WATER TEMPERATURES IN THE SOLENT ESTUARINE SYSTEM

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Introduction

The patterns of water temperature variation throughout the Solent and Southampton Water estuarine systems are controlled by a variety of processes including solar heating and evaporative cooling of the sea water brought in by tidal currents, the mixing of sea water with smaller quantities of river water often at a significantly different temperature, and the thermal effects induced by the periodic contact of sea water with intertidal mud flats acting as variable area radiators. Superimposed on these natural effects is the warming produced by the discharges from industrial outfalls. Following a description of these causal effects, hydraulic and mathematical models for predicting the dispersal of warm industrial effluents will be considered and compared with actual temperature variations which have been recorded in recent years in Southampton Water, the Solent and Chichester Harbour. These data are the result of close co-operation between the British Transport Docks Board, the Southern Water Authority, the University of Southampton and the Central Electricity Generating Board under the co-ordination of the Southampton Marine Research Committee. The biological effects of heated effluents are discussed in subsequent sections.

Heat balance

While the physical processes of heat balance within estuaries are similar in principle to those operating in the oceans (Sverdrup *et al.*, 1942), they differ in detail (Dyer, 1973). Estuarine waters are shallower and so more affected by evaporation, insolation and the heating or cooling of the intertidal (littoral zone) sediments. The effects of tidal excursions and fresh water discharges are more pronounced and the discharges of effluents from industry may also be significant locally. To allow for these additional effects, a revised heat balance equation is applicable, in which each term represents a heat transfer rate, typically expressed in W m^{-2}:

$$Q_s + Q_m + Q_o = Q_t + Q_b + Q_h + Q_e + Q_v$$

In this expression, the left hand side represents heating processes, the right hand side heat accumulation and loss processes. The individual terms are defined as follows:

Q_s = Incident radiation from the sun and sky

Q_m = Indirect heat received from mud flats subjected to previous insolation (positive) or evaporative cooling (negative).

Q_o = Heat emission from industrial outfalls.

Q_t = Heat used to alter the temperature of the estuary water (can be negative).

Q_b = Back radiation from the sea surface.

Q_h = Convection of sensible heat to the atmosphere (can be negative).

Q_e = Surface heat loss due to evaporation.

Q_v = Heat conveyed out of the region by tides, rivers and other currents, ie end losses from the system (can be negative).

The above relation only takes into account major processes and is not intended to be exhaustive. As pointed out by Sverdrup *et al.* (1942), minor heating effects also arise through the condensation of atmospheric water vapour, the transformation of kinetic energy to heat, the liberation of chemical energy and the conduction of geothermal heat.

In the Solent estuarine system, distinctive temperature contributions are provided by river and outfall discharges and intertidal mud flats. In Southampton Water (Fig. 1), the combined river flow from the Rivers Test and Itchen reaches a maximum of about $28m^3s^{-1}$ in late winter, declining to a minimum of $14m^3s^{-1}$ in summer, while the flow of the River Hamble is negligible. These river flows, however, are much smaller than the tidal flow into the estuary, which reaches a maximum of about $7500m^3s^{-1}$ on spring tides. The river water is cooler than sea water in winter, and warmer in summer, and its annual mean temperature (10.9°C) is significantly less than that of Solent water (12.0°C). Salinity measurements indicate that in the upper reaches of Southampton Water, river water is mixed with about 10 times as much sea water, producing a natural local seaward increase in temperature, whose mean annual value is about 0.1°C (Jarman and de Turville, 1974). Much larger differences occur as a result of seasonal and daily variations in weather conditions, tidal range and river flow.

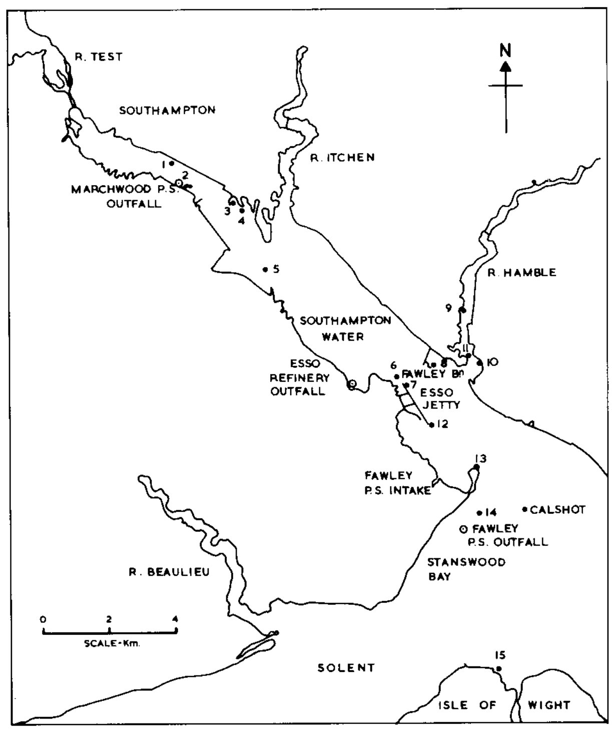


Fig. 1 Thermograph sites 1 to 15 in Southampton Water and The Solent.

The possible influence of the temperature of the intertidal mud flats which border Southampton Water, the Stanswood Bay coastline and the lower reaches of the River Beaulieu, on the ecology and heat balance of the area has been investigated by Spencer (1970-73). For example, at the mouth of the River Beaulieu (Fig. 1) an increase in the intertidal mud temperature of 7°C at 1cm depth and 1.6°C at 10cm over a 3 day period in

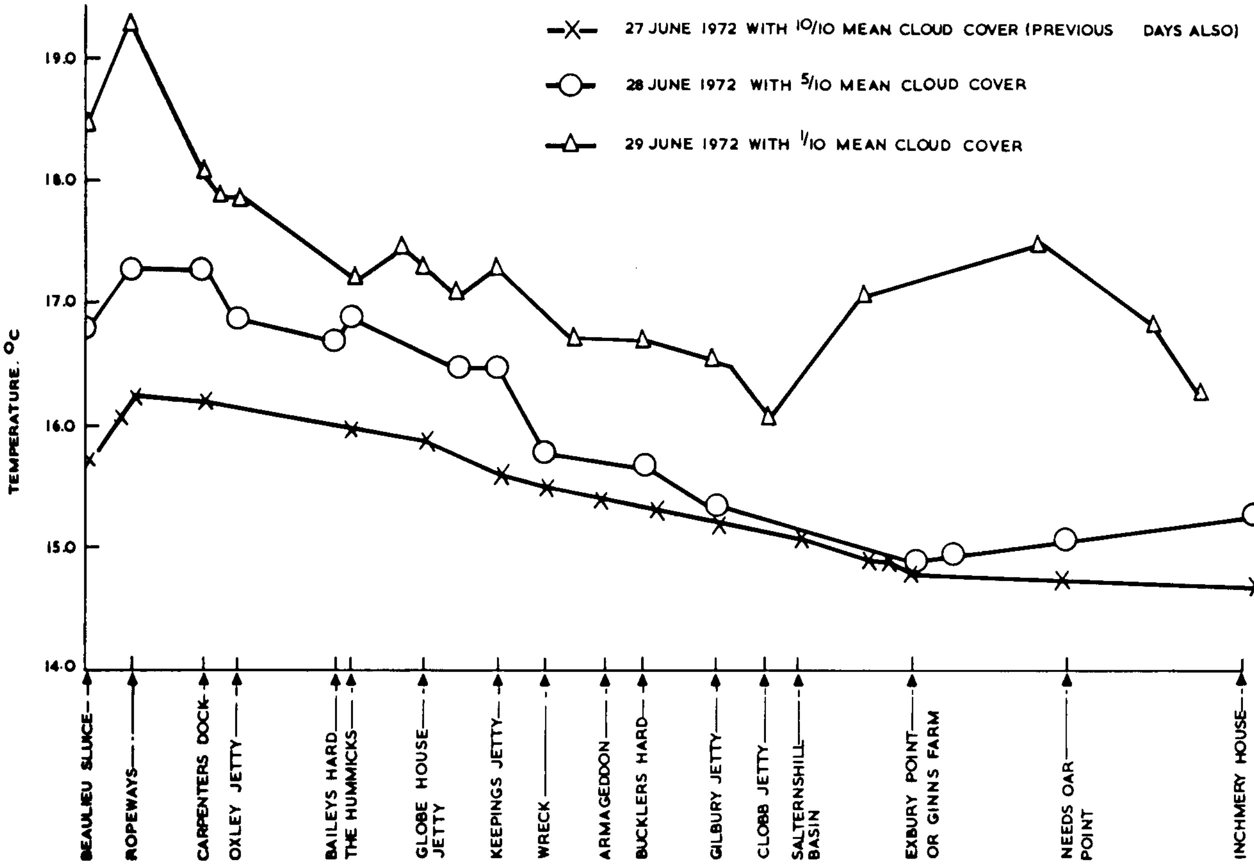


Fig. 2 Surface temperatures on high water slack in June 1972 for the Beaulieu Estuary.

June with diminishing cloud cover and more direct insolation, resulted in river water temperatures rising by as much as 3°C close to shallow areas at high water slack (Fig. 2).

Southampton Water and the Western Solent receive thermal discharges from the Marchwood and Fawley Power Stations and the Esso Refinery at Fawley averaging in recent years approximately 600, 2000 and 400 MW respectively. In a theoretical study of the warming of Southampton Water by industrial waste heat over many tidal cycles, Jarman and de Turville (1974) estimated that approximately 60% of the heat discharged by Marchwood Power Station and Fawley Esso Refinery is dissipated by evaporation within Southampton Water, the remainder being conveyed into the Solent by tidal action.

Processes of effluent dispersion

At Marchwood Power Station the water is discharged over a weir, which becomes submerged at high water, while at Fawley Power Station in the Western Solent, the discharge is effected as a submerged jet. In both cases, turbulence is generated, and there is a tendency for discharged water to rise due to its buoyancy. Mixing with cooler water is rapid at first, and then continues more slowly as the diluted plume from the outfall is entrained by tidal streams. Longitudinal, lateral and vertical diffusion cause the plume to broaden and penetrate to greater depths as it cools at increasing distances from the outfall. The effect of salinity on the buoyancy of a plume can be of great importance. Thus at 20°C an increase of 0.3°/oo in salinity is sufficient to counteract the increase in buoyancy produced by a temperature rise of 1°C. Since the density of sea water is a function of both dissolved salts and temperature, which vary with the seasons and the phase of the tidal cycle, corresponding changes in the behaviour of a plume from a given outfall might be expected. The interplay of tidally variable salinity and temperature gradients between intakes and outfalls probably also contributes to the marked differences between the Marchwood and Fawley plumes.

At some phase of the tidal cycle depending on the relative positions of the outfall and cooling water intake, a power station is liable to recirculate some of its heated effluent, thus lowering the station's efficiency by raising the temperature and back pressure of the condensers. The use of hydraulic and mathematical models at the design stage to determine the optimum location and configuration of intake and outfall structures helps to minimise recirculation. However, in addition to such single tide effects, heat may also accumulate over several tidal cycles in the area influenced by the outfall. As this residual heat is also constantly being abstracted by tidal action, river flows, and losses to the atmosphere, a long term change in equilibrium temperature tends to be set up in the affected area. To determine whether this rise in temperature is sufficient to cause any power station operational problems or significant ecological hazards, data and predictions derived from physical or mathematical models supplemented by boat, thermograph and littoral zone surveys, are invaluable.

Hydraulic model

In the design of the Fawley Power Station cooling water system, the likely pattern of effluent dispersion was estimated by Webber (Section 5) from tests on a hydraulic tidal model of Southampton Water designed by Wright and Leonard (1959) and described by Sara

(1958). Warm dye injections were also used to determine the optimum position of intake and outfall.

Mathematical treatments

(a) Introduction

As the physical factors controlling the dispersion of heat from an estuarine outfall are both complex and subject to irregular fluctuations, any tractable mathematical treatment must use a simplified model which preserves sufficient realism to yield valid conclusions. The two main problems of practical significance, each calling for a different type of treatment and requiring to be placed in perspective with the natural patterns of temperature distribution, are:

(i) to determine the path followed by a plume of heated effluent during the first tidal cycle to which it is exposed, and the corresponding evolution of its temperature pattern;

(ii) to determine the long term temperature distribution produced in an estuary by mixing of the effluent with the tidal stream over many tidal periods.

(b) Instantaneous plume temperature distribution

The warm water discharged at an outfall enters the estuary as a jet (Pearson, 1956) which is progressively dispersed within the estuary. Sutton (1947) has shown that in a stationary but anisotropic turbulent fluid stream of mean velocity $\bar{u}$, the concentration χ downstream of a continuous point source located at the surface and emitting Q units of matter in unit time is given by

$$\chi(x, y, z) = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} \exp\left[-\tfrac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]$$

where x, y, z are the cartesian coordinates of the point, with the source as origin, x along the stream, y across it and z vertically downwards. Also σ_y and σ_z are the root mean square deviations of the displacements of particles produced along the y and z axes by turbulent motions. A similar expression is applicable to the dispersion of heat, and σ_y and σ_z can be evaluated from temperature measurements. The expression for heat dispersion is obtained by replacing the concentration χ (x, y, z) by the temperature rise ΔT (x, y, z) produced by a continuous point source of heat which emits Q units of heat per unit time.

The Fawley Power Station draws in estuarine water which is slightly less saline and hence less dense than Solent sea water. The outfall discharges warmed water near the sea bed in the Solent, and this discharge rises quickly to the surface by virtue of its buoyancy. The heat disperses both laterally and vertically, and the coefficients K_y and K_z (related to σ_y and σ_z) can be estimated from the temperature measurements carried out by Carr (1970-73) and by Spencer (1970-73) during boat surveys. These lateral and vertical coefficients were found to be of the order $8 m^2 s^{-1}$ and $0.0004 m^2 s^{-1}$ respectively (de Turville, 1974). The reason why K_y is much larger than K_z in this estuary was explained by de Turville in terms of the scale of the turbulence, following Pearson (1956).

(c) Temperature distribution in an estuary

A number of theoretical models have been proposed to estimate the long term temperature distribution in an estuary produced by multiple tidal oscillations. A model described by Pearson and Pearson (1965) and further developed by Downing (1966), has been applied to Southampton Water by Jarman and de Turville (1974).

The estuary is considered to be longitudinally divided into a number of differing but individually homogeneous segments, and the water temperature in each segment is derived from the heat input, the heat lost by evaporation, the fresh water entering and leaving the segment, and the boundary mixing with adjacent segments caused by tidal oscillations. Mixing flows are evaluated from the known gradients of salinity distribution, and the thermal distribution is deduced using the fact that salt and heat diffuse in a similar way in horizontal turbulent mixing.

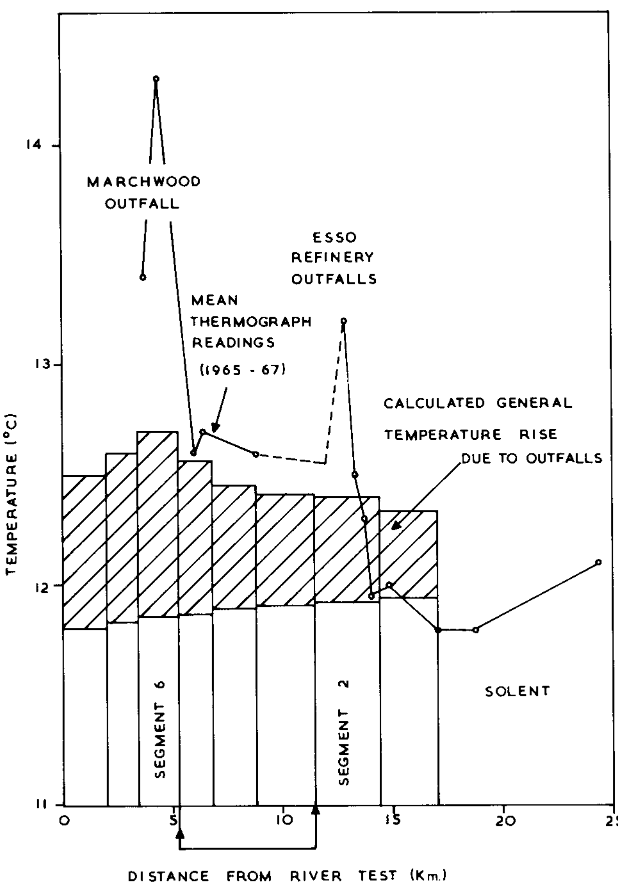
When this model was applied to Southampton Water to determine the long-term temperature distribution produced by the heated discharges from Marchwood Power Station and Fawley Esso Refinery, the estuary was divided into eight segments. Figure 3 shows the individually derived temperature increments for each segment (shaded) together with the calculated temperature distribution produced by the gradual mixing of river water with slightly warmer sea water (unshaded). The mean water temperature profile derived from thermograph data is also shown. The observed mean temperature rise of 0.7°C (Fig. 3) due to industrial effluents agreed well with the calculations, which predicted a temperature rise of 0.4 - 0.8°C and an estuary temperature of 12.4 - 12.6°C. Although finer details such as localised warmed spots near outfalls are not dealt with by the segment method, it is a useful way of predicting the longer term thermal distribution in an estuary from projected or actual heat discharges.

Measured temperatures in the estuary

(a) Introduction

The water temperature within the estuary varies

Fig. 3 Estimated and actual temperatures in Southampton Water.



spatially throughout the year. The three main causes of variation at any given time are, as pointed out earlier:

(i) the differences in temperature between variable inflows of river water and the sea;

(ii) the natural heat transfer processes such as turbulent mixing, insolation, surface evaporation and the contribution from intertidal mud flats acting as variable area radiators;

(iii) the discharge of heated effluents from industrial outfalls.

Thermograph records have been used to study the main features of the resulting temperature patterns. Stubbings and Houghton (1964) reported measurements made in Chichester Harbour and in the eastern branch of the Solent, while the results obtained at the fifteen thermograph sites in Southampton Water (Fig. 1) have been described by Jarman and de Turville (1971, 1974). Boat surveys conducted independently by both Carr and Spencer over the period 1967-1973 were used to provide additional detailed information on temperature patterns in the area influenced by the Fawley Power Station outfall plume.

(b) Southampton Water

As the entire length of Southampton Water is affected by tides, and river discharges are small in relation to the tidal prism, the natural temperature of the deeper water at points well removed from any outfall is similar to that of open coastal sea water. Consequently, in fairly deep waters the diurnal temperature variations are small while in shallow waters, appreciably larger variations are produced by the drainage of heated or cooled water from intertidal mud flats.

To measure continuously the temperature patterns in Southampton Water, mercury-in-steel thermograph recorders were installed at fifteen sites in the estuary and the adjoining River Hamble (Fig. 1). The bulbs of these thermographs were either kept at fixed depth below the water surface (using a pontoon or other floating support) or were secured to a pile at a fixed position (ie variable depth). Experience in similar situations has shown that these alternative arrangements produce significantly different results only near to outfalls. Elsewhere the natural vertical temperature gradients are small, except possibly over freshly flooded mud flats, and boat surveys show differences of only 0.2°C between surface and sea bed, which are comparable with the residual instrumental errors remaining after careful calibration.

The annual mean temperatures at all sites were derived from continuous weekly thermograph charts, analysing only every fourth chart in order to reduce the volume of data. Preliminary tests on the data from two sites showed that the annual mean derived in this way did not generally differ by more than 0.1°C from the annual mean obtained by using all the data. The results for the period 1965-1967 (Table 1) excluding the four sites directly affected by the Marchwood Power Station and Fawley Esso Refinery outfalls, show a general gradient down Southampton Water, with annual mean values of 12.6 - 12.7°C north of the River Hamble, 12.0°C around the confluence of the Hamble and 11.8°C in the Solent. Thus, on average the Solent was approximately 0.8°C cooler than the major part of Southampton Water during this period. For comparison, boat surveys conducted by Carr (1970-73) showed that at a depth of 0.9m, the temperature in Southampton Water, north of the River Hamble, on individual survey days decreased seawards by 1°C, with the western side warmer than the eastern side by about 0.5°C, probably due to the effluents from both Fawley Esso Refinery and Marchwood Power Station. Upstream in the Rivers Hamble and Beaulieu, the water can be warmer than sea water in summer and colder in winter by several degrees according to the prevailing weather. The main causes of temperature variations in Southampton Water have been discussed by Jarman and de Turville (1974) who ascribed them to the mixing of sea and river waters with different temperatures, and to the discharge of industrial waste heat at outfalls. The contribution of re-flooded areas of mud or sand was considered to be less important close to deeper waters than in the shallow margins of the estuary.

Table 1 shows that the annual mean temperature varies year by year within about 1°C (0.7 - 1.4°C in our sample). The standard deviation of individual annual means, estimated from the range, is approximately 0.7°C, although the year to year variations for any one month are likely to be greater.

Longer term variations using temperature data from

TABLE 1 **Annual Mean Temperature (°C) in Southampton Water for the period 1965-67**
(Numbered sites are shown in Fig. 1)

SITE NUMBER AND NAME	YEAR 1965	1966	1967	MEAN 1965-67	RANGE 1965-67
3. Royal Pier	12.2	12.9	12.8	12.6	0.7
4. Town Quay	12.2	13.0	13.0	12.7	0.8
5. Hythe	11.8	13.0	12.9	12.6	1.2
8. Shell Mex	11.4	12.8	12.6	12.3	1.4
9. Port Hamble *	11.2	12.5	12.3	12.0	1.3
10. School of Navigation *	11.2	12.5	12.2	11.9	1.2
11. Fairey Marine *	11.5	12.6	11.8	12.0	1.1
12. Esso South	11.2	12.5	12.3	12.0	1.3
13. Calshot Jetty	11.3	12.0	12.1	11.8	0.8
14. Calshot Survey Dolphin	11.1	12.2	12.0	11.8	1.1
15. West Cowes, Isle of Wight	11.2	12.5	12.5	12.1	1.3

* Situated on River Hamble

TABLE 2 **Annual Temperature Range (°C) in Southampton Water**

SITE	NUMBER OF YEARS ANALYSED	MAXIMUM(T_1) ANNUAL RANGE	MINIMUM(T_2) ANNUAL RANGE	MEAN = ½(T_1 + T_2)
Calshot Jetty	9	20.3	13.6	17.0
Hythe	8	21.2	14.6	17.9
Shell Mex	4	19.9	15.4	17.7
Calshot Survey Dolphin	4	20.3	15.8	18.0

Calshot Jetty (Carr, 1970) have failed to reveal any general warming of the mouth of the estuary over the period 1954-1967. In fact, temperature data for areas distant from any outfall over the period 1954-1962 (Hockley, pers. comm.) indicate that the yearly range can be from 14 to 21°C (Table 2) reflecting warmer summers and colder winters in some years and vice versa in others.

(c) Chichester harbour

The thermal conditions in Chichester Harbour have been described by Stubbings and Houghton (1964). The harbour is shallow and muddy and the fresh water flow into it is slight. At low water, the harbour is particularly shallow and so is appreciably heated by insolation, while at high water, the residual low tide volume is diluted by the large influx of sea water. This leads to a relatively large and regular diurnal variation in water temperature (Fig. 4). Since the harbour water in summer is typically 3°C warmer shortly after low water than at high water during daytime, but only 0.5°C warmer when low water occurs at night or in the early morning, insolation is clearly the cause of the large daytime temperature variations between low and high tide. In the winter, as the mud flats and shallow water cool more readily than the larger bulk of sea water in the eastern Solent, the situation is reversed, with the harbour typically 2°C cooler at low water than at high, both during the day and at night. The lack of any significant difference between day and night temperatures in winter suggests that evaporative cooling of shallow water and re-radiation from intertidal mud flats are the prime causes of the regular temperature variations which accompany the tidal cycle in shallow areas in the winter. Moreover, the daytime high water temperature in

TABLE 3

Water Temperatures (°C) for the Period 1951 - 1955

MONTH	Mean of day HW Chichester Harbour (a)	Mid-Channel (East Solent) (b)	Temperature Differences (a - b)
January	5.7	8.3	-2.6
February	4.4	7.8	-3.4
March	5.9	7.8	-1.9
April	8.5	8.9	-0.4
May	11.3	10.6	+0.7
June	14.8	13.3	+1.5
July	17.1	15.0	+2.1
August	17.5	16.7	+0.8
September	16.1	16.1	0
October	13.5	14.4	-0.9
November	10.5	12.2	-1.7
December	8.3	10.0	-1.7

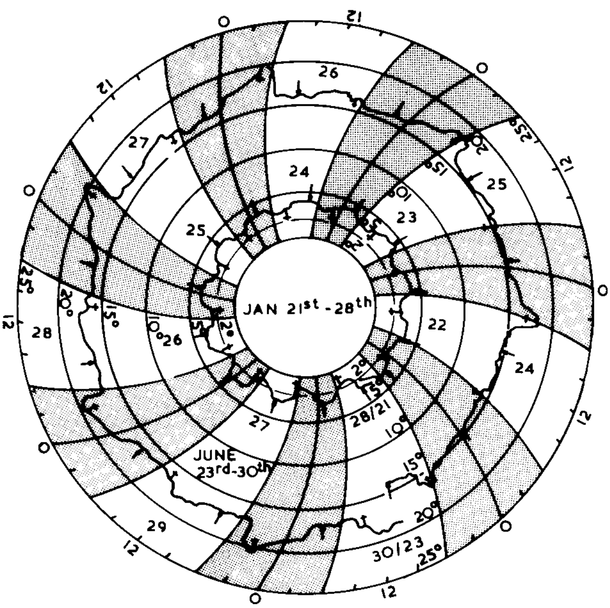


Fig. 4 Seven-day continuous records of sea temperature (°C) at 45 cm below surface for 21 - 28 January 1952 (inner tracing) and 23 - 30 June 1952 (outer tracing). ↓ time of L.W. ↑ time of H.W.

Chichester Harbour differs significantly from the corresponding temperature in the middle of the East Solent channel, due to summer heating and winter cooling of the shallow harbour water near low tide. Thus, harbour temperatures measured from rafts moored in the Emsworth Channel, 600m north of Sandy Point, were up to 3°C cooler in winter and warmer in summer compared with mid-channel water (Table 3). Presumably, harbour temperatures also vary with depth and location, although no data are available to quantify this fact.

From the limited information available, Chichester Harbour with its lack of major industrial discharge, may be 1°C or so cooler during both summer and winter than Southampton Water. Furthermore, mid-channel water of the Solent is warmer in the winter than Southampton Water and cooler during the summer.

Temperatures near outfalls

Many boat surveys to determine the effects of the waste heat discharged from the Marchwood and Fawley Power Stations have been conducted by the Central Electricity Generating Board, both before and during commissioning of the stations (Fig. 5). As expected from the multiplicity of factors known to affect the estuary including tidal conditions peculiar to Southampton Water, these temperature surveys have revealed a complex situation.

In Southampton Water, surface layers can be significantly less saline than deeper water, owing to the

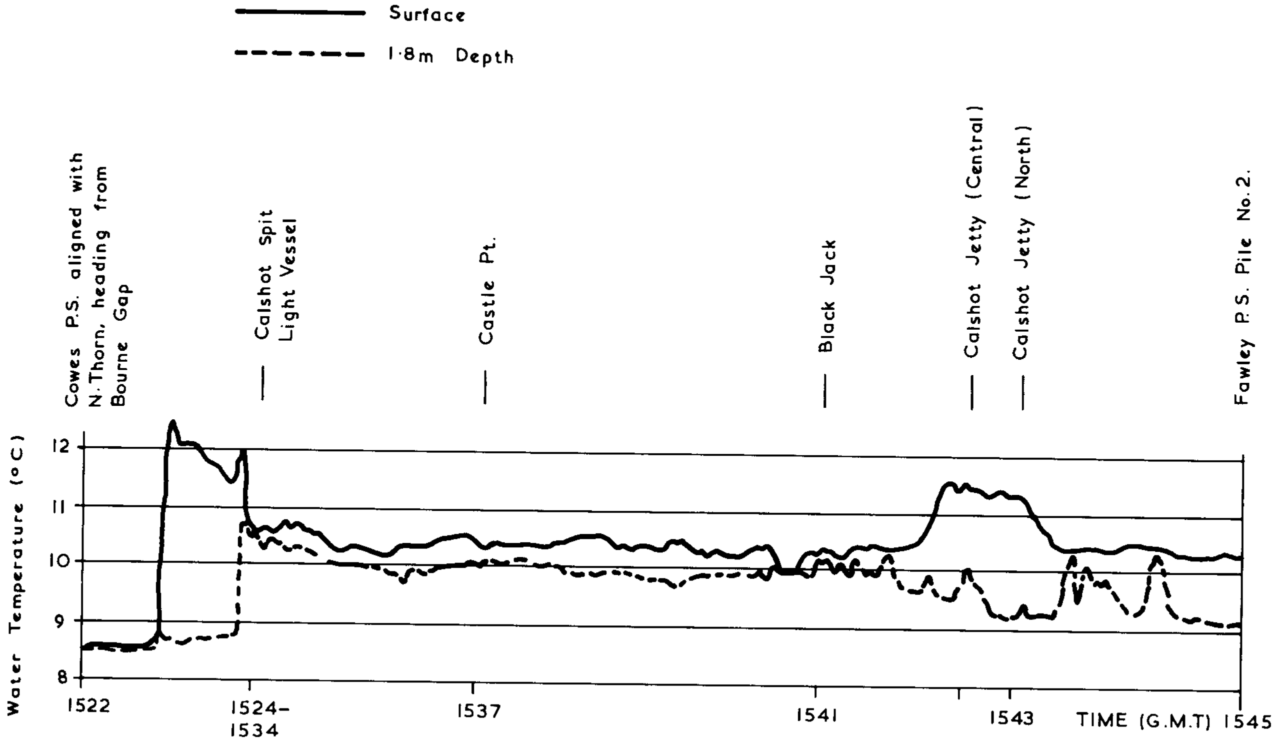


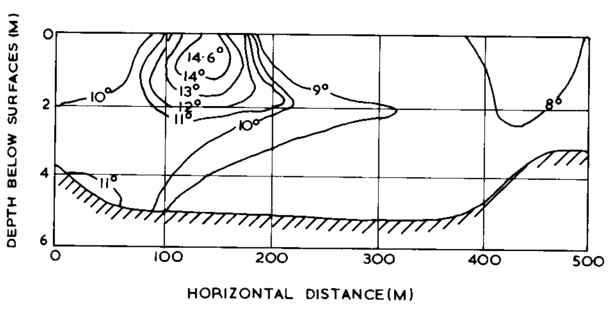
Fig. 5 Temperature transect from westward of Calshot Spit to Fawley Power Station entrance channel at L.W. + 5h (3.8 m tide) on 23 March 1972. Power Station load = 1395 MWE.

inflow of fresh water from the River Test. As the cooling water intake of Marchwood Power Station is situated below low water mark it draws in high salinity water which, after being raised 7 to 9°C in the condensers, is discharged at or near the surface, according to tidal level, into the less saline water. The warm and relatively more dense discharge water tends to sink and forms a 2-3 metre thick submerged layer (Fig. 6) whose excess temperature is reduced by dilution to about 3°C by 300m from the outfall (Pannell *et al.*, 1962).

The situation at the Fawley Esso Refinery outlet is such that the effluent which is discharged at up to 25°C above ambient, although declining in temperature with distance from the outfall, can on occasion be 8°C above ambient near Fawley Beacon around the turn of the tide.

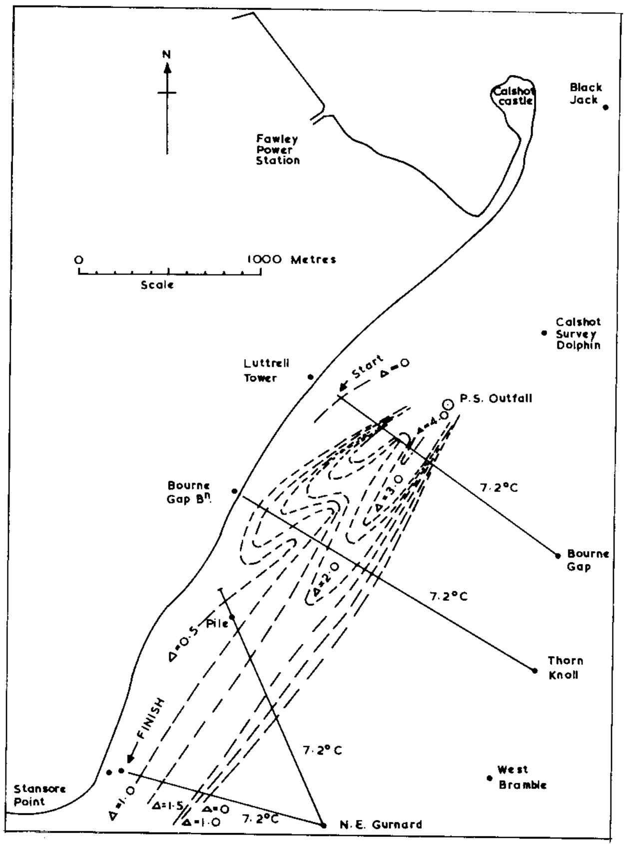
As the cooling water intake of Fawley Power Station is situated in Southampton Water and the outfall is in the slightly more saline Solent, the outfall plume derives buoyancy both from its lower salinity and its higher temperature (about 10°C above ambient) and rises to the surface. After the first kilometre or so, mixing and dispersal cause the surface plume to be less easily defined. On the ebb tide, westward flow at the outfall begins about an hour before high water at Calshot, and a

Fig. 6 Vertical section from centre line of Marchwood Power Station outfall to opposite bank of River Test, showing temperature profile.



well-defined bifurcated plume develops parallel to the Stanswood Bay shoreline (Fig. 7). It later disperses more widely into that part of the Western Solent beyond Stansore Point. At the beginning of the eastward flow of the flood tide, which occurs about an hour before

Fig. 7 Fawley Power Station plume surface temperatures between LW - 3h and LW - 2h (4.0 m tide) on 16 January 1973. Power Station load = 1760 MWE, $\triangle$°C = temperature in excess of 7.2°C.



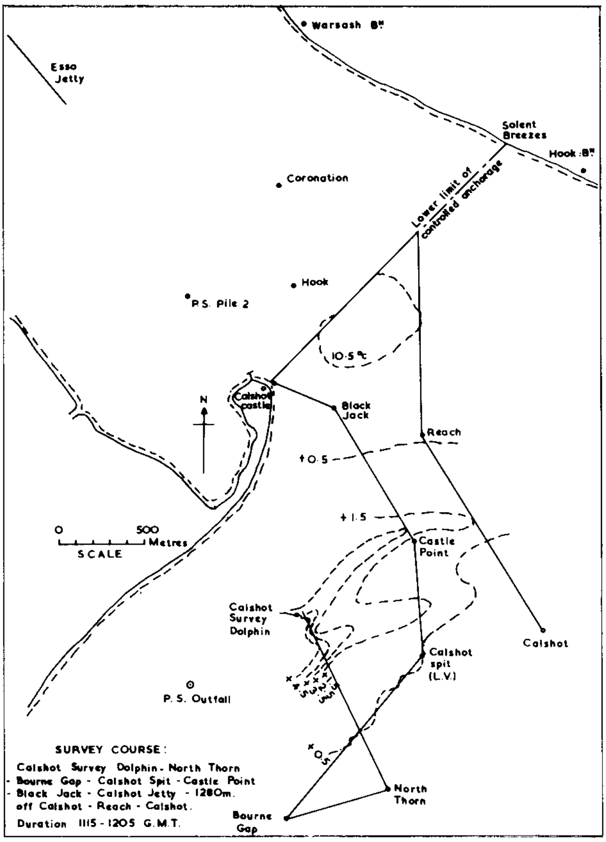


Fig. 8 Fawley Power Station plume surface temperatures at LW + 1h (3.7 m tide) on 15 November 1972. Contours show temperature in excess of 10.5°C. Power Station load = 1380 MWE.

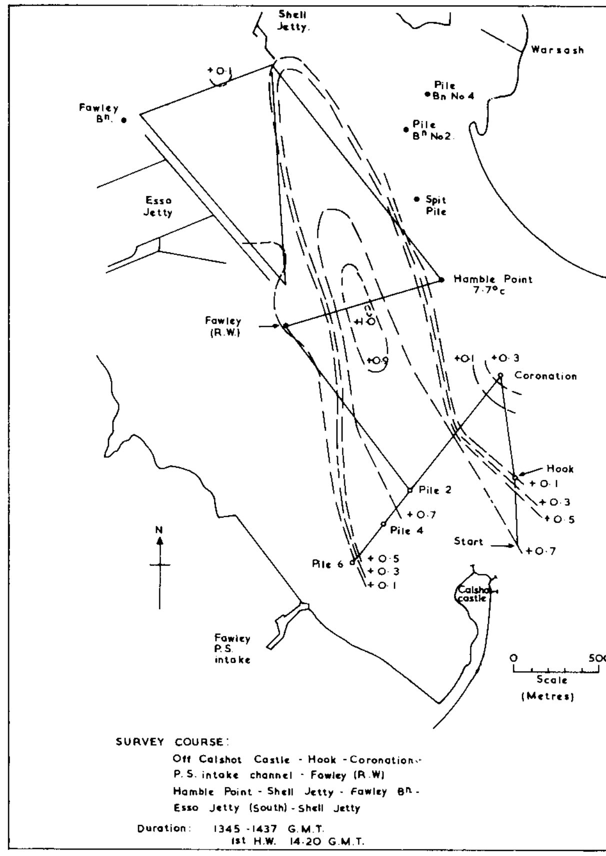


Fig. 9 Surface temperature distribution in Southampton Water at first high water (4.0 m tide) on 10 January 1973. Contours show temperatures in excess of 7.7°C. Power Station load = 1590 MWE.

low water at Calshot, the axis of the plume swings anticlockwise from south-west to north-east shortly before the tide begins to flow from the Western Solent into Southampton Water. The plume which results from these more complex tidal conditions is broader and less well defined than the ebb plume, and again shows evidence of bifurcation (Fig. 8). Also, the residual ebb plume is eventually swept back past the outfall by the flood tide, and has the new plume superimposed upon it. The maximum excess temperature measured at Calshot Reach during neap tides has been 4°C (Fig. 5). The flood plume from the Western Solent does not enter Southampton Water until after the Young Flood stand which occurs about 3 hours after low water. An increasing proportion of water from the Eastern Solent then enters Southampton Water. On a spring tide, the warm plume penetrates into Southampton Water as far as the Esso Jetty as high water is approached (Fig. 9), producing an excess temperature of about 1°C at high station loads. A tongue of cooler water in the estuary, forming the main tidal stream associated with the deeper channel, tends to confine the warm plume to the western side and no penetration of the plume into the River Hamble has been found. Any recirculation of the outfall plume into the Power Station intake on the western side is slight; an analysis of intake temperature records for the period January-March 1972 indicated this to be approximately 0.1°C.

Across the mouth of Southampton Water, the warmest water is generally found at the surface, though it can occur at intermediate depths either when the surface salinity is low enough to initiate density currents in the warmer but more saline plume effluent, or when sufficiently turbulent conditions exist.

Main conclusions

(i) The main features of the temperature pattern in Southampton Water have been established, but the detailed microstructure has yet to be studied.

(ii) Natural temperature variations between summer and winter ranged from 14°C to 21°C over a nine year period.

(iii) Southampton Water is approximately 1°C (on average) warmer than the Solent.

(iv) Over the period 1954-1967, no detectable warming of the water has been noticed at Calshot Jetty.

(v) Temperature variations in Chichester Harbour over a tidal cycle are more pronounced than in Southampton Water due to insolation of intertidal mud flats in summer or evaporative cooling in the winter. Similar natural variations have been found in more limited areas, notably in the lower reaches of the River Beaulieu.

(vi) The marked difference in the behaviour of the outfall plumes from Marchwood and Fawley Power Stations can be explained in terms of salinity effects on buoyancy.

(vii) The temperature rise due to Fawley Power Station outfall does not generally reach more than 2-3°C except in its immediate neighbourhood. During the ebb tide, the plume is well defined and largely confined to surface layers as it flows parallel to the Stanswood Bay coastline, while during the flood tide, it is more complex and swings north-east and penetrates into Southampton Water as far as the Esso Jetty at high water.

Acknowledgements

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REFERENCES

NOTE: References relating to Carr, de Turville and Spencer refer to C.E.G.B. internal reports which may be consulted on application.

Carr, J.F. (1970). *Calshot water temperatures.* SSD/SW/M8023.

Carr, J.F. (1970-73). *Fawley Power Station cooling water surveys.* (Memoranda SSD/SW/M8002, 8016, 8027, 8039, 8068, 8080, 8087, 8092, 8101 and 8103).

de Turville, C.M. (1974). *Turbulent diffusion in The Solent.* SSD/SW/M603.

Downing, A.L. (1966). *Some aspects of the work of the Water Pollution Research Laboratory.* Association of River Authorities Year Book, 1966.

Dyer, K.R. (1973). *Estuaries: A Physical Introduction.* pp xv + 140. Wiley, London.

Jarman, R.T. and de Turville, C.M. (1971). Industrial heating of Southampton Water, *Dock and Harbour Authority, 51,* No. 606.

Jarman, R.T. and de Turville, C.M. (1974). Dispersion of Heat in Southampton Water. *Proc. Inst. civ. Engrs., 57,* 129-142.

Pannell, J.P.M., Johnson, A.E. and Raymont, J.E.G. (1962). An investigation into the effects of warmed water from Marchwood Power Station into Southampton Water. *Proc. Inst. civ. Engrs, 23,* 35-62.

Pearson, E.A. (1956). *An investigation of the efficacy of submarine outfall disposal of sewage and sludge.* Publication No. 14, California State Water Pollution Control Board, Sacramento.

Pearson, C.R. and Pearson, J.R.A. (1965). A simple method for predicting the dispersion of effluents in estuaries. *Instn Chem. Engrs. A.I.Ch.E. - I. Chem. E. Symposium Series, 9,* 50-56.

Sara, H.J. (1958). Tidal model for Southampton Water. *Engineering, 185,* 198-200.

Spencer, J.F. (1970-73). Central Electricity Research Laboratory reports: *Surface water temperatures near Fawley Power Station.* RD/L/N183/70. *The dispersal of heated effluent from Fawley Power Station into Stanswood Bay.* RD/L/N136/71. *Water Temperatures in the vicinity of Fawley Power Station related to a load of 1440 MW.* RD/L/N169/72. *An investigation into the water temperature of the Beaulieu estuary in relation to insolation and to the operation of Fawley P.S.* RD/L/N98/73.

Stubbings, H.G. and Houghton, D.R. (1964). The ecology of Chichester Harbour, S.. England, with special reference to some fouling species. *Int. Revue ges.Hydrobiol., 49,* 233-279.

Sutton, O.G. (1947). The problem of diffusion in the lower atmosphere. *Quart. J.R. Met. Soc., 73,* 257-426.

Sverdrup, H.U., Johnson, M.W. and Fleming, R.H. (1942). *The Oceans.* pp. 1087, Prentice-Hall, New Jersey.

Wright, W. and Leonard, R.D. (1959). An investigation of the effects of a proposed dredging scheme in Southampton Water by means of a hydraulic model. *Proc. Inst. civ. Engrs., 00,* 1-18.