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THE DISPERSAL OF HEAT FROM POWER STATIONS

by

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S U M M A R Y

With present technology, the conversion of thermal energy into electrical energy at power stations necessitates considerable quantities of low grade heat being dissipated into the atmosphere from the stations' cooling water system. The demand for electrical energy is doubling approximately every decade and available water resources must be utilised in disposing of this increasing heat load.

Methods available include simple single pass systems in which the available water is used only once, to more elaborate systems employing cooling towers,cooling ponds or marine estuaries and bays. These systems involve an understanding of the heat transfer processes and its effect on the environment which can become highly complex in tidal estuaries.

Field studies, together with mathematical and/or hydraulic models, can assist in determining the physical features of a proposed system, while biological studies can indicate the probable effect on aquatic life.

The paper will discuss these aspects and describe some examples in Victoria.

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1. INTRODUCTION

Over the past two decades the demand for electrical energy within Victoria and the Australian continent generally has been doubling at the approximate rate of once in every eight years. Although the rate has shown a tendency to decrease slightly in recent years, the ever increasing demand for power will require careful investigation and planning of development to utilise the country's natural resources to the best advantage whilst at the same time adequately conserving the environment.

Up to the present, power generation needs have been met by a combination of hydro-electric plant utilising natural stream flow and steam generating plant using mainly black or brown coal as a fuel. With the completion of the Snowy Mountains hydro scheme in 1974, the major part of the economical hydro generating potential on the mainland will have been developed. The main source of future electrical energy must therefore come from the steam-electric type of plant. This type of plant could use various fuels and, in the case of the Victorian generating system, the choice will probably lie between brown coal, natural gas, oil or nuclear fuel, depending on the required plant duty and economics of the particular development.

Irrespective of fuel choice the steam-electric plants pose a common problem through the rejection of low grade heat to the cooling water flowing through the steam condensers. A typical example of a power generation and water cooling system for a nuclear plant is illustrated in Figure 1. The steam and water cooling circuits as shown would be similar in the case of fossil fuelled plant. Steady development of steam plant during this century has substantially increased efficiency and thus reduced the quantity of heat rejected relative to power output. However, the modern fossil fuelled generating plant has an efficiency of about 38 per cent in converting heat into electrical energy. Even with further development over the next decade, it is not anticipated that an increase much beyond 40 per cent will be achieved. Nuclear plant at its present state of development has an even lower efficiency than fossil fuelled plant. Looking into the future there are some possibilities for improvement. Fast breeder reactors will increase the efficiency of nuclear plant whilst such things as nuclear fusion, fuel cells and magnetohydrodynamics offer further opportunities for increasingly efficient energy conversion.

It is nevertheless obvious that for some years in the immediate future, large quantities of heat will be rejected from the power plant by medium of the condenser cooling water flows. This will require adequate means of dispersal in order to avoid an undesirable impact on the receiving ecosystem and the environment generally.

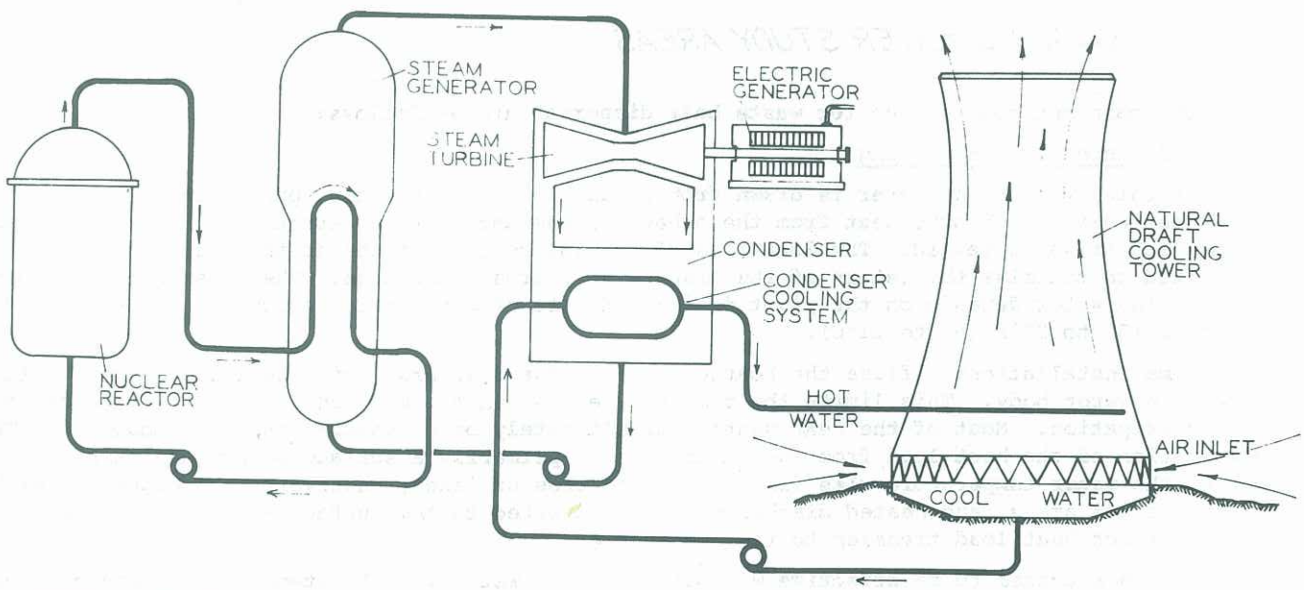

FIG. 1 TYPICAL COOLING SYSTEM FOR NUCLEAR POWER STATION

2. METHODS OF HEAT DISPERSAL

A number of different methods are employed for the dispersal of the thermal discharge depending largely on the resources available at the site selected for the power station. However, in some cases, the provision of adequate supplies of circulating cooling water and the subsequent dispersal of heat load may be the major factor in the selection of a power station site. Some of the sites under investigation for future power stations in Victoria are shown in Figure 2.

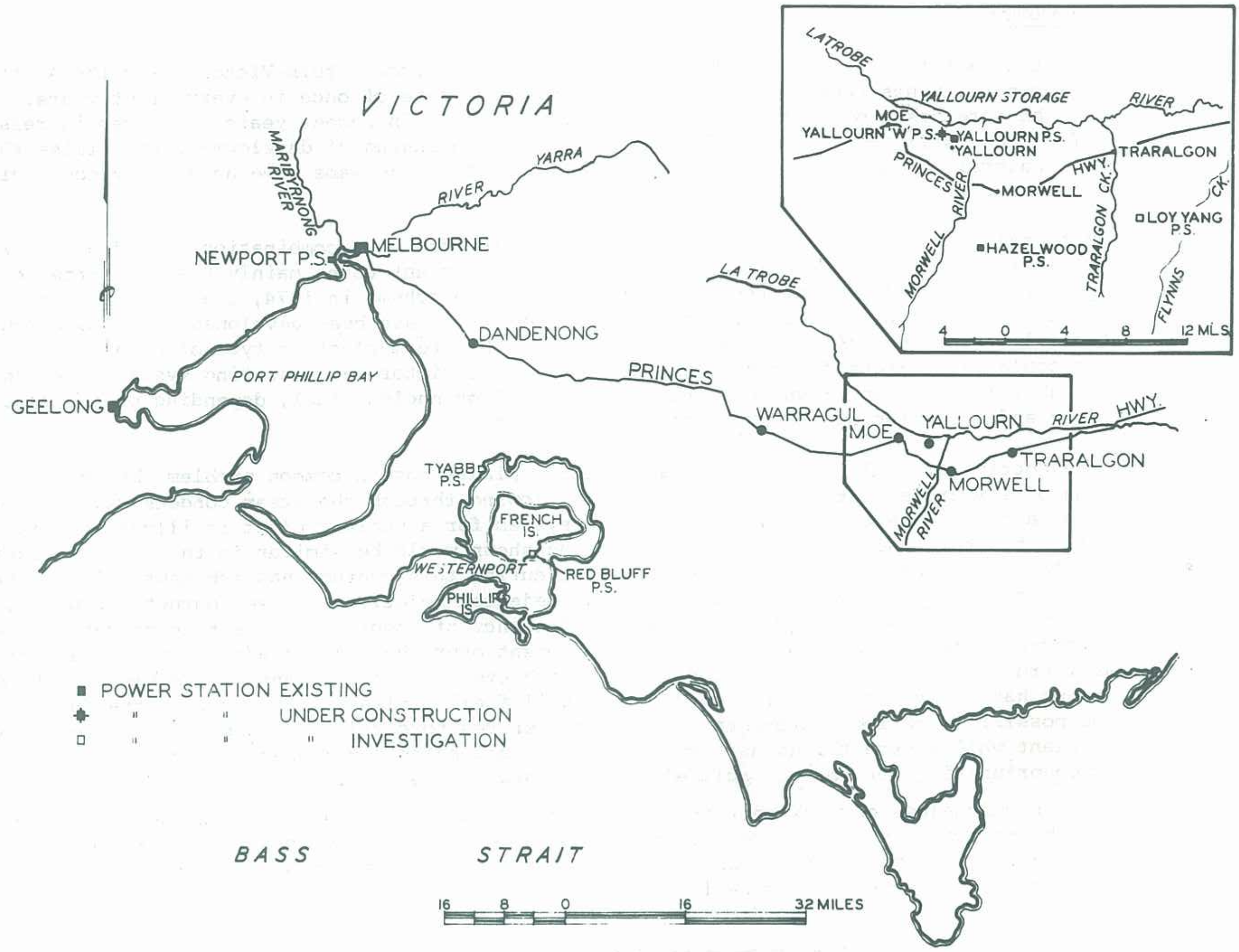

FIG. 2 COOLING WATER STUDY AREAS

The main methods adopted for waste heat dispersal are as follows:

2.1 <u>Once Through Cooling</u>

In this system cool water is drawn from a lake, river or the sea, pumped through the condenser where it absorbs heat from the exhaust steam and is then returned to the body of water from which it was obtained. The locations of the inlets and outlets of the circulating conduit are fixed to minimise the return of the dispersing thermal discharge. The rise in temperature of the cooling water depends on the plant design and rate of water circulation but is usually of the order of 15° to 20°F (8° to 11°C).

Some installations diffuse the heated water at the discharge point to induce mixing with the receiving water body. This limits the temperature rise in the body but it also limits the rate of heat dissipation. Most of the heat waste must ultimately be discharged to the atmosphere. The dissipation of the heat load from the water body is primarily a surface phenomenon mainly dependent on the water temperature rise (1, 4). In the case of lakes, reservoirs and estuaries with large surface areas, the heated discharge may be directed to the surface where it spreads to obtain a more direct heat load transfer to the atmosphere.

For this system to be effective without violating water quality standards a large body of receiving water is necessary. Although frequently adopted overseas, the once through system for power stations located on rivers is not favoured in Australia for large stations as flows, particularly in summer periods, are not sufficiently large to prevent unduly high temperatures occurring downstream of the heat discharge point. Tidal estuaries may offer considerable potential for the conveyance and dispersal of thermal discharges from power generating plant. The major part of the New South Wales generating plant is located on tidal estuaries using a once through system. A similar water cooling system has been used for many years at the Newport Power Station located on Hobson's Bay, Victoria, and further major additions to this station are proposed using a similar heat discharge method. Both Port Phillip and Westernport Bays, having very large bodies of moving water, offer considerable potential for thermal dispersion for future power generation development without causing undue loading on their ecosystems.

2.2 Recycling Systems

Where water supplies are limited and suitable topography exists, cooling ponds can be constructed to meet cooling water heat rejection needs. The essential features of a cooling pond, as illustrated in Figure 3, are heated water outlet works directing the discharge to pond surface, adequate water surface for dispersal of heat load to atmosphere and a deep water intake located to draw off water from the coolest part of the pond. Whilst the generating plant is operating, the cooling water is circulated continuously through the circuit provided by condensers, conduits and cooling ponds. As the main transfer of heat from the pond to atmosphere is by the process of evaporation it is necessary to provide a supply of make up water. Additional water quantities must also be added to the pond as a purge to prevent build up of dissolved minerals resulting from evaporation losses.

In locations where suitable sites for ponds are not available, and stream flows are limited, some form of cooling tower must be used. In the 'wet' cooling tower, condenser water is spread as a thin film and brought into direct contact with flowing air. The heat is carried away to atmosphere almost entirely by vaporising some of the water into the air stream. Air flow through the tower is maintained by either a forced draft provided by power driven fans or by a natural draft created in a hyperbolic tower configuration. Similarly, as in the case of ponds, a make up supply of water is necessary to replace evaporation losses and to provide a purge against a build up of dissolved minerals. As an example, a natural draft cooling tower at the Yallourn W power station is shown in Figure 4.

Some development has taken place on 'dry' cooling towers similar in principle to a car radiator. There are no evaporative losses of water but air movement must be much greater and the heat exchanger area must be quite large to remove sufficient heat. Accordingly, the capital cost is many times that of its 'wet' tower counterpart. As a result of this disability and the relative lower cooling efficiency of the dry tower, no large towers of this type have yet been constructed.

3. EFFECTS OF HEAT WASTES ON ENVIRONMENT

Thermal discharge to a river, lake or tidal estuary may result in physiological and behavioural effects on aquatic organisms. Although considerable research and investigation in a number of locations has been carried out in recent years (1, 2, 3) to determine these effects it is difficult to formulate fixed rules. The aquatic ecosystem is an extremely diverse one containing a large variety of organisms which vary from one locality to another. In addition, many diverse factors such as diet, activity, age and weather play a role in determining the lethal water temperature for a given species of aquatic life. Sub-lethal temperatures may also produce adverse effects. However, a few generalisations on the effects of heated discharge may be made (3):

- Physiologically, chemical reaction rates within the cell appear to be sensitive to thermal stimulation and an increase in temperatures may accelerate the life processes.
- Temperature change effects on behaviour are greater when the rate of change is greater.
- The young of a species can withstand a greater range of temperatures because of their metabolic simplicity.
- Adults can tolerate greater rates of change because of their greater ability to compensate by behaviour.

In general, studies completed to date indicate that organisms are tolerant to some temperature variations and this tolerance varies between species.

There is also an ability to acclimatise to changes in the ambient environment. The mobile aquatic organisms have the additional characteristic of moving into regions of preferred temperature. These characteristics of biological life seem pertinent in the evaluation of the effects of thermal additions and devising methods of control.

The main objective in siting studies therefore appears to be to determine the temperature tolerance of the more important aquatic species in conjunction with all other organisms essential to maintain the complete food chain.

At first sight, cooling towers may appear to be the answer to the problem of heat disposal as they considerably reduce the thermal impact on the aquatic environment. However, since cooling occurs mainly by evaporation a large amount of water vapour is created which may produce fog under certain conditions as well as icing in the event of low temperatures. The evaporative effect on the cooling water, as mentioned previously, creates a build up of dissolved mineral content in the circulating system. Although this content may be controlled in the system by passing through additional quantities of fresh water, the purge discharge must, in most cases, be eventually returned to a river system.

Cooling ponds, if adequately designed and constructed, may be very pleasing aesthetically and have the added advantage of providing pleasant facilities for aquatic recreation. The main cooling process is by evaporation, but as this amounts to about 50 per cent of total heat dispersal and is spread over a large area, the likely effect of fog plumes is much less than with towers. Nevertheless, there is a concentration of dissolved minerals caused by the evaporation as a result of condenser cooling heat input as well as the solar input. Purging is necessary, and, as in the case of cooling towers, the standard of water in the receiving streams must be maintained.

4. PROBLEMS IN DETERMINATION OF EFFECTS

As a basis for the determination of effects of thermal discharges it is first necessary to determine the generating plant characteristics and the operating regimes over the working life of the installation. Different plant types have variation in quantity of heat rejected, volume of cooling water circulated and range of temperature increase during circulation. The amount of thermal discharge may vary considerably according to the particular duty assigned to the power station. This may even change markedly over the life of the station as newer and more efficient plant is added to the generating system or load demand characteristics alter.

4.1 Physical

The dispersal of the thermal discharge is primarily governed by the physical conditions applying at a particular site. A comprehensive investigation to determine the physical data is necessary before the effects of the discharge and dispersal of the thermal wastes can be determined and evaluated.

Where cooling towers are considered, the micro-meteorology is of major importance because their efficiency is influenced markedly by weather conditions. The 'wet' tower is very dependent on the site ambient wet bulb temperature conditions and it is necessary to determine these for daily, seasonal and yearly variations. Meteorological conditions, including atmospheric inversion, also effect the formation and shape characteristic of any fog plumes that may occur. Wind intensitites and directions must be determined for the study of effects of fog plumes on the adjacent environment and for the structural design of the towers.

Cooling ponds present a complex situation for the dispersal of heat wastes. The principal problem is to determine what is often termed the pond's heat budget. This provides an answer in terms of the net rates of heat transfer between the body of water and the atmosphere. Besides the heat input from the condenser cooling water,the pond receives additional heat from other sources such as direct radiation from the sun and long wave radiation from clouds and water vapour in the atmosphere. Output of heat by the pond is by evaporation, by convection heat transfer, by infrared radiation back into space and by conduction to the pond surrounds.

It may therefore be seen that the temperature of the pond and its heat dispersal activity is dependent on many physical criteria such as thermal waste input pattern, amount of sunlight, wind speed, air temperature, humidity and cloud cover, all of which will vary throughout the year. To this must be added a variable thermal plume pattern in the pond with change of conditions and stratification effects. It is quite obvious that the prediction of cooling pond operation and performance is indeed a complex one. The problem can be simplified to a certain extent by determining the surface water temperature increment above natural water temperature necessary to dissipate the artificial heat load.

Similar physical criteria affect the heat dispersal activity of a tidal estuary as for a pond. The major difference is that the estuary is in most cases an open ended pond through which a variable reversing tidal flow occurs making the establishment of a heat budget more difficult. To add to the complexity of the situation there may be substantial fresh water inflows producing further density stratification, channel and wind current effects,all of which will be independent time variables and will influence to some degree the thermal plume pattern and behaviour.

4.2 Chemical

Of particular importance in the case of rivers, lakes and estuaries is the dissolved oxygen content of the water body. This property largely determines the ability of the water to purify itself and thereby safely absorb the normal organic pollutant load by means of aerobic bacterial action. Temperature rise can reduce the ability of the water to carry oxygen and this effect must also be evaluated in relation to other effects on aquatic life by the thermal discharge.

4.3 Biological

As indicated earlier, the effects of temperature rise on aquatic life in both the short and long term are difficult to determine due to the extreme diversity of the aquatic ecosystem and the further variation in species between different locations. Careful studies are therefore necessary at each site where thermal discharges are contemplated.

Aquatic life has the ability to continue to live and reproduce free from detrimental effects under a certain range of temperature variations. The fundamental problems to be solved in the thermal discharge to water bodies are therefore -

- The restriction of initial mixing temperatures of the discharge plume to below the lethal limit for aquatic life.

- Provision for avoidance or rapid escape of mobile species from the higher temperature areas of the thermal plume.
- Limitation of temperatures and patterns of the plume during thermal dispersal within the limits necessary for the long term healthy growth and reproduction of the aquatic community as a whole.

In order to define the problems for a particular location it is necessary to determine in detail the full extent of the existing aquatic community, the inter-relation between species and the reaction of specific species to varying temperature changes or other pollutant effects.

5. SOLUTION OF PROBLEMS

In selecting a suitable means of disposal of the low grade heat from a future power station, it is necessary to determine the general physical path by which the heat will be dispersed into the atmosphere and then determine the probable impact this arrangement may have on the ecosystem.

5.1 Field Studies

For cooling ponds the incremental water temperature necessary to dissipate an artificial heat load on the water body can be estimated in a heat budget calculation if the natural occurring water surface temperature is known. To supplement existing meteorological data required in cooling pond and tower heat loss calculations, a number of stations have been established at various locations within the State for monitoring the main ground level meteorological parameters. Water temperature recorders have been established in a number of lakes, rivers and in Port Phillip and Westernport Bays for establishing long term average and abnormal conditions. Correlations have also been obtained between water temperature observations and wet and dry bulb air temperature observations over periods up to 20 years. This enables estimates of water temperature of existing or proposed receiving water bodies to be obtained for areas where only air temperature data is available.

In Port Phillip and Westernport Bays special surveys have been conducted to obtain additional information on water depths, tidal heights and currents. Heat budget estimates due to solar inputs into a shallow tidal inlet have been compared with field observations and the dispersion of the naturally induced thermal plumes have been observed during ebb tides. Some aerial infra-red line scan photographs have been obtained and isothermal plans are to be prepared.

In the Yarra River estuary information has been obtained on tidal influence and persistence of the bottom saline wedge which penetrates upstream. Water temperatures are observed at the intakes to the adjacent Newport Power Station which commenced operation over 50 years ago. More recent observations have shown that substantially lower maximum water temperatures in summer can be achieved by drawing water from the adjacent deep shipping channel. This is of considerable benefit to both the economical performance of the power station and to reducing the effects of the rejected heat on the Bay. The recently announced proposal for a 1,000 MW capacity power station at Newport will incorporate this feature when operation commences in 1976.

5.2 Newport Power Station Tests

The existing Newport Power Station provided an excellent opportunity for testing the proposal for the new station referred to above. The two proposed gas fired units of 500 MW each will operate on an intermediate load duty and reject about 1.35 MW of low grade heat for each MW of electrical energy sent out. By contrast, the old station has a heat rejection ratio of 2.4, so that the total rejection load from the old station operating at 180 MW capacity represents about 32 per cent of the heat rejection load of the proposed station.

The inlet and outlet works of the existing station were reversed and a temporary deep intake skimmer wall constructed in the Yarra River to simulate the future arrangement as shown in Figure 5. The existing station was then operated on two 8 hour shifts with the proposed 15°F (8°C) cooling water temperature rise for 12 consecutive days in March, 1971. Five boats were employed for 12 hours each day measuring surface and subsurface water temperatures and salinities over a wide area of Hobson's Bay. Floats were released at regular intervals throughout the test and their locations recorded each hour by pairs of aerial photographs taken at an interval of a quarter hour. On two days, aerial infra-red line scan photographs were obtained at intervals of 1-1/2 hours to complement the boat traverse data.

From this information, the time dependent three dimensional nature of the cooling water plume could be ascertained as well as its heat loss characteristics. Isothermal plots of surface water temperatures obtained from both the infra-red technique and the boat traverse data compared favourably. The results showed that the temperature of the warm water in the outlet channel dropped very quickly before the discharge spread out as a buoyant surface plume in Hobson's Bay. The plume varied its location according to the prevailing wind and tidal currents but there was no apparent increase in the inlet water temperature above normal. Regular observations of dissolved oxygen in water samples taken from the intake and outlet channel during the test indicated no significant change in water quality.

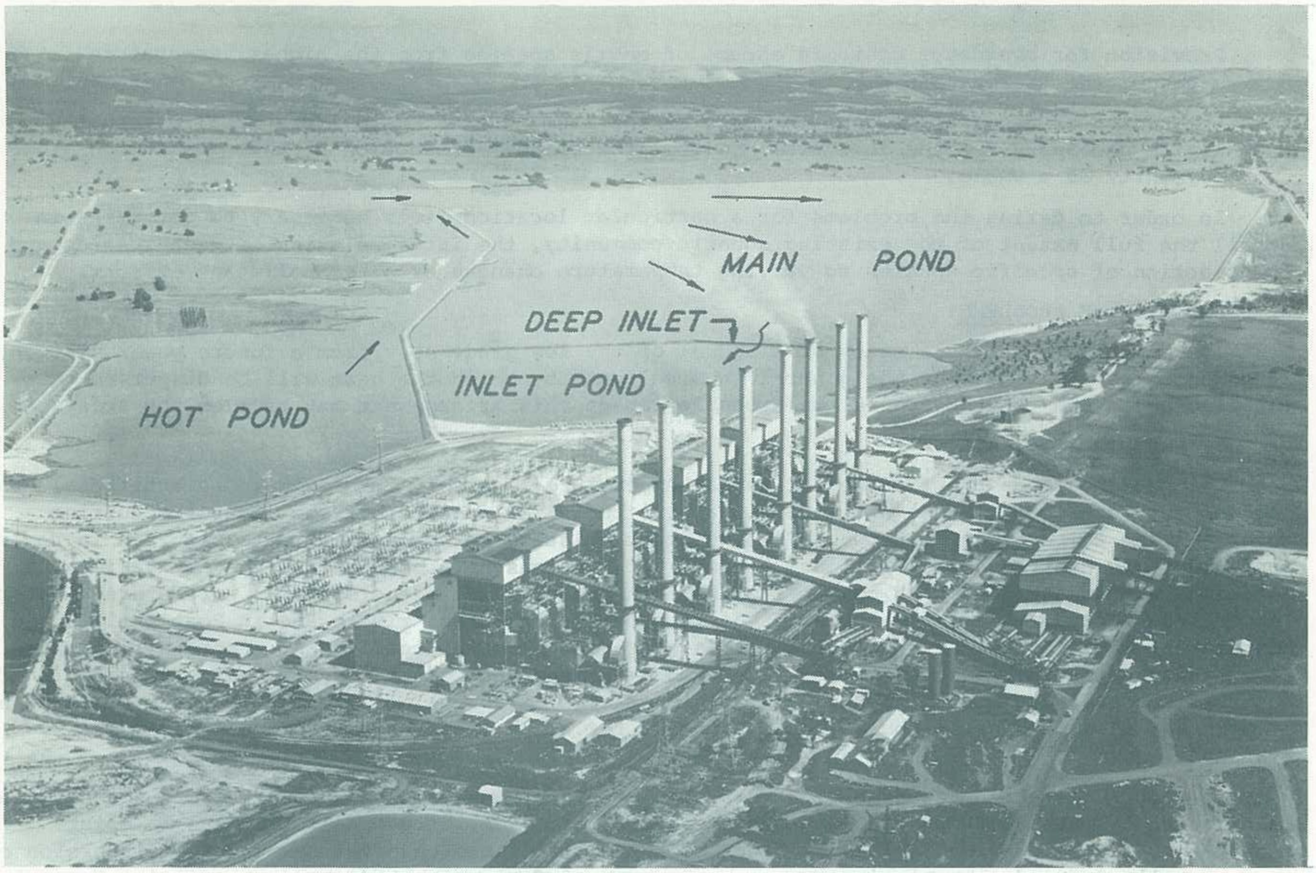

FIG. 3 HAZELWOOD POWER STATION & COOLING POND

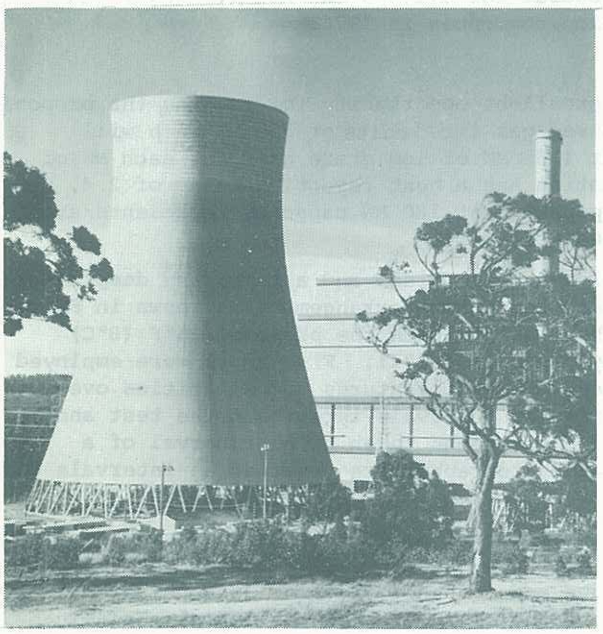

FIG. 4 NATURAL DRAFT COOLING TOWER

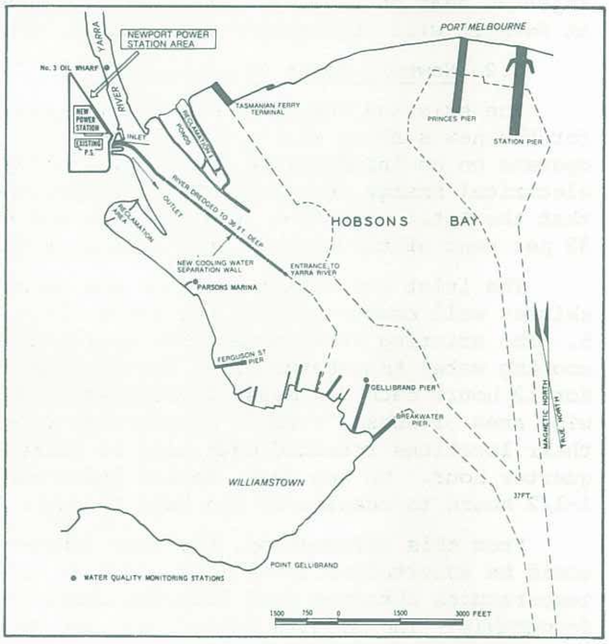

FIG. 5 NEWPORT POWER STATION COOLING WATER ARRANGEMENT

5.3 Model Studies

Heat dissipation processes from water bodies can be simulated mathematically in some cases where certain approximations are permissable. Where flow and dispersion processes are poorly understood hydraulic models can simulate thermal density current patterns required for estimates of heat losses. If the atmosphere of an hydraulic laboratory can be controlled as well as other major model variables, then the entire heat dissipation process can be simulated.

At the time of writing, a simple hydraulic model of the proposed Newport Power Station development is being designed and built by the Water Research Laboratory of the University of New South Wales in conjunction with the State Electricity Commission of Victoria. It is proposed that this distorted tidal model will have saline and thermal density currents scaled on the densimetric Froude Number. The model will be verified using data obtained from the major field test in March, 1971. A variety of possible cooling water designs will be tested under a range of tidal, river, wind and power station operating conditions.

5.4 Biological Studies

To establish the effect a waste load can have on a dynamic biological system it is desirable to establish base line data on the number and types of fauna and flora, monitored over several years to indicate its natural variability. Studies of this type have been conducted by others for several years in Port Phillip Bay and Westernport Bay. It is proposed to expand these studies by a detailed survey of the marine biota in the Hobson's Bay area and elsewhere. This will be supplemented by detailed research into the effects of heated effluents on various species of flora and fauna and the local ecosystem generally. Consideration will also be given to possible beneficial application of the heat additions such as fish farming.

6. CONCLUSIONS

With increasing power demands the amount of low grade heat rejected to the atmosphere will increase in the foreseeable future. A determined effort will be required in the development of methods of heat dispersal in order to conserve the environment to an acceptable standard.

As an aid to the design of heat dispersal works and before the general physical path of the heat dispersion can be determined, it is necessary to monitor in detail the governing physical conditions of the particular area. As a basis of determining the effects of heat dispersion on the area ecology, comprehensive biological studies are required on the unit environment.

Continued advances are taking place in the understanding of hydraulic and fluid mechanic processes. Similarly, advances are being made in our knowledge of biological systems.

Both mathematical and physical hydraulic model studies are providing a useful aid in the determination of heat dispersal paths and patterns.

Considerable research and development in both the biological and hydraulic fields are required to simplify the techniques of environment protection from thermal discharges. However, with current advances in knowledge and techniques of heat dispersal, power generating facilities can be satisfactorily integrated into the environment to provide substantial community benefits without damage to the ecosystem.

7. ACKNOWLEDGEMENTS

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