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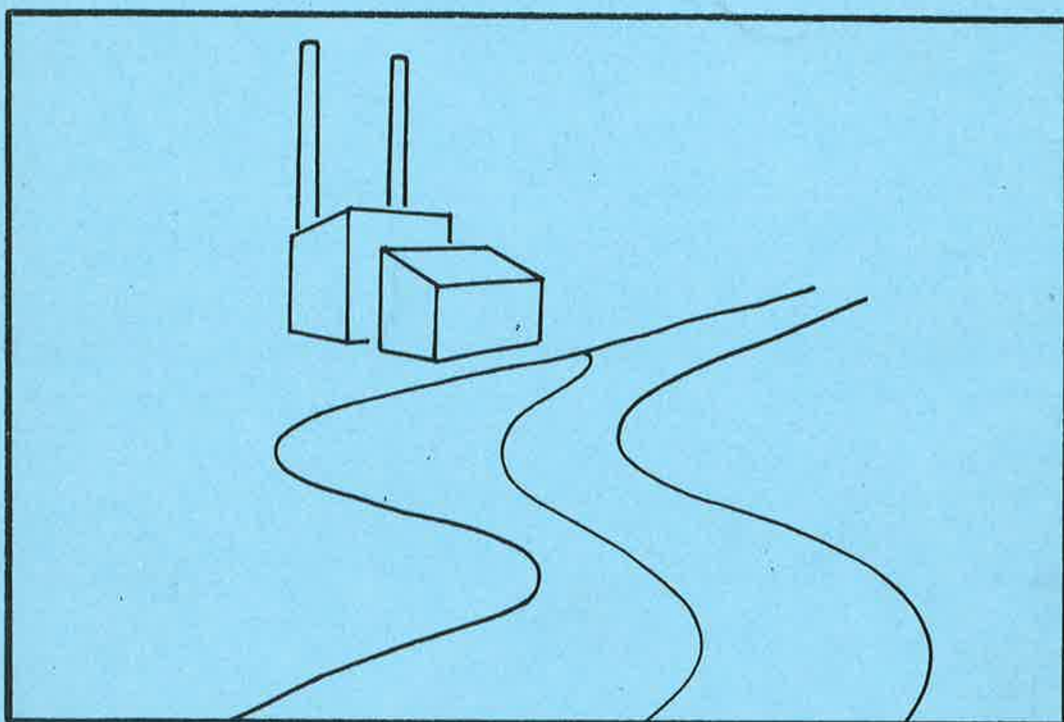

WAIKATO COAL-FIRED POWER STATION:

An Assessment of the Likely Impact of Waste Heat Disposal

J.C. Rutherford

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Water Quality Centre Publication No. 4

Water Quality Centre
Ministry of Works and Development
Hamilton

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1 OUTLINE

1.1 Background

This report has been commissioned by NZ Electricity to assist in the preparation of an Environmental Impact Report for the proposed Waikato coal-fired power station. It sets out to predict the likely effect on river water temperatures of waste heat discharges from the existing Huntly and proposed Waikato power stations (hereafter referred to as 'Huntly' and 'Waikato'). Section 2 considers fully mixed temperatures, Section 3: the distribution of temperature across the channel, possible plume temperatures at the point of discharge, and the potential impact on river biota and Section 4: the effects of waste heat discharge on some apsects of water chemistry.

It is envisaged that some restrictions will be imposed on the permissible waste heat discharge from the Waikato station eg in the form of a water right. Three possible control rules are discussed here including the current Huntly control rule. It is hoped that this discussion paper will aid in an appreciation of the likely impacts of the proposed station but it is not intended that this report should prejudice any other possible control rule.

1.2 Acknowledgements

River temperature data were made available by N R Hall, NZ Electricity, although the source is Huntly Borough Council. River flows were measured by Water and Soil Division, MWD, but extracted by N R Hall. Dr R J Wilcock kindly calculated the solubility of nitrogen shown in Table 6 . M Simons and M Davenport, Waikato Valley Authority, made valuable contributions in discussion on the impacts of cooling-water discharge on river biota. G Latimer and R Pope, Gillman and Partners Limited, Hamilton kindly made available the results of dye studies at Taupiri. Calculations were performed on the Vogel Computer Centre IBM 3033 using STATS.

G B McBride made valuable comments on a draft of the report.

2 PREDICTION OF AVERAGE RIVER TEMPERATURES

2.1 Introduction

An eight year record of daily river water temperatures and flows at Huntly was used to simulate the fully-mixed temperatures expected to result from waste heat discharge from the proposed Waikato station for various options of capacity and siting. Note that near the point of discharge, plume temperatures somewhat higher than the fully-mixed temperatures are likely, as discussed in Section 3. Waste heat discharge at Huntly and excess temperature decay in the river downstream from Huntly were accounted for but Meremere Power Station was assumed not to be operational.

2.2 Ambient River Temperatures

Water temperatures were measured once daily at 0800 hours at the Huntly Municipal Water Treatment Station between 1973 and 1980 by the Huntly Borough Council. Diurnal surveys conducted by Water and Soil Division, MWD, and the Auckland Regional Authority during the same period indicate that river water temperatures attain their daily minimum value around 0800 hours. Data from 18 diurnal surveys at Huntly (4) and Rangiriri (14) gave an average diurnal temperature range of 1.6°C (standard deviation 0.85°C). The diurnal range is highest in early summer and decreases with flow, according to the linear regression model

$$R = 3.21 - 0.004Q - 0.7 \sin (2\pi t/365) + 0.15 \cos (2\pi t/365) \qquad (1)$$

$r^2 = 0.31 \quad n = 18$

where R = diurnal range, °C; Q = river flow, $m^3\ s^{-1}$; t = Julian day number. For each day between 1973 and 1980, equation (1) was used to predict the most probable daily temperature range. 24-hour average temperature was then estimated by adding R/2 to the measured 0800 temperature. The frequency distribution of these estimated 24-hour average ambient temperatures is shown in Tables 1 and 3. When compared with the distribution of daytime temperatures between 1974-1976 given by Davies-Colley (1979), daytime temperatures between 18-22^{o}C is slightly more frequent (2-3%), but in other respects the two distributions are very similar.

2.3 Waste Heat Discharges

The present Huntly Power Station water right imposes a limit on the quantity of waste heat which can be discharged

$$W = \begin{cases} 12.6Q & T < 11^{o}C \\ 22Q\,(1 - T/26) & 11 < T < 26^{o}C \\ 0 & T > 26^{o} \end{cases} \qquad (2)$$

where W = permissible waste heat discharge, MW; Q = river flow at Huntly, $m^3\ s^{-1}$; T = ambient river temperatures (viz temperature upstream from the power station). Equation (2) is designed to ensure that the fully-mixed river temperature never rises by more than 3^{o}C, is never increased above 26^{o}C by waste heat discharge, and that the fully-mixed temperature rise decreases linearly from 3^{o}C at 11^{o}C to zero at 26^{o}C. Equation (2) has been suggested as a possible control rule for the proposed Waikato station (Anon 1982a). It will hereafter be referred to as the 'Huntly rule'.

An alternative control rule has been suggested (Anon 1982b and Town 1983) which is designed to ensure that below an ambient river temperature of 20^{o}C, a fully-mixed temperature rise up to 3^{o}C, is permissible, that above 23^{o}C ambient no rise is permissible, and that between 20^{o}C and 23^{o}C the permissible temperature rise decreases linearly from $3^{o}C$ to zero. In terms of permissible waste heat,

$$W = \begin{cases} 12.6Q & T < 20^{o}C \\ 96Q\,(1 - T/23) & 20 < T < 23^{o}C \\ 0 & T > 23^{o}C \end{cases} \qquad (3)$$

Equation (3) will hereafter be referred to as the '23^{o} rule'.

A third alternative control rule, the '25^{o} rule' (Anon 1982b and Town 1983) is similar to the '23^{o} rule' : below $22^{o}C$ a rise of $3^{o}C$ is permissible, above $25^{o}C$ no rise is permissible and between $22^{o}C$ and $25^{o}C$ the permissible rise decreases linearly from $3^{o}C$ to zero.

$$W = \begin{cases} 12.6Q & T < 22^{o}C \\ 105Q\,(1-T/25) & 22 < T < 25^{o}C \\ 0 & T > 25^{o}C \end{cases} \qquad (4)$$

At Huntly it was assumed that for six months during summer (November-April) one unit is always out of operation (Anon 1982b) leaving generation capacity at 750 MW (maximum waste heat 956 MW). For six months over winter (May-October) generation capacity is assumed to be 1000 MW (1275 MW waste heat). Thus the average operating capacity is 875 MW, (waste heat 1115 MW).

In the simulation, the power generated at Huntly on each day was calculated subject to the constraints on permissible waste heat and operational capacity described above. No unscheduled down-time was simulated.

Three different assumptions were made concerning generation capacity at the proposed Waikato station :

a 1000 MW station without supplementary cooling. The potential generation capacity was 750 MW (956 MW waste heat) for six months over summer and 1000 MW (1275 MW waste heat) for six months over winter.

b 1000 MW station with 50% supplementary cooling. Potential generation capacity was 750 MW (478 MW waste heat) over summer and 1000 MW (638 MW waste heat) over winter. This case closely approximates waste heat discharge for a 500 MW station without supplementary cooling in which maximum generation is only 75% of the installed capacity during summer.

c 1000 MW station with 75% supplementary cooling. Potential generation capacity was 750 MW (239 MW waste) over summer and 1000 MW (319 MW waste) over winter. This case closely approximates waste heat discharge for a 500 MW station with 50% supplementary cooling in which maximum generation is only 75% of the installed capacity during summer.

For each day of the simulation, the actual power generated at the Waikato station was determined to ensure that the waste heat discharged at Waikato plus the residual waste heat from Huntly (after allowance for excess heat decay) did not infringe the operative control rule, viz equation 2, 3 or 4, in which ambient temperature was that occuring upstream from Huntly. The total amount of power generation forgone as a result of the control rules was also calculated.

2.4 Waste Heat Decay Below Huntly Power Station

A study of the rates of decay of excess temperature below the Huntly Power Station is underway. Some preliminary data are available which suggest the following figures for the residual waste heat at the two proposed sites, see Figure 1, expressed as a percentage of the station heat rejection

Rangiriri 70 ± 10%

Clune Road 50 ± 10%

In the calculations the upper bounds were used viz 80 and 60% respectively.

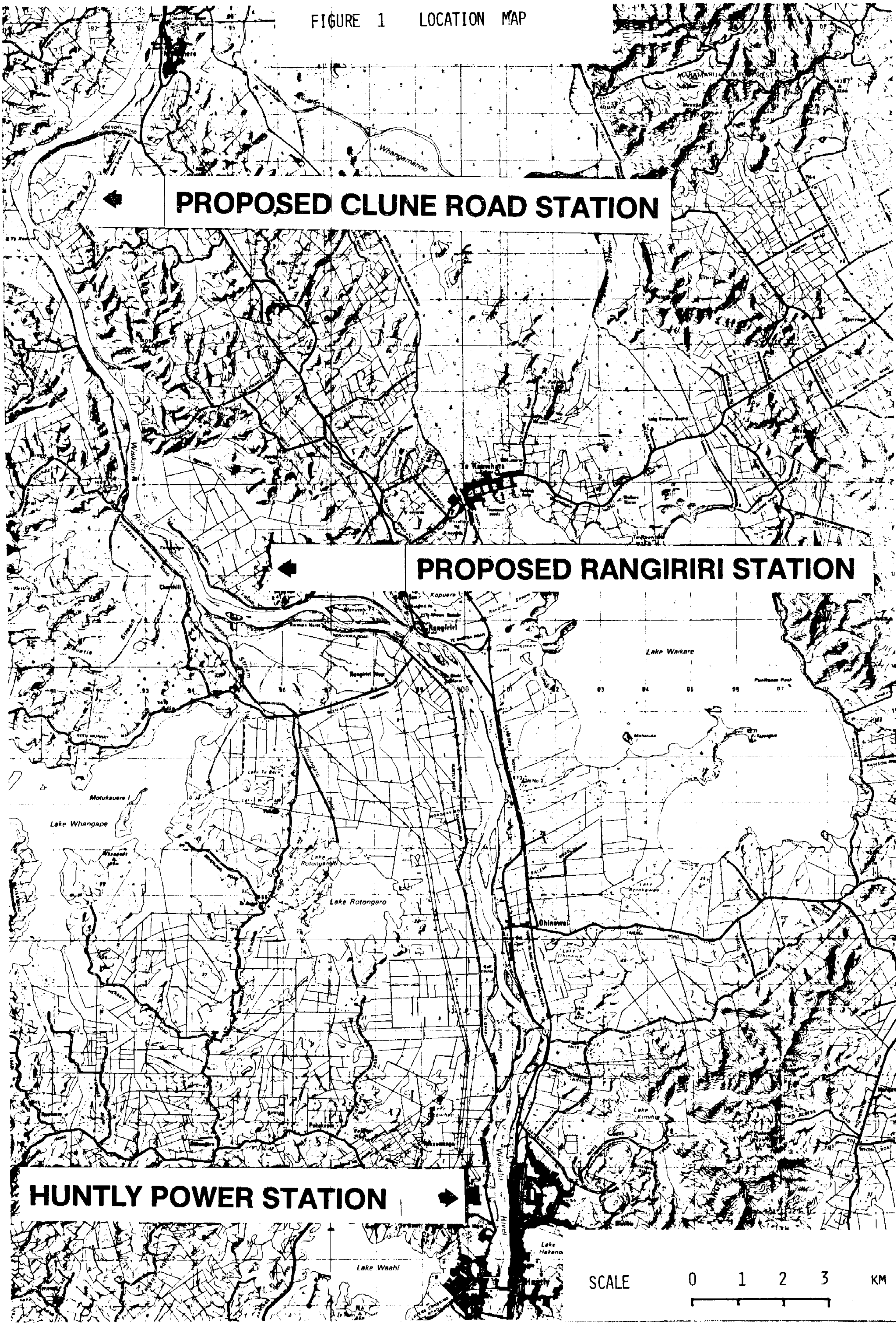
2.5 Impact of Huntly Station on Fully-Mixed Temperature Distributions

For the period simulated, ambient river temperature at Huntly show a weak bimodal frequency distribution with 11-13^{o}C (20%) and 21-23^{o}C (15%) the most common temperatures, see Table 1. Simulation results indicate that when fully operational, waste heat discharge from Huntly will cause an average predicted temperature rise of 0.75^{o}C (standard deviation ± 0.24^{o}C). There will be a 5% decrease in the frequency of temperatures in the range 11-13^{o}C and a 4% increase in the range 23-25^{o}C. The frequency of other temperatures is not greatly affected, although the annual pattern of water temperatures undergoes a slight change with autumn cooling occuring later and spring warming earlier than at present. The power generation foregone at Huntly as a result of equation (2) averages 305 GWhr per year over the eight year period simulated (4% of average operational capacity, 875 MW).

2.6 Impact of Waikato Station on Fully-Mixed Temperature Distributions

A total of eighteen simulations were run (two sites, three levels of cooling and three alternative control rules) from which the frequency

FIGURE 1 LOCATION MAP



TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
TO	FROM	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.04	0.16	0.24	0.08	0.20	0.28	0.24
9.00	11.00	5.01	2.67	3.19	3.56	2.87	3.44	3.72	3.64
11.00	13.00	20.21	9.78	13.62	14.63	11.28	14.43	16.17	14.93
13.00	15.00	14.11	18.07	16.49	16.21	17.46	16.37	15.36	16.25
15.00	17.00	13.54	12.41	12.29	13.02	12.33	12.85	13.38	13.18
17.00	19.00	13.95	14.19	13.90	13.70	13.78	13.70	14.35	13.62
19.00	21.00	13.18	16.29	15.04	14.23	15.97	14.27	13.26	14.07
21.00	23.00	14.71	18.11	16.86	16.01	17.78	16.33	15.40	15.76
23.00	25.00	3.60	7.60	7.60	7.56	7.60	7.56	7.24	7.56
25.00	27.00	0.49	0.53	0.53	0.53	0.53	0.53	0.53	0.53
27.00	29.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
29.00	31.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
31.00	33.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refer to degree of supplementary cooling
(b) Huntly assumed fully operational

Table 1.1 : Frequency distributions of fully-mixed temperatures for a 1000 MW Waikato Station : waste heat discharge restricted by the 'Huntly Rule'.

distributions of fully-mixed temperatures were estimated. For each combination of site and supplementary cooling, the three different control rules give almost identical frequencies for temperatures in the range 7-19°C. The frequency of low temperatures in the range 7-13°C is everywhere lower than for ambient conditions and the frequency of 11-13°C is lower than below Huntly for open-cycle cooling at Rangiriri (by 5%) and Clune Road (by 3.5%). The frequency of temperatures in the range 13-15°C is increased compared with ambient most noticeably for open cycle cooling and at the Rangiriri site.

The effect of waste heat discharge on high temperatures varies markedly between control rules. Under the 'Huntly rule', see Table 1.1, the frequency of 19-23°C increases compared with ambient and below Huntly, most noticeably for 0% and 50% supplementary cooling. The frequency of 23-25°C is similar to the frequency below Huntly: both are twice ambient frequency.

For the '23° rule', see Table 1.2, the frequency of temperatures in the range 21-23°C is higher than below Huntly by 5% for open cycle cooling, by 2% for 50% supplementary cooling, and by 1% for 75% supplementary cooling. There is a slight reduction in the frequency of temperatures in the range 23-25°C compared with the frequency below Huntly.

For the '25° rule', see Table 1.3, the frequency of temperatures in the range 21-23°C is reduced for open-cycle and 50% supplementary cooling below ambient frequency. This comes at the expense an of increase in the

TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
TO	FROM	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.04	0.16	0.24	0.08	0.20	0.28	0.24
9.00	11.00	5.01	2.67	3.19	3.56	2.87	3.44	3.72	3.64
11.00	13.00	20.21	9.78	13.62	14.63	11.28	14.43	16.17	14.83
13.00	15.00	14.11	18.07	16.49	16.21	17.46	16.37	15.36	16.25
15.00	17.00	13.54	12.09	12.29	13.02	12.17	12.85	13.38	13.18
17.00	19.00	13.95	14.11	13.90	13.70	13.82	13.70	14.35	13.62
19.00	21.00	13.18	15.16	14.83	14.19	15.08	14.23	13.26	14.07
21.00	23.00	14.71	20.57	17.99	16.94	20.61	18.15	16.86	15.76
23.00	25.00	3.60	6.67	6.67	6.67	5.78	5.78	5.78	7.56
25.00	27.00	0.49	0.53	0.53	0.53	0.53	0.53	0.53	0.53
27.00	29.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
29.00	31.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
31.00	33.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refer to degree of supplementary cooling
(b) Huntly assumed fully operational

Table 1.2 : Frequency distributions of fully-mixed temperatures for a 1000 MW station at Rangiriri or Clune Road : waste heat discharge restricted by the '23^{o} rule'.

TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
FROM	TO	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.04	0.16	0.24	0.08	0.20	0.28	0.24
9.00	11.00	5.01	2.67	3.19	3.56	2.87	3.44	3.72	3.64
11.00	13.00	20.21	9.78	13.62	14.63	11.28	14.43	16.17	14.83
13.00	15.00	14.11	18.07	16.49	16.21	17.46	16.37	15.36	16.25
15.00	17.00	13.54	12.09	12.29	13.02	12.17	12.85	13.38	13.18
17.00	19.00	13.95	14.11	13.90	13.70	13.82	13.70	14.35	13.62
19.00	21.00	13.18	15.16	14.83	14.19	15.08	14.23	13.26	14.07
21.00	23.00	14.71	12.45	13.22	15.12	13.14	13.90	15.40	15.76
23.00	25.00	3.60	14.79	11.44	8.49	13.26	10.02	7.24	7.56
25.00	27.00	0.49	0.53	0.53	0.53	0.53	0.53	0.53	0.53
27.00	29.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
29.00	31.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
31.00	33.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refers to degree of supplementary cooling
(b) Huntly assumed fully operational

Table 1.3 : Frequency distributions of fully-mixed temperatures for a 1000 MW station at Rangiriri or Clune Road : waste heat discharge restricted by the '25^{o} rule'.

frequency of 23-25°C temperatures above the frequency occurring below Huntly : by 6-7% for open-cycle cooling and 2-4% for 50% supplementary cooling. The frequency of temperatures in the range 23-25°C is thus four times ambient frequency for open-cycle cooling, three times for 50% supplementary cooling and twice for 75% supplementary cooling.

To summarise, fully-mixed temperatures below Huntly are likely to be significantly different from ambient : 11-13°C being 5% less frequent and 23-25°C 4% more frequent. Below the proposed Waikato station there would be further reductions in frequency of low temperatures similar for each of the three control rules : the largest being a further reduction of 3.5-5% in 11-13°C for open-cycle cooling. The 'Huntly rule' would increase slightly the frequency of temperatures in the range 19-23°C from below Huntly, most noticeably by 1-2% for open-cycle cooling. The '23° rule' would increase the frequency of temperatures in the range 21-23°C most noticeably by 5% for open-cycle and by 2% for 50% supplementary cooling. The '25° rule' would decrease the frequency of 21-23°C but increase the frequency of 23-25°C for open-cycle cooling by 6-7% and for 50% supplementary cooling by 2-4%. The '25° rule' would increase the frequency of 23-25°C above ambient by a factor of about four for open-cycle cooling and about three for 50% supplementary cooling.

2.7 Power Forgone by Compliance with the Control Rules

The total power generation foregone in one year by the Waikato station as a result of compliance with the control rules is given in Table 2. Critical assumptions made were: (a) during summer one unit (250 MW) was assumed down for scheduled maintenance, (b) there was zero unscheduled downtime, and (c) upper bound waste heat residuals from the Huntly Power Station were used (viz. 80% and 60% as discussed in Section 2.4).

	0% cooling	50% cooling	75% cooling
HUNTLY CONTROL RULE			
Rangiriri	1420 (18.5%)	894 (11.7%)	447 (5.8%)
Clune Road	1043 (13.6%)	465 (6%)	98 (1.3%)
23^{o} CONTROL RULE			
Rangiriri	771 (10.0%)	640 (8.3%)	543 (7.1%)
Clune Road	684 (8.9%)	543 (7.1%)	482 (6.3%)
25^{o} CONTROL RULE			
Rangiriri	72 (0.7%)	52 (0.5%)	48 (0.5%)
Clune Road	65 (0.7%)	50 (0.5%)	47 (0.5%)

Units : GWhr

Table 2 : Average power foregone in one year by the proposed Waikato Thermal Power Station assuming a 1000 MW station at three alternative sites with three levels of supplementary cooling.

Notes :

(a) Operational capacity = 875 MW (see text for details).

(b) Huntly Power Station assumed operational (see text for details). Average power foregone in one year at Huntly = 307 GWhr.

(c) Power foregone by a 500 MW station with no supplementary cooling is approximately 0.5 times the figure in column 2, but the percentage remains the same.

(d) Power foregone by a 500 MW station with 50% supplementary cooling is approximately 0.5 times the figure in column 3, but the percentage remains the same.

For zero supplementary cooling the power foregone is substantially higher for the 'Huntly rule' than for the '23° rule'. The '25° rule' results in very small losses (<1%). With 50% supplementary cooling the power foregone is comparable for the 'Huntly' and '23°' control rules but substantially lower for the '25° rule'. With 75% supplementary cooling the 'Huntly rule' gives consistently lower figures for power foregone than the '23° rule' but the '25° rule' gives the lowest losses.

Restrictions on waste heat discharge are not distributed uniformly throughout the year. For the Huntly Power Station there are no restrictions between June and October. There are restrictions in November and May (<1% of total power foregone), December and April (about 2%), March (16%), January (35%) and February (45%). The patterns of restriction at the Waikato Power Station are similar regardless of location and the amount of supplementary cooling.

3 TEMPERATURE DISTRIBUTIONS

3.1 Observed Temperature Gradients Below Huntly

Vertical and transverse temperature gradients in the river below the Huntly Power Station are being studied at present . Preliminary results indicate that vertical mixing is rapid but transverse gradients are detectable some 30 km below Huntly. Measurements made with Huntly cooling water flows about 1/3 maximum design values indicated that at Rangiriri waste heat was confined to the left bank and spread over about ½ of the flow while at Clune Road waste heat was spread over about 2/3 - 3/4 of the flow. In the simulations discussed below, residual waste heat from Huntly was assumed mixed with 2/3 of the flow at Rangiriri and 3/4 of the flow at Clune Road: a likely lower bound estimate of mixing.

3.2 Average Plume Temperatures at Waikato

At the Huntly Power Station waste heat is discharged from the left bank from a structure designed to achieve rapid mixing over about 40-50% of the flow. In Tables 3 reported Huntly plume temperature is the average after mixing with 50% of the river flow.

At each proposed site for the Waikato station the choice is available to discharge waste heat near the left bank, near the right bank, or near the mid-channel. For any outfall it is thought desirable to achieve rapid mixing with about 50% of the flow. Figure 2 shows possible plume configurations. Tables 3 summarise the frequency of average temperatures in the region where the Huntly and Waikato plumes overlap, estimated as a simple extension of the simulations described in Section 2, making the following assumptions :

Legend A = Huntly plume, B_1 B_2 = Waikato plume, C_1 C_2 = region of overlap.

NOTE: Temperatures in Tables 3 are in the region of overlap.

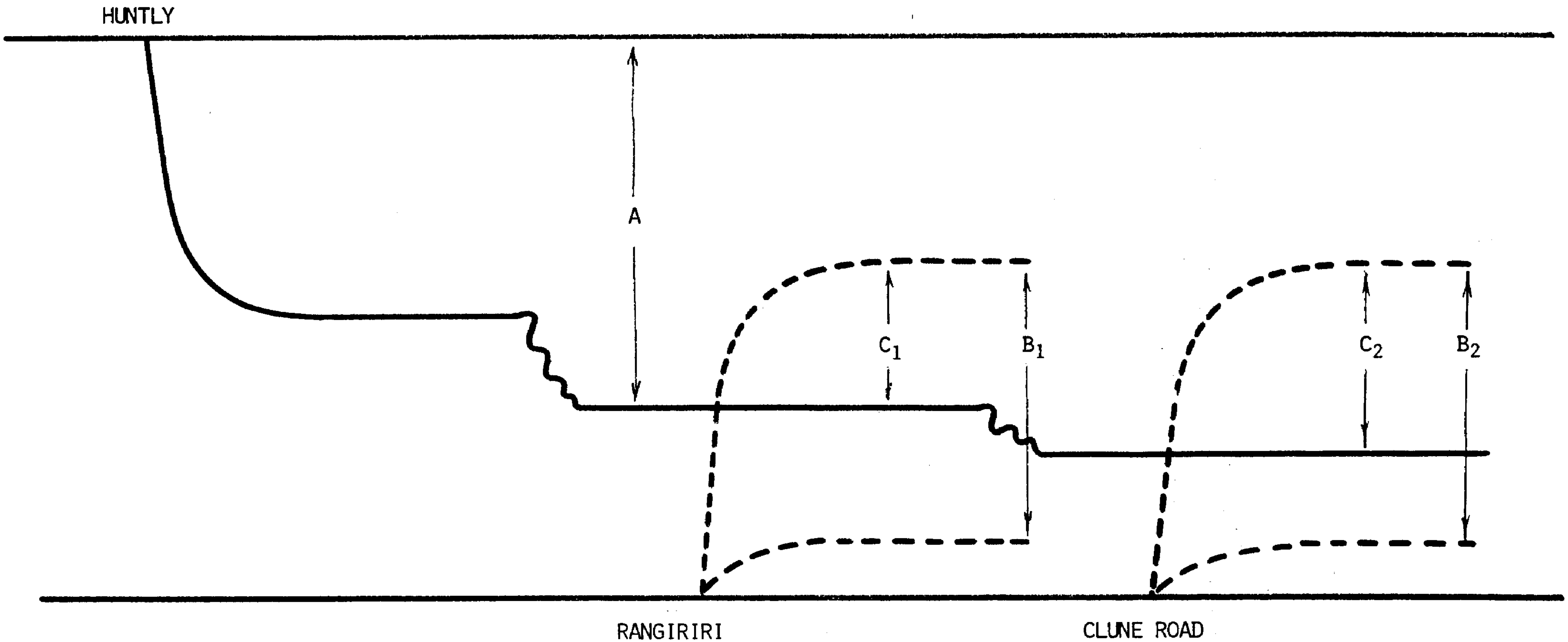


FIGURE 2 : Schematic of plumes from the Huntly and proposed Waikato power stations.

(a) residual waste heat is 80% and 60% of the discharge from Huntly (b) residual waste heat is mixed with 2/3 and 3/4 of the river flow at Rangiriri and Clune Road respectively (c) the outfall at the Waikato station mixes rapidly with ½ the river flow (d) reported temperatures are average values occuring where the Huntly and Waikato plumes overlap: a substantial fraction of the flow for any of the likely outfalls. Note that this analysis does not consider the higher temperatures which may be encountered very close to the outfalls: these are considered for low flows only in Section 3.3.

At Huntly there is a marked difference in temperature distribution between fully-mixed and plume temperatures: compare Tables 1 and 3. 11-13°C reduces in frequency by 6% and 23-25°C increases by 8%. Compared with ambient conditions, 11-13°C decreases in frequency from 20.2% to 8.6% and 23-25°C increases from 3.6% to 15.9%.

When the 'Huntly rule' restricts generation and for the outfall mixing described, plume temperatures at Waikato cannot exceed those at Huntly i.e. the Waikato Station can at most only take up any slack allowed by heat decay in the river. Plume temperatures in the range 23-25°C occur 11-14% of the time, compared with 16% in the Huntly plume and 4% under ambient conditions. When there is no restriction, additional warming may occur. Thus, for open-cycle cooling, temperatures in the range 11-13°C decrease in frequency to 5-6% compared with 9% in the Huntly plume and 20% under ambient conditions. For 50% supplementary cooling 11-13°C are of comparable frequency in the Huntly and Waikato plumes, 7-10%.

For the '23° rule' there is an increase in frequency of plume temperatures in the range 23-25°C for open-cycle cooling and 50% cooling at Rangiriri to 18-23% compared with 16% at Huntly and 4% under ambient conditions.

TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
FROM	TO	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.00	11.00	5.01	1.37	2.22	0.08	0.0	0.04	0.16	0.0
11.00	13.00	20.21	4.97	7.48	2.75	1.62	2.67	3.19	2.34
13.00	15.00	14.11	16.41	18.55	10.47	5.78	9.78	13.62	8.57
15.00	17.00	13.54	12.97	12.81	18.03	17.87	18.07	16.49	18.59
17.00	19.00	13.95	15.52	14.03	11.96	12.41	12.09	12.29	12.37
19.00	21.00	13.18	14.23	14.96	13.86	15.16	14.11	13.90	13.95
21.00	23.00	14.71	19.32	14.92	15.32	14.35	15.16	14.83	15.32
23.00	25.00	3.60	14.27	14.11	13.58	17.62	13.99	13.22	11.76
25.00	27.00	0.49	0.61	0.61	13.02	14.27	13.18	11.36	15.89
27.00	29.00	0.28	0.28	0.28	0.61	0.61	0.61	0.61	0.89
29.00	31.00	0.04	0.04	0.04	0.28	0.28	0.28	0.28	0.28
31.00	33.00	0.0	0.0	0.0	0.04	0.04	0.04	0.04	0.04
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refer to degree of supplementary cooling
(b) Huntly assumed fully operational
(c) Residual waste heat from Huntly assumed 2/3 mixed at Rangiriri and 3/4 mixed at Clune Road
(d) Waste heat from proposed Waikato Station assumed ½ mixed at outlet

Table 3.1 : Frequency distributions of plume temperatures for a 1000 MW station : waste heat discharge restricted by the 'Huntly rule'.

TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
FROM	TO	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.0	0.0	0.08	0.0	0.04	0.16	0.0
9.00	11.00	5.01	1.37	2.22	2.75	1.62	2.67	3.19	2.34
11.00	13.00	20.21	4.97	7.48	10.47	5.78	9.78	13.62	8.57
13.00	15.00	14.11	16.41	18.55	18.03	17.87	18.07	16.49	18.59
15.00	17.00	13.54	12.97	12.81	11.96	12.41	12.09	12.29	12.37
17.00	19.00	13.95	14.83	14.03	13.86	14.87	14.11	13.90	13.95
19.00	21.00	13.18	12.89	14.67	15.32	13.54	15.16	14.83	15.32
21.00	23.00	14.71	12.97	11.48	12.85	12.00	12.45	13.22	11.76
23.00	25.00	3.60	22.72	17.91	13.82	21.06	14.79	11.44	15.89
25.00	27.00	0.49	0.53	0.53	0.53	0.53	0.53	0.53	0.89
27.00	29.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
29.00	31.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
31.00	33.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refer to degree of supplementary cooling
(b) Huntly assumed fully operational
(c) Residual waste heat from Huntly assumed 2/3 mixed at Rangiriri and 3/4 mixed at Clune Road
(d) Waste heat from proposed Waikato Station assumed ½ mixed at outlet

Table 3.2 : Frequency distributions of plume temperatures for a 1000 MW station : waste heat discharge restricted by the '23^o rule'.

TEMPERATURE RANGE			RANGIRIRI			CLUNE ROAD			HUNTLY
FROM	TO	AMBIENT	0%	50%	75%	0%	50%	75%	
1.00	3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00	7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.00	9.00	0.89	0.0	0.0	0.08	0.0	0.04	0.16	0.0
9.00	11.00	5.01	1.37	2.22	2.75	1.62	2.67	3.19	2.34
11.00	13.00	20.21	4.97	7.48	10.47	5.78	9.78	13.62	8.57
13.00	15.00	14.11	16.41	18.55	18.03	17.87	18.07	16.49	18.59
15.00	17.00	13.54	12.97	12.81	11.96	12.41	12.09	12.29	12.37
17.00	19.00	13.95	14.83	14.03	13.86	14.87	14.11	13.90	13.95
19.00	21.00	13.18	12.89	14.67	15.32	13.54	15.16	14.83	15.32
21.00	23.00	14.71	12.97	11.48	12.85	12.00	12.45	13.22	11.76
23.00	25.00	3.60	13.74	15.76	13.22	14.71	13.18	11.03	15.89
25.00	27.00	0.49	9.50	2.67	1.13	6.87	2.14	0.93	0.89
27.00	29.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
29.00	31.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
31.00	33.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.00	37.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.00	39.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes : (a) 0% 50% 75% etc refer to degree of supplementary cooling
(b) Huntly assumed fully operational
(c) Residual waste heat from Huntly assumed 2/3 mixed at Rangiriri and 3/4 mixed at Clune Road
(d) Waste heat from proposed Waikato station assumed ½ mixed at outlet

Table 3.3 : Frequency distributions of plume temperatures for a 1000 MW station : waste heat discharge restricted by the '25^{o} rule'.

Low temperatures are not noticeably different from those prevailing under the Huntly rule : viz there is a marked reduction in frequency only for open-cycle cooling.

For the '25^{o} rule' the frequency of 23-25^{o}C plume temperatures, 11-16%, is slightly lower than the frequency in the Huntly plume, 16%, but both are markedly higher than the ambient frequency, 4%. There is an increase in the frequency of 25-27^{o}C plume temperatures: for open-cycle cooling to 7-9.5% and for 50% supplementary cooling to 2-2.7%, from 1% in the Huntly plume and 0.5% under ambient conditions.

3.3 Plume heating and cooling rates

Section 3.2 describes the frequency of 'average' plume temperatures. This section investigates how plume temperatures vary with distance from the outfall and estimates heating and cooling rates.

One possibility for cooling water discharge is via a sub-surface diffuser, discharging near mid-channel in order to minimise plume impingement on the littoral zones. In the calculations described below the diffuser is arbitrarily assumed : to have 40 ports located at 2 m centres each capable of discharging 1 $m^3.s^{-1}$ parallel with the river flow at a port velocity of 3 $m.s^{-1}$; and to be near mid-channel. Further calculations and/or field tests would be essential to optimise the design of such a diffuser. Results discussed here, however, illustrate the mixing patterns and range of temperatures possible for such a diffuser. Figure 3 shows the mixing zones below such a diffuser.

Jet region

Close to the diffuser, in Zone 1, the discharge was assumed to behave like

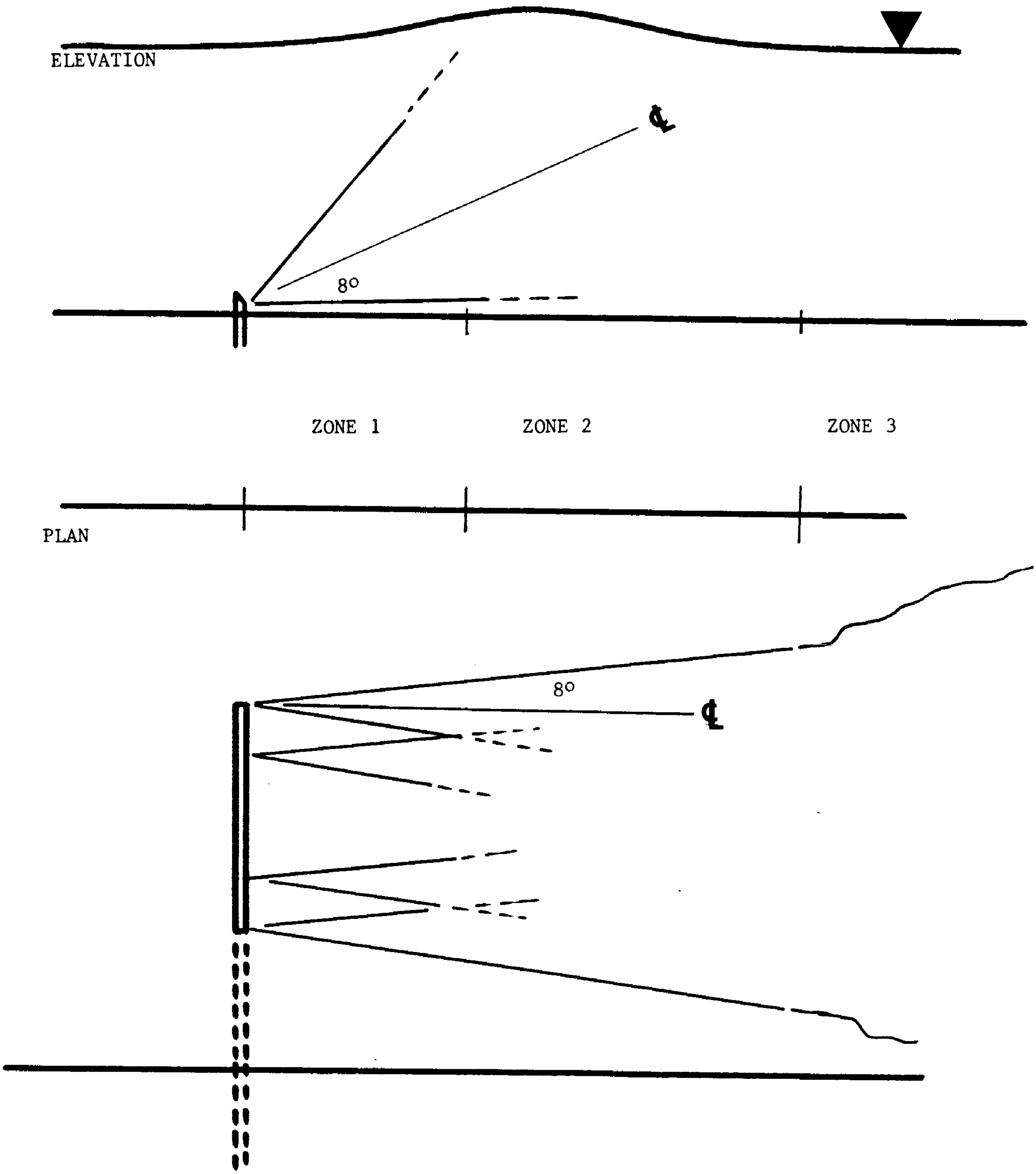


FIGURE 3 : Schematic of mixing below a diffuser.

a series of simple jets. Using well-known formulae (Fischer _et al._ 1979) estimates were made of the times taken for a jet to increase in diameter to 2 m (the maximum channel depth), and for the maximum jet velocity to decrease to 10% of the port velocity. The former approximates the time for the jets to coalesce and impinge on the surface : the latter the point where the jet vanishes.

For estimating the initial dilution, in Zone 1, the standard jet formulae cannot be used because the close proximity to each jet of the channel bed, the water surface and other jets reduces the amount of ambient river water available for entrainment and causes considerable re-entrainment of hot water (Jirka and Harlemann 1973). Indeed a complete analytical solution to this problem is not available. Jirka and Harlemann (1973) discuss dilutions at the downstream end of a jet (i.e. near the beginning of Zone 3) but not dilutions at various points within a plume. Accordingly a heuristic estimate of dilution was made by assuming that the discharge per unit width remains constant across the channel everywhere in the jet region and applying continuity. For example for a flow of 160 m^3s^{-1} and channel width of 200 m, 64 m^3s^{-1} would cross an 80 m wide diffuser; comprising 40 m^3s^{-1} of cooling water and 24 m^3s^{-1} of entrained river water. This almost certainly furnishes an underestimate of initial dilution since in a very strong cross flow some 48 m^3s^{-1} would cross the diffuser and the jet momentum would accelerate and entrain additional river water (Adams, 1972, cited and Jirka and Harlemann, 1973). At the downstream end of the jet this approach becomes more accurate provided the plume width is known. It would be advisable to investigate plume dynamics more fully for particular sites and cooling water flows.

Dispersion region

Below the jet region, in Zone 3 the discharge was assumed fully-mixed vertically and its transverse spreading was assumed to follow the classical Fickian model for a passive pollutant. A notional point source was located someway upstream from the actual diffuser which produced the same average temperature estimated at the downstream end of the jet region. At nominated points downstream the maximum plume temperature, T_m, was estimated from nomograph solutions to the problem of the continuous point source in the centre of a uniform channel (Rutherford, 1981). The 'average' plume temperature, T_{av}, was

$$T_{av} = 0.75\ T_m \qquad (5)$$

where the edges of the plume are the points where the temperature is 0.3679 (1/e) times the maximum temperature. This analysis neglects any buoyant spreading which may increase transverse mixing rates just below the jet region.

The transverse dispersion coefficient, D_z, in the Waikato River is about 0.10 $m^2.s^{-1}$ (Rutherford <u>et al.</u> 1980). For this D_z point sources released at 25% and 50% of the channel width (200 m) become fully mixed transversely (C_{max}/C_{av} <10%) some 28 hours (53 km) and 9 hours (18 km) below the point of discharge respectively (Rutherford 1981).

Rates of heating and cooling in the dispersion region

Neglecting the effects of lateral boundaries, the transverse spreading of vertically averaged temperature is given by

$$T(z,t) = \frac{H}{4.186\ dU \sqrt{4\pi Dt}} \exp\left(-\frac{z^2}{4Dt}\right) \qquad (6)$$

where z = transverse distance (m), t = time of travel below the injection point (sec), H = heat input (MW), d = mean depth (m), U = mean velocity ($m.s^{-1}$) and D = transverse dispersion coefficient ($m^2.s^{-1}$).

The rate of change of temperature with time has two stationary points corresponding to the maximum cooling rate (which occurs in the centre of the plume)

$$C = - \frac{0.5H}{4.186\ dUt\sqrt{4\pi Dt}} \qquad \text{at } z=0 \tag{7}$$

and the maximum heating rate (which occurs on the edges of the plume)

$$W = + \frac{0.2231H}{4.186\ dUt\sqrt{4\pi Dt}} \qquad \text{at } Z=\pm\sqrt{6Dt} \tag{8}$$

Equation (8) is valid for $\sqrt{6Dt} < B/2$ where B = channel width.

The rates of dispersive cooling given by equations (7) and (8) can be compared with the average rate of evaporative cooling, E_{av}, given by

$$E_{av} = -kT_{av} \tag{9}$$

where k = excess temperature decay rate which from preliminary analysis of Waikato river data to have a value of the order k = 0.03 hr^{-1}.

Figure 4 shows the temperatures experienced by river water and hence members of the drift community as they pass the power station and are either entrained in the cooling-water or mix with the effluent. River and cooling water flows are 160 and 40 $m^3.s^{-1}$ respectively and temperatures are expressed as multiples of the 'fully-mixed' value.

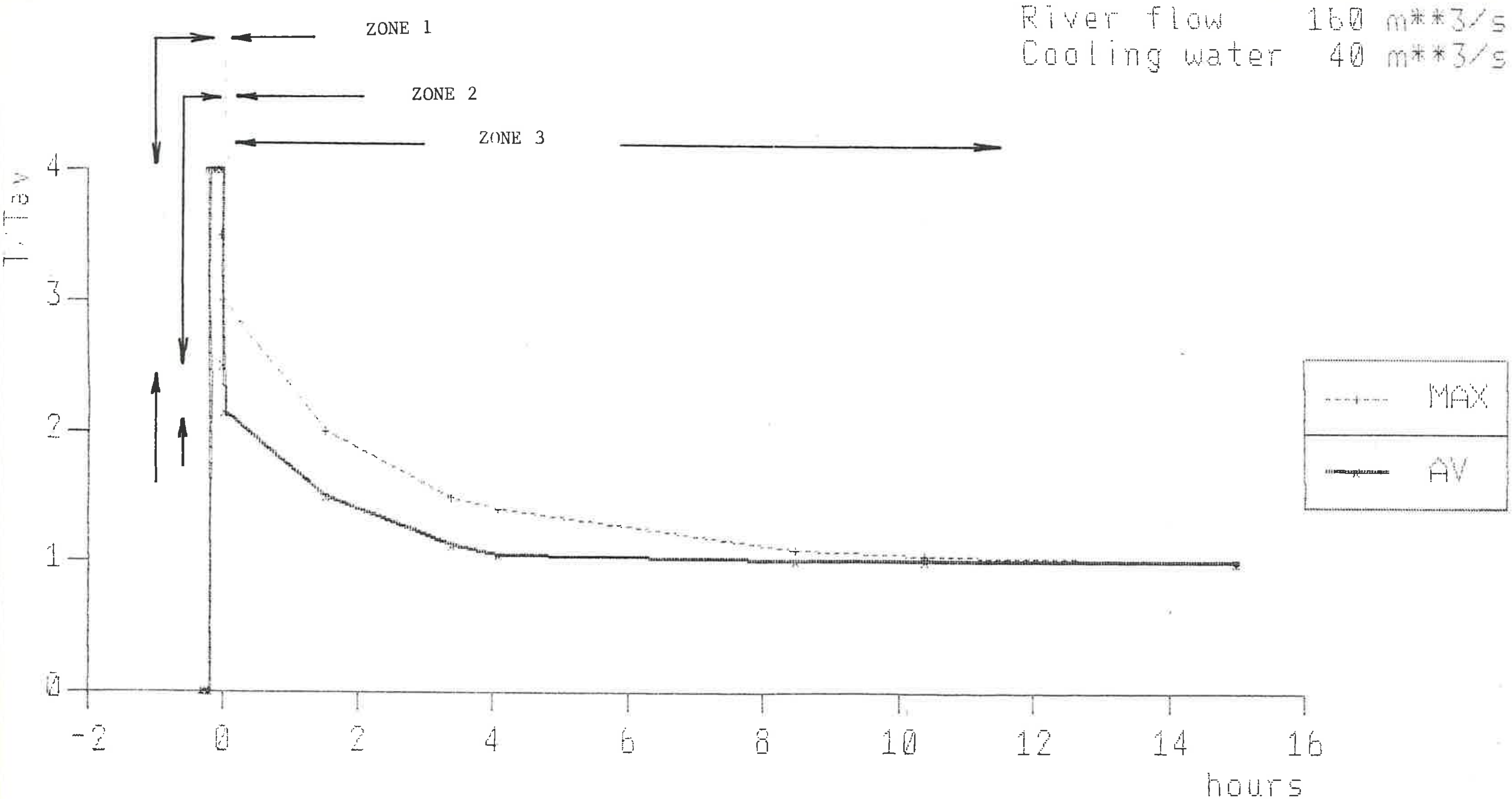


FIGURE 4 : Temperatures experienced by water passing the proposed Waikato power station : cooling water flow 40 m^3s^{-1}.

The following is an illustration of the use of Figure 4. Under the '25^{o} rule' (see above) for an ambient river temperature of $23^{o}C$, no restriction is placed on waste heat rejection at a flow of 160 m^3s^{-1}, about 1330 MW waste heat can be discharged* giving a fully mixed temperature rise of $+2^{o}C$, neglecting evaporative cooling. Members of the drift community entrained at the cooling-water and not successfully 'screened' out, are subject to rapid heating ($10^{o}C.min^{-1}$ or greater) in the heat-exchangers up to $+8^{o}C$ ($31^{o}C$). In addition to thermal shock, organisms are subject to pressure changes in the cooling water pumps.

Upon discharge to the river, the cooling water entrains ambient river water. This subjects those organisms which have passed through the power station to rapid cooling and those organisms entrained from the river near the outfall to rapid heating. Table 4 summarises heating and cooling rates.

*1330 MW is 5% higher than the 1275 MW adopted earlier but was chosen for convenience because it gives a fully-mixed temperature of exactly $+2^{o}C$ at a river flow of 160 m^3s^{-1}.

TABLE 4 : Summary of plume temperatures, heating and cooling rates

Zone	Time Since Discharge	Heating Rate	Cooling Rate	Excess Temperature		Average Evaporative Cooling Rate
	hour	$^oC.hour^{-1}$	$^oC.hour^{-1}$	max.^oC	av.^oC	$^oC.hour^{-1}$
1	0.0056	-1260- +900	-540	7.0	5.0	-
2	0.026	+206	-34	6.0	4.3	-0.12
3	0.026	+5.20	-12	5.6	4.2	-0.12
3	1.5	+0.69	-1.6	4	3	-0.09
3	3.4	+0.21	-0.47	3.6	2.7	-0.08
3	4.1	+0.16	-0.36	2.8	2.1	-0.06
3	8.5	(+0.054)	-0.120	2.2	2.0	-0.06
3	10.4	(+0.040)	-0.089	2.1	2.0	-0.06

Note

a River flow = 160 m^3s^{-1}

b Cooling water flow = 40 m^3s^{-1}

c Cooling water temperature = + 8^oC

d See text for details of diffuser.

A simple jet with a discharge of 1 m^3s^{-1} and a port velocity of 3 $m.s^{-1}$ discharging into stagnant water becomes fully developed within 6 m, attains a diameter of 2 m (maximum river depth) within 10 m (20 seconds) and the maximum velocity drops to 10% of the port velocity within 50 metres (95 seconds) (Fischer et al. 1979). A mean river velocity of 0.53 $m.s^{-1}$ is used to compute times from distances. These results are not directly applicable to the case of multiple jets discharging buoyant effluent into a swift shallow river : but may be taken as a first approximation. Thus for the proposed diffuser, Zone 1 (see Figure 3), in which the 40 individual jets are likely to coalesce and impinge on the surface, is likely to extend some 10 m below the outfall. Assuming that the discharge per unit width remains constant (0.8 $m^3.s^{-1}.m^{-1}$) across the diffuser, then the cooling water flow (initially 40 m^3s^{-1}) entrains 24 m^3s^{-1}) of river water into Zone 1 and drops in average temperature to + 5.0^oC (28^oC) in about 20s at a rate of about 9$^oC.min^{-1}$. Much of the entrained flow is sub-surface river water. Temperature in zone 1 is highly variable : theory suggesting a maximum of + 7.0^oC (30^oC) (1.4 times the average) (Fischer et al. 1979). Water entrained into zone 1 increases in temperature by +5-7^oC to 28-30^oC in about 20s (heating rate 15-21^oC min^{-1}). As mentioned above, dilution is Zone 1 may be somewhat higher than this. Assuming that the momentum of the river water flow dominates the problem, then 48 m^3s^{-1} of river water would be entrained into Zone 1 giving an average plume temperature of + 3.6^oC (26.6^oC) with a likely maximum of + 5.1^oC. If jet momentum is important, still more river water may be entrained into Zone 1 (Adams, 1972, cited in Jirka and Harlemann, 1973).

After impinging on the surface, the cooling water is likely to persist as a jet for about another 40 metres (75 seconds) by which time it spreads to at least 95 metres wide (average jet angle 8^o : Fischer et al. 1979). The area from 10-40 m below the diffuser is denoted Zone 2, see Figure 3. Again assuming that discharge per unit width remains constant then another 10 m^3s^{-1} of river water is entrained into Zone 2 from along the edges of the plume reducing the average temperature from $+5^oC$ to $+4.2^oC$ (27.2^oC) (cooling rate $0.56^oC.min^{-1}$). There is considerable mixing between the jets in Zone 2 and the plume becomes vertically homogeneous. Entrained water increases in temperature to $+4.2^oC$ (27.2^oC) at a rate of $3.4^oC.min^{-1}$. This entrainment is likely to contain a substantial proportion of surface water.

At distances greater than 40 m from the outfall, transverse spreading approximates a one-dimensional Fickian process. This is denoted Zone 3 see Figure 3. The fully mixed temperature ($+2^oC$, 25^oC) is attained 9 hours (18 km) below the outfall. (Note that in recent field studies below the Huntly Power Station (where cooling water was released over about 1/3 of the river width starting at the left bank) a small but detectable transverse temperature gradient was measured (0.10^oC over 250 m) some 30 km downstream.) Beyond 5 hours (9 km) from the outfall the dispersive cooling rate and the evaporative cooling rate are comparable (see Table 4). Note that in Zones 1 and 2 and in the upstream part of Zone 3 the dispersive heating and cooling rates are markedly higher than the evaporative cooling rate, viz cooling can be neglected.

For an ambient river temperature of 24^oC, the '25^o rule' restricts waste heat rejection to 665 MW and the fully-mixed temperature rise to $+1^oC$. If cooling-water flow is maintained at 40 $m^3.s^{-1}$ then Figure 4 can still be used to estimate plume temperatures but the rates of change of temperature are half those in Table 4. Thus temperature increases by +4^oC (to 28^oC) in the heat exchangers; decreases to +2.5-3.5^oC (26.5-27.5^oC) (rate 1.5-4.5$^oC.min^{-1}$) in Zone 1; and decreases to +2.2^oC (26.2^oC) (rate 0.24$^oC.min^{-1}$) in Zone 2. River water entrained into Zone 1 increases to +2.5-3.5^oC (rate 7.5-10.5$^oC.min^{-1}$) and water entrained into zone 2 increases to +2.2^oC (26.2^oC) (rate 1.8$^oC.min^{-1}$).

If 665 MW waste heat is rejected but cooling-water flow is reduced to 20 $m^3.s^{-1}$ then Figure 5 can be used to estimate plume temperatures. Temperature increases in the heat exchangers to +8^oC (32^oC). In Zone 1, at least 44 m^3s^{-1} of river water is entrained, reducing plume temperatures to +2.5-3.5^oC (26.5-27.5^oC) (rate 13.5-16.5$^oC.min^{-1}$) and heating entrained water at a rate of 7.5-10.5$^oC.min^{-1}$. In Zone 2, plume temperature reduces to +2.2^oC (26.2^oC) and in Zone 3 plume temperatures are similar to those in the previous example.

Table 5 summarises the estimated plume temperatures at low flow (160 m^3s^{-1}) for each of the three control rules outlined in Section 2.3. Note that in each calculation it is the sum of the residual Huntly heat flux and the Waikato heat flux that is constrained either by the control rule or the capacity of the power station(s). Note also that temperatures in Table 5 are averages in each zone, and maximum values may be greater by up to 1-2^oC. Under the 'Huntly rule' Waikato plume temperatures are unlikely to exceed 26-27^oC, under the '23^o rule' they are unlikely to exceed 27-28^oC, while under the '25^o rule' they are unlikely to exceed 29-30^oC for open-cycle cooling and the diffuser described.

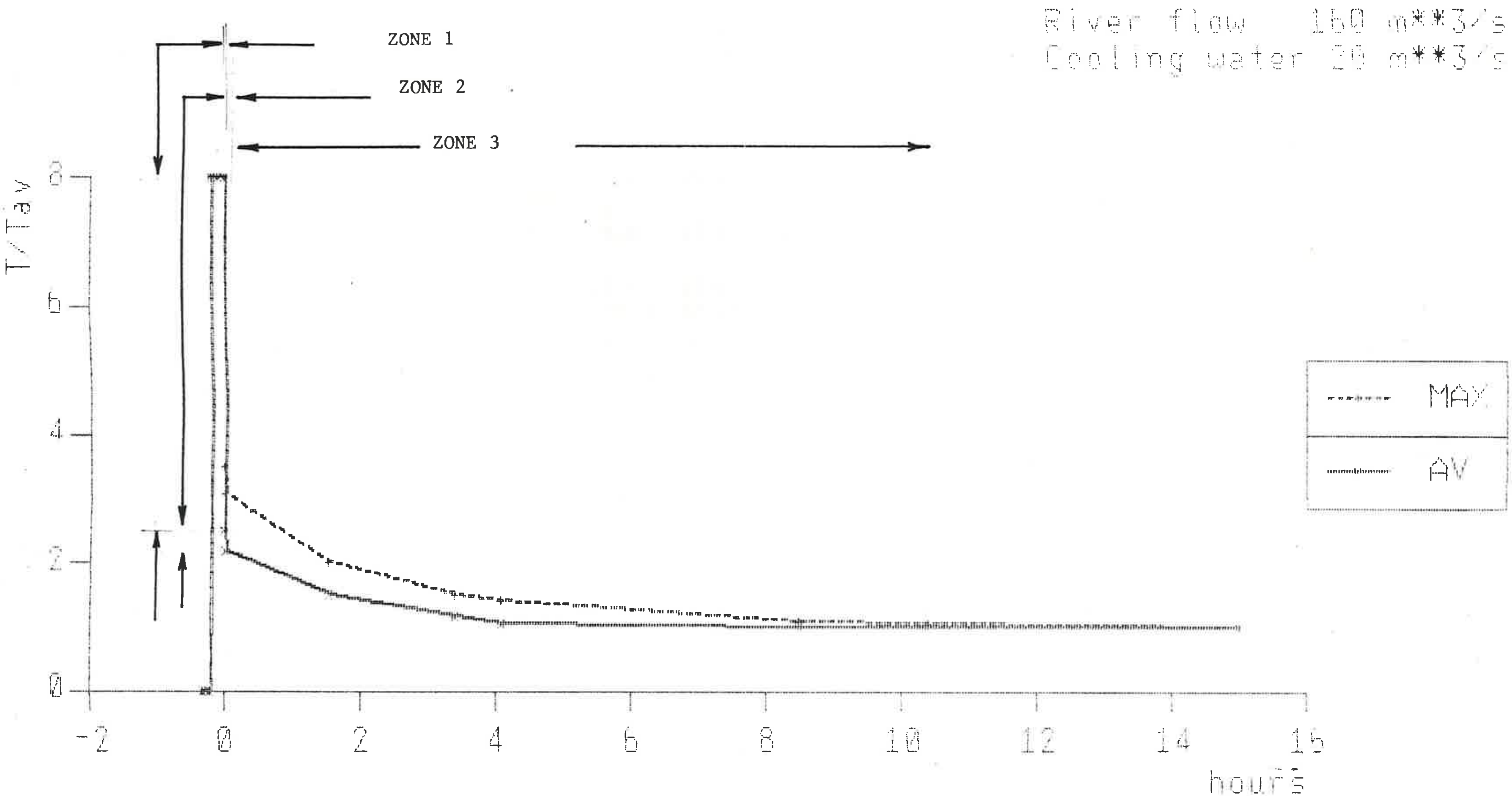


FIGURE 5 : Temperatures experienced by water passing the proposed Waikato power station : cooling water flow 20 m^3s^{-1}.

Ambient River	RANGIRI Huntly Plume Residue	Huntly rule Zone 1	 Zone 2	23° rule Zone 1	 Zone 2	25° rule Zone 1	 Zone 2	CLUNE ROAD Huntly Plume Residual	Huntly rule Zone 1	 Zone 2	23° rule Zone 1	 Zone 2	25° rule Zone 1	 Zone 2
18	19.9	20.7	20.6	24.9	24.1	24.9	24.1	19.3	20.9	20.7	24.3	23.5	24.3	23.5
19	20.7	21.4	21.3	25.7	24.9	25.7	24.9	20.1	21.5	21.3	25.1	24.3	25.1	24.3
20	21.5	22.1	22.0	26.5	25.7	26.5	25.7	21.0	22.2	22.1	26.0	25.2	26.0	25.2
21	22.2	22.7	22.6	25.2 (26.0)	24.8 (26.4)	27.2	26.4	21.8	22.8	22.7	25.3 (26.0)	24.8 (25.2)	26.8	26.0
22	23.0	23.4	23.4	23.9 (24.5)	23.8 (24.2)	28.0	27.2	22.6	23.4	23.3	23.9 (24.5)	23.7 (24.2)	27.6	26.8
23	23.7	24.0	23.9	-	-	27.5 (28.0)	27.0 (27.2)	23.5	24.1	24.0	-	-	27.6 (28.0)	27.1 (27.2)
24	24.5	24.7	24.7	-	-	26.2 (26.5)	26.0 (26.2)	24.3	24.7	24.7	-	-	26.2 (26.5)	25.9 (26.2)
25	25.2	25.3	25.3	-	-	-	-	25.2	25.4	25.4	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5 : Estimated plume temperatures at low flow, 160 m^3s^{-1}.

NOTES

1 Huntly residual plume temperatures estimated assuming 20% and 40% heat decay and 2/3 and 3/4 mixing at Rangiriri and Clune Road.
2 Bracketed temperatures are those for zero Huntly discharge where different.
3 Zones 1 and 2 defined in Figure and in the text.
4 Open cycle cooling.

3.4 Impact on the drift community

One of the river communities most at risk from operation of the power station is the drift community: notably larval fish which have limited ability to avoid entrainment and are fragile.

Organisms passing through the power station in the cooling water are subjected to thermal and pressure shock in the pumps, heat-exchangers and when discharged back into the river. It appears from studies at Meremere that phytoplankton can survive such shocks (Clayton, 1981). It is likely, however, that sensitive organisms such as larval and juvenile fish will be damaged. The maximum cooling-water flow, 40 m^3s^{-1}, is 25% of the summer low flow but in practice scheduled maintenance may reduce maximum cooling-water flow in summer to 30 m^3s^{-1}, about 20% of river flow. The major downstream migrations of larval fish appear to occur in winter when flow averages 350 m^3s^{-1} and maximum cooling-water flow represents about 10% of river flow. Thus we must contemplate damage to 10-20% of the drift community by passage through the power station unless the intakes can be designed to exclude such organisms.

At peak generation some 40 $m^3.s^{-1}$ of river water is entrained into the plume and subject to excess temperatures of + 4^oC or greater. It is not possible to quantify with confidence what damage (if any) will be sustained by members of the drift community entrained into the cooling water plume, because of a scarcity of data on temperature tolerances and the spatial distribution of larval fish. However, of the 40 m^3s^{-1} entrained, about half is predominantly sub-surface water thought to contain smaller numbers of larval fish than surface waters. The remaining 20 m^3s^{-1} represents 13% of low flow. For organisms concentrated in the littoral zone, entrainment in mid-channel may represent a smaller threat than for organisms distributed uniformly or concentrated in the thalweg. Overall it appears that drift organisms at greatest risk from the thermal plume would comprise at most 15% of a uniformly distributed community at low flow. This figure probably reduces to about 10% at higher river flows. Because of the scarcity of biological information it is not possible at present to quantify precisely the difference in impact on river biota of the three control rules. Work presently underway at the Waikato Valley Authority (M. Simons and M. Davenport pers. comm.), Fisheries Research Division (C. Mitchell pers. comm.) and University of Waikato (G. McLean, pers. comm.) is addressing this problem.

3.5 Plume Impingement on the Littoral Zone

Many river communities and upstream migrant juveniles are concentrated in the littoral zone (ie near the river banks) and would be threatened least by a cooling water discharge located near the mid-channel. Estimation of how far from a bank it is necessary to locate an outfall to avoid direct impingement is difficult because currents and dispersion rates near the banks of natural rivers and close to diffusers are poorly understood. In the Lower Waikato River, two sets of dye tracer studies have been undertaken (Rutherford et al. 1980 and Gillman and Partners pers. comm) which, although dealing with small quantities of non-buoyant traces, allow an initial investigation of the problem,

Aerial photographs showed that two dye patches released about 50 m from the left and right banks at Fairfield Bridge, Hamilton did not impinge on the bank within 750 m : one released 25 m from the left bank impinged within 500 m and one released 20 m from the right bank was immediately swept into the bank. The channel was fairly uniform although on a slight right hand bend.

From bankside observations, dye patches released at 25 and 35 m from the right bank near Taupiri impinged on the bank within 50 m. The bulk of a dye release 50 m from the bank remained clear of the bank for at least 500 m downstream although a small patch drifted into the bank. For a release 75 m from the bank, no dye approached closer than 40 m at 500 m downstream. This reach was just upstream from a sharp left-hand bend and some currents towards the bank would be anticipated.

Overall it appears that an outfall would need to be at least 50 m from the bank to avoid impingement of largely undiluted cooling water on the littoral zone. This figure is tentative, and may be a substantially higher if the diffuser induces strong transverse flows. It should be optimised in a future study.

4. EFFECTS OF WASTE HEAT DISCHARGE ON WATER CHEMISTRY

4.1 Dissolved Oxygen

Temperature increases through the heat exchangers at both the Waikato and Huntly power stations will be of the order +8°C which would reduce the oxygen saturation concentration by 1.2 g.m^{-3} (14%) at an ambient temperature of 22°C and by 1.8 g.m^{-3} (16%) at 10°C. After mixing with 1/2 of the river flow, oxygen saturation concentrations in the 'plume' would be at most 1 g.m^{-3} (~10%) below ambient, and as the 'plume' mixed transversely and cooled this would decrease to less than 0.5 g.m^{-3} (~5%) at distances some tens of kilometres below the power station.

During summer low flows in the period 1973-1976 there was a maximum oxygen deficit in the Waikato River near Rangiriri of about 2 g.m^{-3} (Rutherford, 1979) resulting from the combined effects of effluent discharge further upstream. Reductions in saturation concentration would reduce this deficit to about 1 g.m^{-3} in the 'plume' and about 1.5 g.m^{-3} after complete mixing. The reaeration rate coefficient increases with temperature by about 10% in the plume and 5% after mixing. Overall there would be a reduction in reaeration rate of at most 50% in the plume and 20% after complete mixing.

Temperature rises would also increase the rate of bacterial breakdown of organic waste matter by about 15% and hence would increase the rate of consumption of oxygen in the river. The combined effect of reduced reaeration and increased consumption rates would be to cause an overall reduction of dissolved oxygen concentrations in the lower reaches of the river. However, on the basis of the extensive simulations made on the likely impact of the Huntly station (Rutherford, 1979), it was concluded that the size of any reduction would be small. Huntly is not yet fully operational and so there has been no real opportunity to check the simulations. Recent reductions in the quantities of effluent discharged to the river (WVA, unpublished) will have reduced respiration rates and oxygen deficits.

One area of potential concern about Huntly Power Station was the possibility that passage of water through the cooling water system could kill phytoplankton, thereby increasing the concentrations of bio-degradable organic matter in the water and aggravating DO depletion (Rutherford, 1979). Subsequent work by Clayton (1981) has indicated that phytoplankton were not damaged by passage through the cooling water system at the Meremere Thermal Power Station (where temperature rises are comparable to those at Huntly). There are no indications in studies done to date that the situation at Huntly is any different.

Thus on the basis of the available evidence it appears unlikely that operation of the power station will have a major impact on river dissolved oxygen concentrations.

4.2 pH

Slight reductions in CO_2 concentration (about 5%) could occur as a result of waste heat discharge. These would be expected to have only a very small effect on river pH given the buffering capacity of natural waters. Aquatic plant metabolism causes diurnal variations of pH very much larger than those likely to result from waste heat discharge.

4.3 Nitrogen

Nitrogen saturation concentrations are shown in Table 4.1 (Wilcock pers. comm.). In the cooling water, saturation concentration changes are likely of 2.5 $g.m^{-3}$ (15%) at $10^{o}C$ ambient and 1.9 $g.m^{-3}$ (13%) at $20^{o}C$ ambient. In the plume these changes would be reduced to about 1/2 and after complete mixing to about 1/4. The author is not competent to comment on the likely impact on fish encountering the cooling water of such changes of nitrogen solubility.

Temperature	Nitrogen Saturation Concentration
^{o}C	$g.m^{-3}$
10	18.3
15	16.5
20	15.1
25	18.9
30	12.8

Table 6 : Nitrogen saturation concentrations

4.4 Other Determinands

Increases in solubility of determinands such as heavy metals might be theoretically possible at higher temperatures. However, the changes in solubility associated with the likely temperature changes are very small, and will not result in conditions significantly outside the natural range. Thus it is difficult to see how waste heat discharge, controlled in a manner such as that described above, could pose a serious environmental threat.

Note that this assessment does not consider the potential impact of chemicals which may find their way into the cooling water for example from boiler cleaning operations, dosing with biocides, ash supernatant etc. It is understood that the effect discharge of such chemicals might have is being discussed elsewhere.

5 CONCLUSIONS

Simulations were made of fully mixed river temperatures and plume temperatures likely as a result of waste heat discharge from the Huntly and the proposed Waikato Power Stations. Measured river temperatures and flows for the eight year period 1973-1980 provided the basic data. Two different sites, three levels of supplementary cooling, and three alternative control rules were simulated.

The '23^{o} rule' results in less power foregone than the 'Huntly rule' only in the case of a 1000 MW station using open cycle cooling : for 50% and 75% supplementary cooling the 'Huntly rule' gives similar or lower figures. For the '25^{o} rule' the power forgone is almost negligible (0.7% operational capacity) even for open-cycle cooling. Note that it is assumed that one unit (250 MW) will always be down for scheduled maintenance during the summer.

Temperature frequency distributions are changed least by the 'Huntly rule' from those likely to occur below Huntly. For open-cycle and 50% cooling the '23^{o} rule' increases the frequency of fully-mixed temperatures in the range 21-23^{o}C by 2-5% while the '25^{o} rule' increases the frequency of 23-25^{o}C by 2-7% to three-four times ambient frequency. The temperature frequency distributions are affected most by a station at Rangiriri operating on open cycle cooling : for a station at Clune Road using supplementary cooling and either the '23^{o} rule' or 'Huntly rule' the distributions will be little different from below Huntly.

Residual waste heat from Huntly is unlikely to be fully mixed across the river width at any site although the degree of mixing increases downstream. However, there is likely to be substantial overlap between the Huntly and Waikato plumes. If waste heat discharge from the Waikato Station is restricted by the 'Huntly rule' and initial mixing is with about ½ the flow then the combined plume temperatures at the Waikato station will not exceed those at the Huntly Power Station. For open-cycle cooling with the '23^{o} rule' there will be a substantial increase in frequency of 23-25^{o}C to 18-23% compared with 16% at Huntly and 4% ambient. For the '25^{o} rule' there will be a substantial increase in frequency to 25-27^{o}C temperatures for open-cycle, 7-10%, and 50% supplementary cooling, 2-3%, compared with 1% in the Huntly plume and 0.5% under ambient conditions.

10-20% of the drift community (notably larval smelt and galaxiids) are at risk from passage through the power station unless intakes can be designed to exclude them. In addition another 10-15% may be threatened by entrainment in the plume although it is very difficult to quantify this precisely because of a scarcity of data on temperature tolerances and spatial distribution of the organisms concerned. This scarcity of data also makes it difficult to quantify precisely the impact on biota of alternative control rules. Work currently underway at Waikato Valley Authority, Fisheries Research Division and the University of Waikato should provide valuable information, although a complete quantification of impacts may never be attainable.

The threat to upstream migrating juveniles (elvers and whitebait) would be minimised by a sub-surface diffuser located of the order 50 metres from the nearest bank. This would also least threaten resident predominantly littoral communities. Further work is desirable to optimise diffuser location and design.

Waste heat discharge will reduce dissolved oxygen concentrations and reaeration rates in the lower Waikato River but the impact is likely to be small. Nitrogen saturation could change by a maximum of 15% in the cooling water, about 7% in the plume and less than 5% after complete mixing. The author is not competent to assess the impact of such changes on fish. Changes in pH are also likely to be very small compared with natural diurnal changes. It is hard to envisage waste heat discharge alone significantly affecting concentrations of determinands such as heavy metals.

No attempt has been made here to assess the impact of chemical discharges such as boiler cleaning compounds, ash supernatant, biocides (eg from supplementary-cooling systems) or storm runoff : although each of these may pose a threat to river biota either separately or synergistically with temperature.

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