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A MODEL STUDY OF THE COOLING WATER DISCHARGE FROM NEWPORT 'D' POWER STATION

by

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SUMMARY

The performance of a small scale thermal hydraulic model is presented. The verification of the model both as a hydraulic model and as a heat loss model is outlined. The limitations on such a model operating without a controlled atmosphere and under severe scale distortion are discussed.

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Glossary of terms used

F_o = densimetric Froude number = $\frac{v}{\sqrt{(\frac{\Delta\rho}{\rho} gh)}}$
v = plume velocity m/s
$\Delta\rho$ = density difference between plume and receiving waters kg/m^3
ρ = density of receiving water kg/m^3
h = plume depth m
ΔT = temperature excess above ambient ^oC
ΔT_o = temperature excess at outlet ^oC
K = surface heat exchange coefficient $W/m^2/^oK$
K_o = surface heat exchange coefficient at jet outlet $W/m^2/^oK$
A = area in hectares or m^2
Q = discharge m^3/s
c = specific heat of water $J/kg/^oK$
X_R = horizontal scale ratio
Y_R = vertical scale ratio

Introduction

The proposed Newport 'D' Power Station will burn natural gas to generate 1000 MW of electricity. It is located at the northern-most tip of Port Phillip Bay in Victoria in the estuary of the Yarra River 7 km south-west of the City of Melbourne. Figure 1 shows the area that was modelled and emphasises the extensive dredging associated with the Port of Melbourne that plays a vital part in providing a deep salt water source for condenser cooling water for the station. The heat release to the cooling water is 1.36×10^6 kJ/s discharged in a total cooling water flow (including auxiliaries) of 40 m^3/sec with a temperature rise of 8^oC.

An existing power station of 180 MW capacity on the same site uses a similar cooling water system. During March, 1971, it was operated with a cooling water discharge of 10 m^3/s and a temperature rise of 8^oC and field tests (1) were conducted to provide verification data for a mathematical model and for this physical model of the cooling water discharge. Only the latter is discussed in this paper.

The Model

The model was constructed at the Water Research Laboratory of the University of New South Wales for the State Electricity Commission of Victoria. Operation was principally by staff of WRL with some direct assistance by SECV. The model was a fixed bed distorted model with a horizontal scale of 830:1 and a vertical scale of 25:1. The distortion of the model (33.2:1) was dictated by the space and tide generation equipment available as well as the necessity to accurately measure tidal stage and the need to ensure turbulence of the warm water jet for the smaller flow during verification of the model.

Model design used the same densimetric Froude Number, temperature excess, and fluid salinity as in the prototype so that the density differences were also the same in both cases. Scaling parameters were thus identical with those for conventional Froudian models since the scale ratio of $\Delta\rho/\rho$ was equal to unity.

Based on the work of Ackers (2) and Barr (3), the required relation between horizontal and vertical scale to ensure that the model correctly simulates heat loss (without wind) can be simply shown to be -

$$X_R = Y_R^{\frac{3}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This requires a vertical scale of 88.3 to correspond to the 830 horizontal scale used.

Measurement of temperature profiles occurring with the 25:1 vertical scale model showed that the plume was buoyant and confined to the surface a short distance from the discharge point; a fact which was also observed in the March, 1971, field tests. The deep nature of the dredged areas for some distance from the outlet also made it likely that bottom effects on the plume would be negligible except within the discharge channel itself. After verification of hydraulic performance with a vertical scale of 25:1 the vertical scale was changed to 88.3:1. In doing so the model bed was altered only in the outlet channel; elsewhere it remained as for the 25:1 scale.

With the model operating in this mode, an infrared technique similar to that used by Hindley et al(4) was used to determine the location of surface isotherms both for the fully established and steady state plume and during growth of the plume. The technique, described fully by McConchie(5), enables a particular surface isotherm on the model surface to be chosen and photographed. Providing a careful check is maintained on calibration, this is a powerful tool in such work. Infrared scanning equipment enables the continuous observation of water surface temperature and provides data that requires a minimum of reduction and avoids the need for interpolation between discrete measuring points.

The equipment used at Manly Vale was an AGA Thermovision System No. 680/102B hired in Sydney. A maximum depression angle of 45 degrees to the horizontal enabled the model to be scanned from a height of about 7 metres. A sweep angle of 11° (square) meant that several positionings of the camera were necessary to cover the discharge plume completely.

A certain amount of operator experience is required before repeatable and accurate readings can be attained. Although calibration curves are supplied with the equipment direct calibration with known temperature samples proved the easiest way to allow for the emissivity correction for water (since water is a non-blackbody radiator) and the actual range of temperatures being examined on the day. Figure 2 is a composite photograph showing a complete isotherm examined under steady state conditions.

When attempting to simulate the effect of wind on the model the problem becomes more complex. Ryan(6) presents the most comprehensive surface heat loss equation currently available. This gives for the rate of heat loss:

$$K = 23.0 + [14W_2 + 22.4 (\Delta\Theta_v)^{1/3}] (\beta_s + 0.255) + 7.5 (\Delta\Theta_v)^{-2/3} [e_s - e_a + 0.255 (T_s - T_a)] \quad \ldots\ldots\ldots\ldots(2)$$

where W_2 is wind speed at 2 m and other terms are as described in Ryan's paper.

Shemdin(7), when discussing wind shear effects gives the relation for induced surface velocities as

$$v_{induced} = 0.03\ v_{wind} \quad \ldots\ldots\ldots\ldots(3)$$

The 3% factor varies in the literature, Liu(8) gives 5%, Larson(9) gives 1% and Bains(10) gives 2%.

When simulating heat loss from the model in the presence of a wind field the single scale relationship of equation (1) is not applicable due to the presence of wind function terms in equation (2). The latter requires a scale ratio of unity if heat loss rates are to be the same in model and prototype. However, as far as simulating the wind shear imparted to the water surface is concerned the model wind should be such that equation (3) is satisfied. It is apparent that simultaneous modelling of shear and cooling effects of the wind is not possible.

The result of adopting Froudian scaling for wind will be that heat loss rates will fall short of those in the prototype. The orientation of the plume will be correct, but areas within isotherms will become progressively larger than they should be as the lower isotherms are approached.

Verification

The extensive field testing carried out by the SECV in March, 1971, provided surface isotherms produced from the temperature surveys for 14 days of operation of the station, temperature profiles through the plume, surface water movements in the area and two days of aerial infrared thermographs taken at hourly intervals. This information, together with tidal and meteorological information from a large number of points, provided sufficient data with which to verify the model. The reproduction of tidal levels at several points on the west coast of Hobson's Bay and in the Yarra iteself was satisfactory. Figure 3 is typical verification of tide levels for 24th March, 1971, at a point 6 km from the river mouth. Temperature profiles within the field plume and model equivalent at corresponding points are compared in Figure 4. In Figure 5 areas within isotherms taken from the field tests and from the model are compared.

Apart from confirming tidal performance, near field plume entrainment and surface velocities, which could be termed 'hydraulic' performance, the rate of surface heat exchange needed careful checking before any reliable prediction could be made of the extent of plume. It should be borne in mind that a significant amount of 'near field' information, such as recirculation between outlet and cooling water intake structure, tidal influence on the discharge plume within the river mouth and the depth of warm water that could be expected near the intake structure, would be little affected by errors in surface heat loss. On the other hand, assessment of the environmental impact of the warm water plume requires knowledge of its physical dimensions and position and of its susceptability to wind, tide and ambient currents.

Figure 6 is a dimensionless plot of the area within a particular surface isotherm against its temperature for a large number of model runs with a variety of flows and temperature excess. It is apparent from the figure that the model at any rate is consistent in its results and that the area contained within a given isotherm, expressed in dimensionless terms, for a jet with a discharge Froude number near or equal to unity is given by

$$\frac{\Delta T}{\Delta T_o} = 0.087 - 0.518 \log \frac{K_o A}{\rho Q c} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The line of best fit from Figure 6 is replotted in Figure 7, together with field data from Newport and from two NSW power stations illustrating the consistency of this relationship with these prototype examples.

Predictions from the Model

A parametric approach was adopted to examine the behaviour of the discharge plume from the proposed Newport 'D' development.

Tidal effects were found to be slight except in the immediate vicinity of the river mouth. Tidal range is about one metre at the river mouth and tidal velocities within Hobson's Bay are consequently very small. Examination of a specific surface isotherm revealed a regular oscilation with the tide cycle with movements restricted to about 250 metres. To simplify model operation most tests were therefore run without tide.

The steady state isothermal pattern developed by the discharge of 40 m^3/s of water with a temperature excess of $8^\circ C$ is presented in Figure 8 for model operation without wind, tide or river flow.

Stratification of the receiving waters can markedly effect the surface extent of the plume and can be present in a tidal estuary as a result of diurnal temperature fluctuations or from the presence of a brackish surface layer resulting from mixing of any river flow with the underlying salt water. Although the exaggeration of the model ($\approx$ 9:1) prohibits the correct simulation of diffusion processes, useful qualitative information on the interaction of the warm water plume and adjacent river plume was obtained. It was apparent that a 'three layer situation' of fresh water overlying warm salt water which in turn overlays cold salt water can exist. However, rapid entrainment along the interfaces quickly destoryed the effect and a stable though somewhat cooler single surface layer was established. The interaction of a 10 m^3/s river flow with a 40 m^3/s power station discharge is shown in Figure 9.

Earlier remarks relating to the modelling of wind effects outlined limitations to examining cooling and shear effects of a wind field simultaneously. However, operation under Froudian scaling gave useful quantitative information on plume position even though plume areas would be conservatively large.

In relation to the design of cooling water intake structures associated with the proposed development, the extent of stratification to be expected within the Yarra River mouth adjacent to the site was determined. This information was relayed to a second model, undistorted, in which the performance of an intake skimmer wall was examined.

Conclusions

Provided outlet densimetric Froude Numbers are low (≈ 1.0) a good representation of plume spread rate, shape, area and cooling effects can be obtained in quite small scale distorted models. Good information with which to verify model performance is however essential in this type of model where the simulteneous examination of a variety of physical processes is undertaken.

The simultaneous modelling of wind cooling and surface shear effects is not practicable while a density scaling of unity is maintained. Modelling of wind flows over large areas, such as a hydraulic model, is itself difficult and full verification is not likely to be achieved anyway due to the variability of wind in nature.

The entrainment processes associated with jet development (both warm water jet and river flow) would be modelled incorrectly in distorted models such as the one described by the authors. However, the penetration of a cold water wedge beneath the cooling water outflow and a salt water wedge beneath the river outflow were observed and associated with the correct critical Froude numbers.

Acknowledgement

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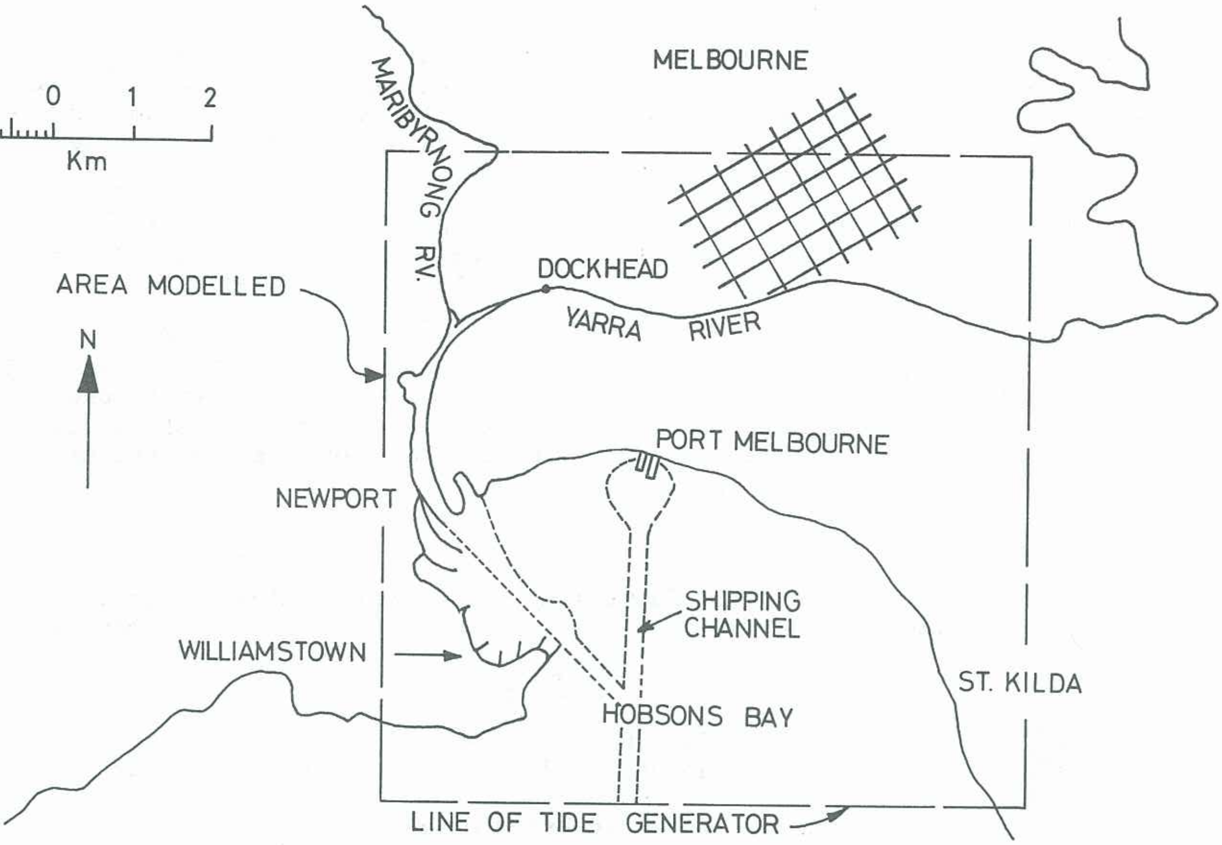

FIGURE 1 LOCALITY PLAN

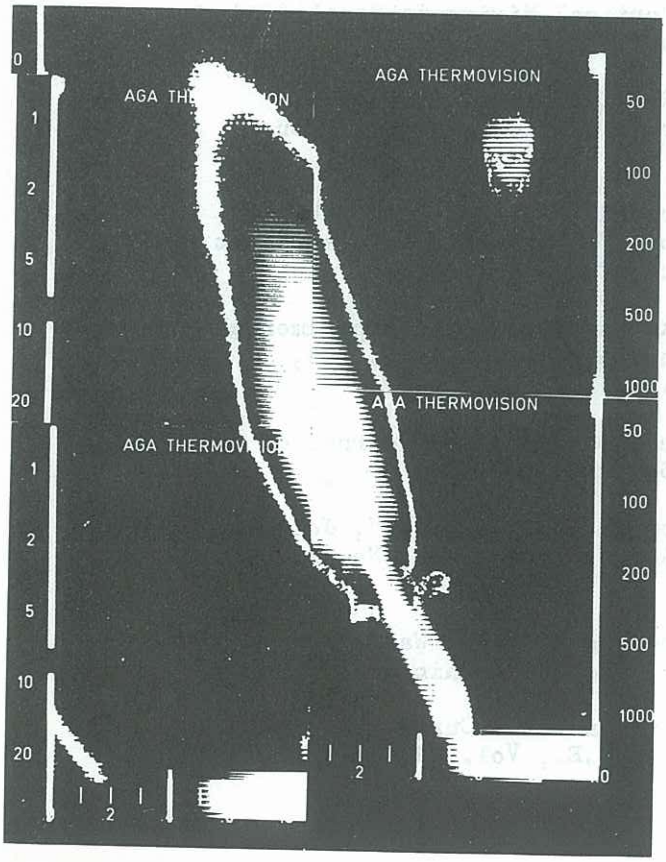

FIGURE 2 COMPOSITE ISOTHERM

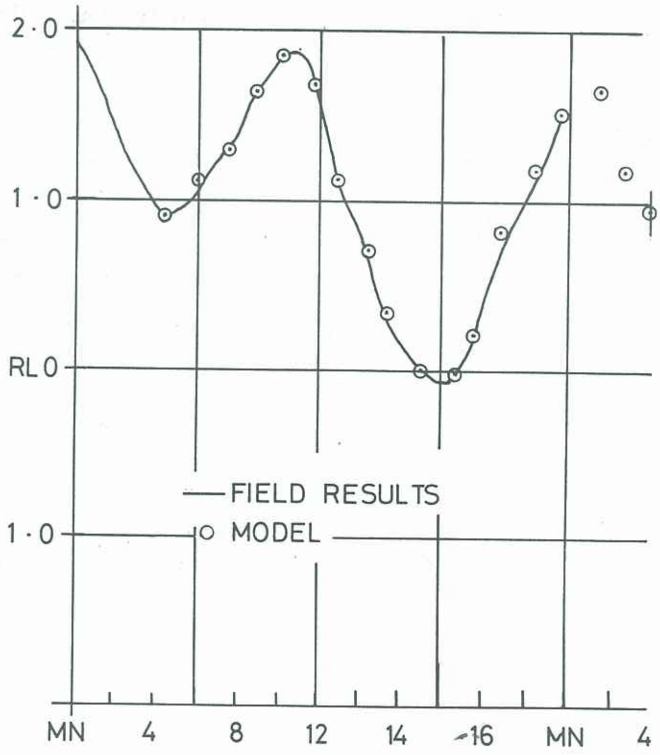

FIGURE 3 TIDE AT DOCKHEAD (24-3-71)

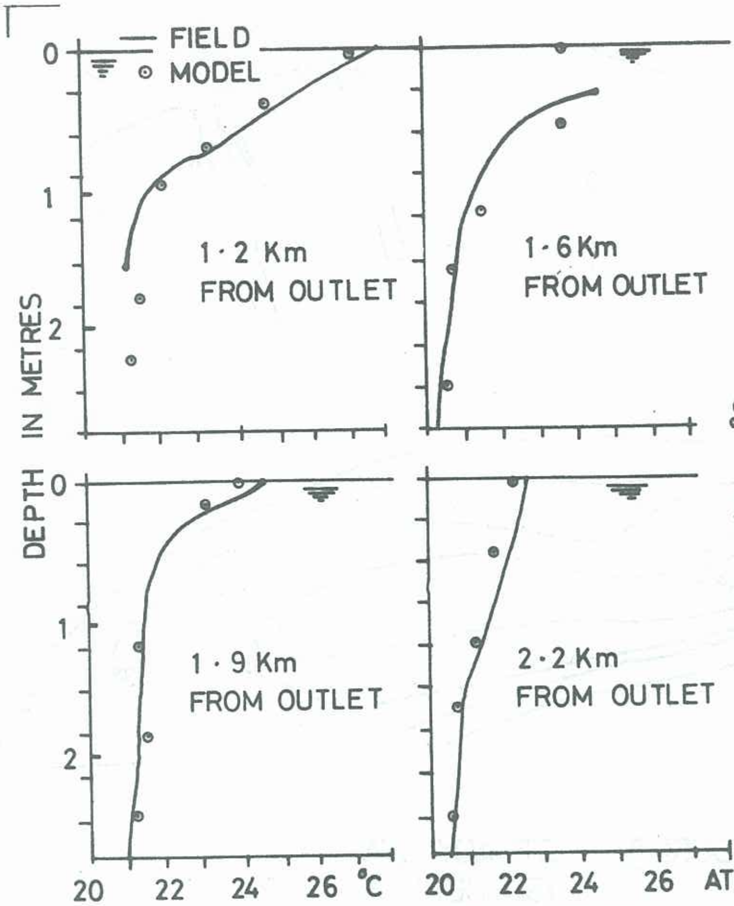

FIGURE 4 TEMPERATURE PROFILES

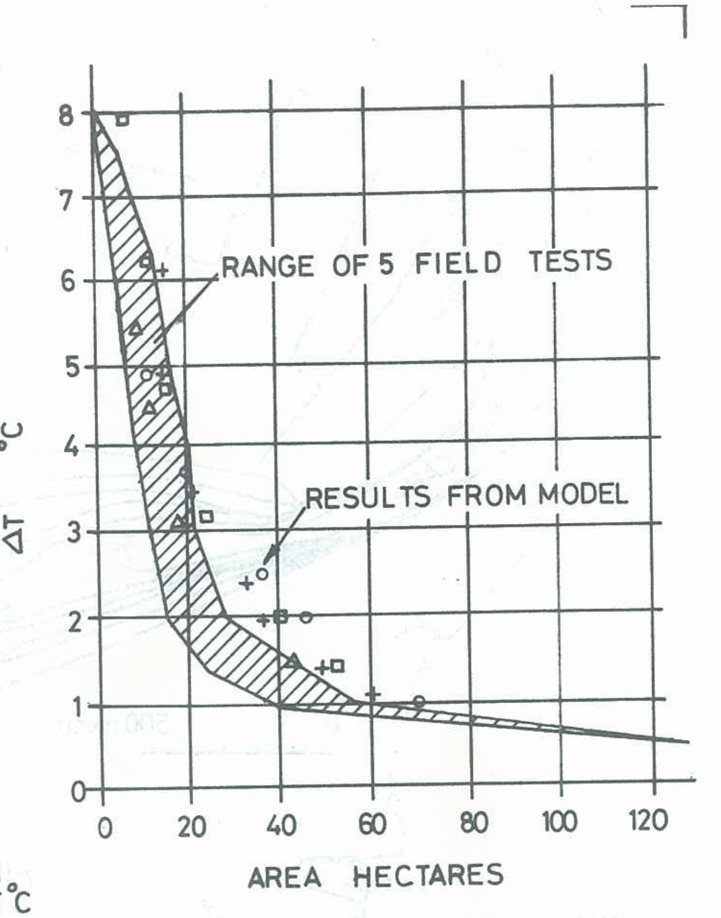

FIGURE 5 AREAS WITHIN ISOTHERMS

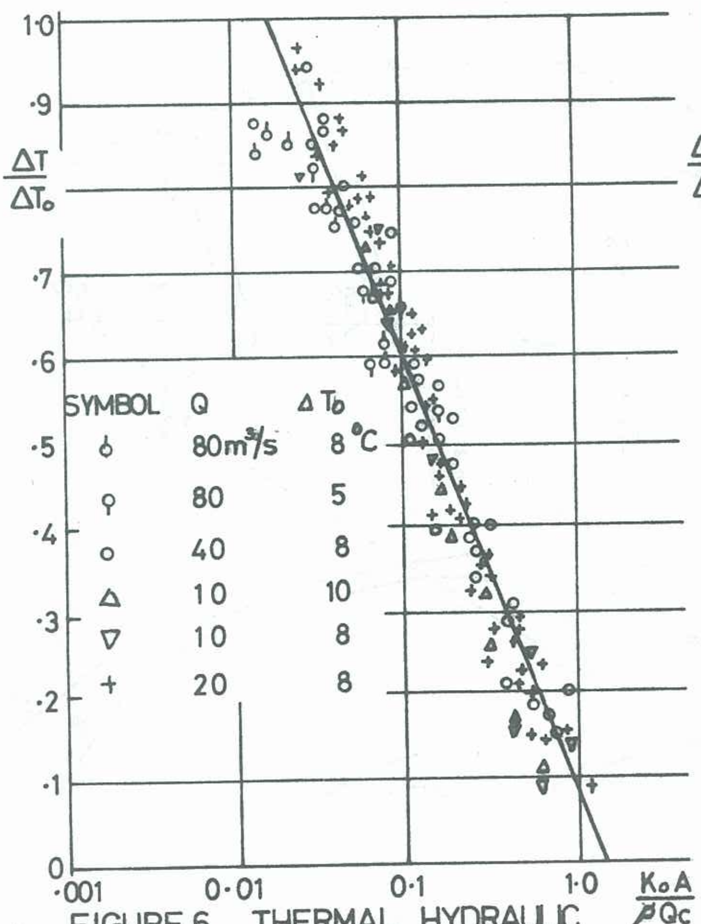

FIGURE 6 THERMAL HYDRAULIC MODEL RESULTS

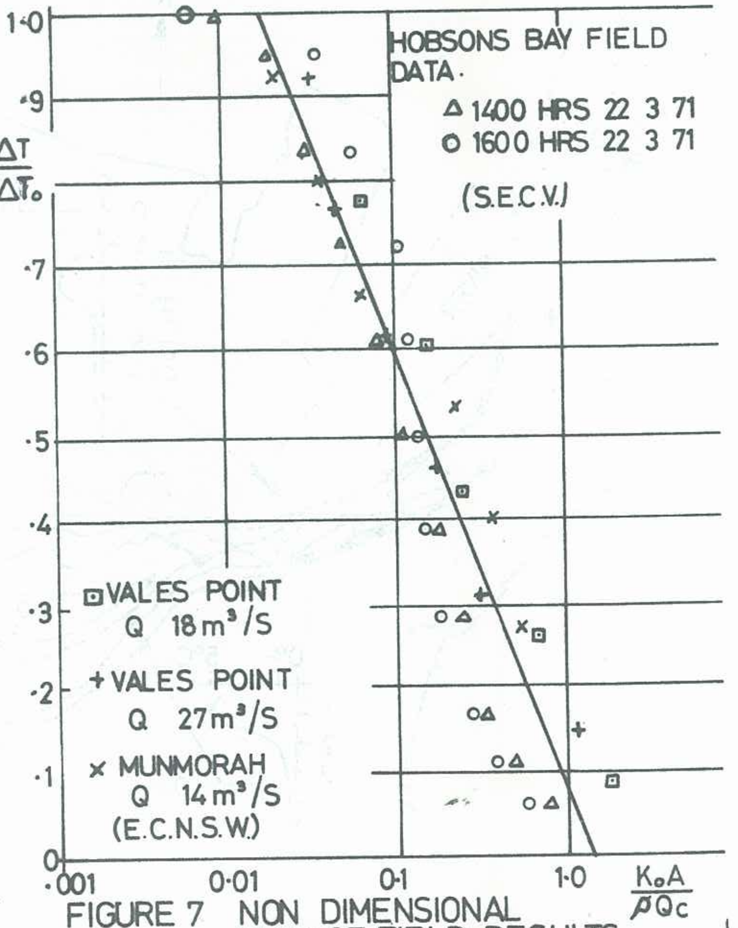

FIGURE 7 NON DIMENSIONAL PLOT OF FIELD RESULTS

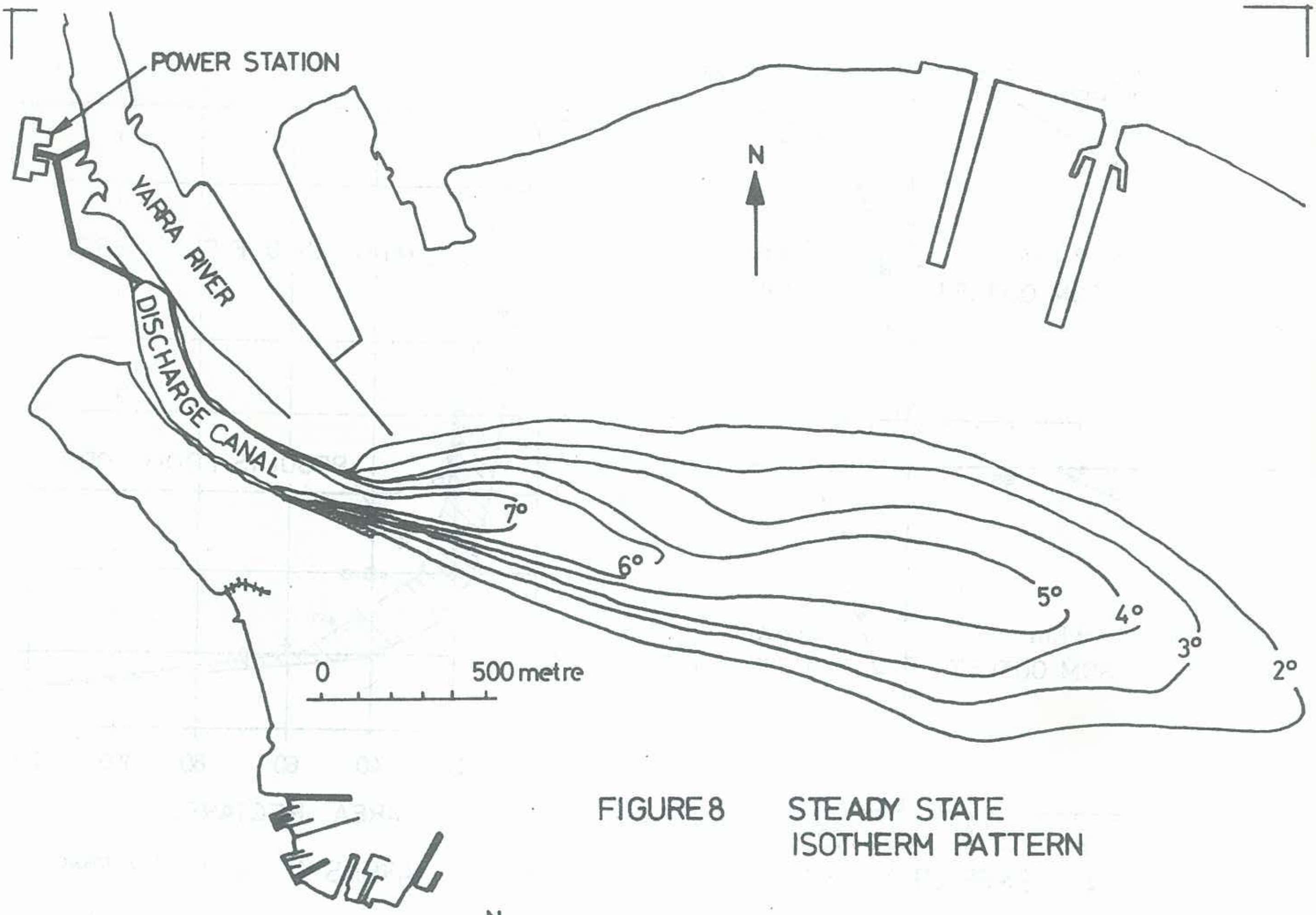

FIGURE 8 STEADY STATE ISOTHERM PATTERN

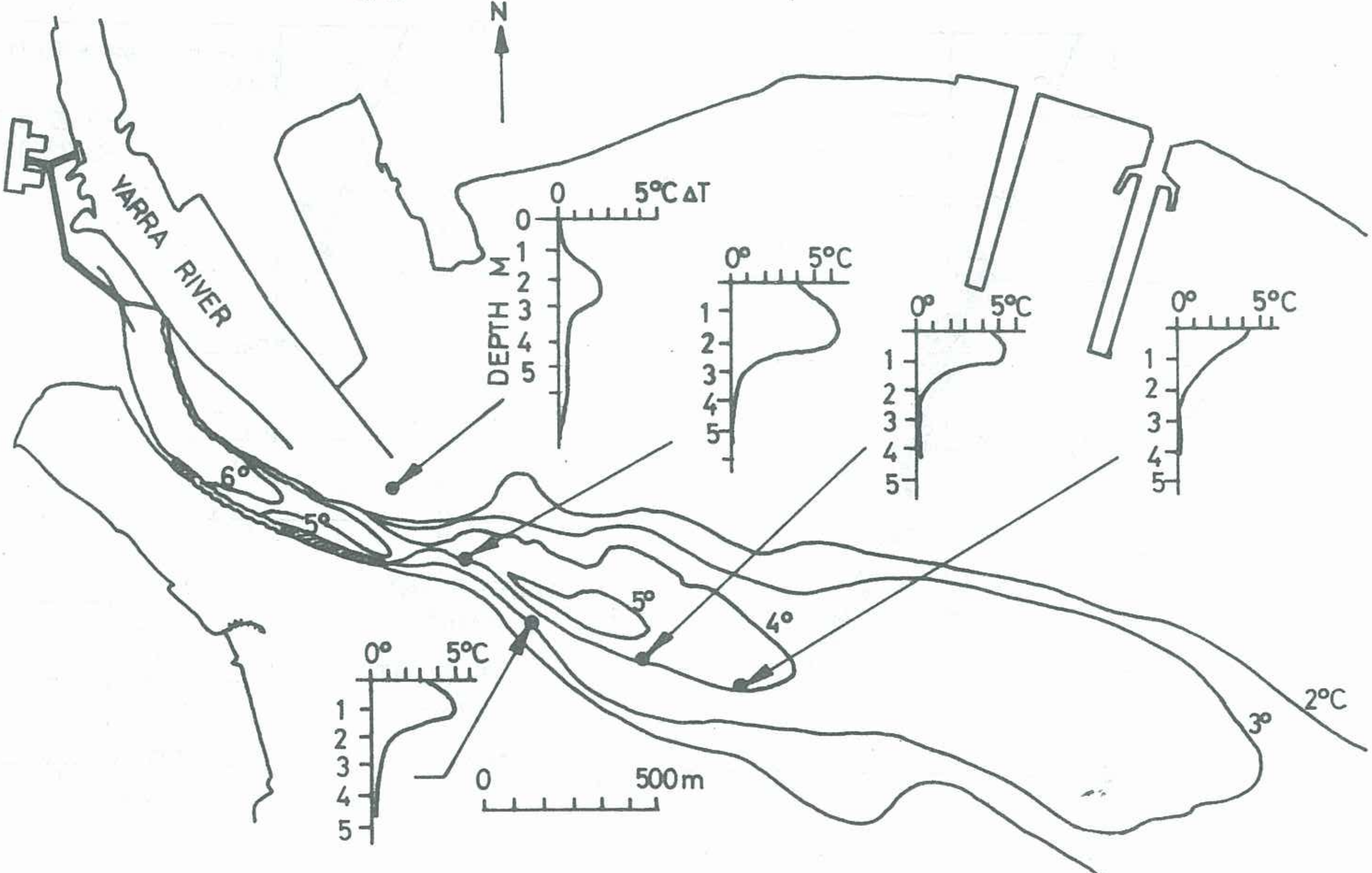

FIGURE 9. INFLUENCE OF RIVER FLOW ON THE PLUME.