditions. Mullet was a southern fish, and though well known in the English Channel, tended to seek warmer water such as would be present off Marchwood. It also fed at least in part on microscopic plant life, the growth of which would be stimulated by high nutrient concentrations in the estuary.

173. As regards wood-borers, the Authors would like to add only one further comment, following Mr Hockley's observations. They did not believe that cyclic outbreaks of *Teredo* were likely except in so far as the following two factors were operative: infected timber providing a centre for attack; increased temperature which, since *Teredo* was near its temperature limit in Great Britain, gave the possibility of high infection. The well-known outbreaks which had previously occurred, such as the great outbreak at Swansea, could probably be attributed to those two factors.

174. Mr Townsend referred to oxygen content. They had been aware of the

importance of oxygen concentration; any marked reduction might have most serious biological consequences. However, at present the oxygen concentration in Southampton Water seemed to be satisfactory. The situation was complex, because occasionally there was oil spillage in the area and oxygen values might then be suspect.

175. The Authors wished to add that, with their ordinary method of sampling, mussel larvae accounted for only an extremely small fraction of the plankton population. Samplings with very fine plankton nets, however, showed that very large populations of mussel larvae might be encountered in Southampton Water at intervals during the period April to August, so that very heavy settlements were possible over the summer.

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CORRIGENDA

In the first line of § 37 of the Paper, 'higher' should read 'lower'.

The captions of Figs 6 and 7 should be transposed.