THERMAL MAPPING OF THE BLOWDOWN DISCHARGE FROM CARROLL COUNTY POWER STATION

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I. INTRODUCTION

This report is a supplement to COOLING-WATER-INTAKE AND BLOWDOWN-DISCHARGE STUDY FOR CARROLL COUNTY POWER STATION, PHASE II, submitted to Commonwealth Edison Company, May 1978. The report provides a thermal mapping of the blowdown discharge quantifying the areal extent of the thermal impact on the Mississippi River.

The projected discharge structure includes a buried, 36-in. diameter main line extending 150 ft into the nearshore channel. The heated water is discharged in the form of a jet into the river through a 46 ft long, 36-in. diameter extension of the main line. The extension, which is connected to the main line by a 90° elbow, points downstream at an angle of 15° with the bottom of the river, cutting through the bottom approximately 20 ft south of the main line (SL's Drawing No. CS-74 of June 7, 1978). The water depth at the point of discharge is 15 ft. The anticipated maximum blowdown is between 10 and 30 cfs. Conservatively, 60 cfs is considered, too.

II. STABILITY OF THE FLOW FIELD

The rate at which the blowdown discharge is diluted depends on the stability of the flow field in the discharge area, especially the density gradient across the interface between the heated water and the ambient river water. If the density difference is large, turbulent spreading is hampered, and the heated water will rise to the surface of the ambient water and form a stable plume which will drift downstream with little reduction in temperature.

The stability of the flow field is reduced when the heated water is discharged in the form of a jet. The stability may be determined on the basis of Jirka and Harleman's findings (Ref. 1) on the stability of a two-dimensional buoyant slot jet in stagnant shallow water. They found that for a certain combination of H/L (a measure of shallowness) and F_s (a measure of the buoyancy of the discharge) no stably stratified flow is possible near the jet. The stability criterion given by Jirka and Harleman for a horizontal slot buoyant jet in stagnant water is

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$$H/L > 1.5\ F_s^{4/3} \qquad (1)$$

where

H = water depth

L = equivalent slot jet width = $\pi D^2/(4s)$

D = nozzle diameter

s = nozzle (or port) spacing

F_s = densimetric Froude number = $U_s/\sqrt{g(\Delta\rho_o/\rho_a)L}$

U_s = equivalent slot jet velocity

$\Delta\rho_o$ = initial density difference

ρ_a = ambient water density

For a discharge of 10 to 30 cfs through one 36-in. diameter diffuser port at a depth of 11.5 ft, $H/L \cong 4$ while $1.5\ F_s^{4/5}$ is between 13 and 190; i.e., $H/L \ll 1.5\ F_s^{4/3}$. It is seen that for all realistic combinations of port diameter and spacing, the downstream flow field will be highly unstable. Intensive vertical mixing will be created and consequently the temperature profile downstream will be vertically homogeneous.

III. MATHEMATICAL MODEL

Gaussian profiles were assumed for all transverse distributions of excess temperature and velocity:

$$\Delta T = \Delta T_c \exp\ (-\ n^2/B^2) \qquad (2)$$

$$\Delta U = \Delta U_c \exp\ (-\ n^2/B^2) \qquad (3)$$

where

ΔT = temperature rise above ambient water temperature

ΔT_c = temperature rise above ambient water temperature at the centerline of the jet

ΔU = velocity increase above the velocity of the ambient water

ΔU_c = velocity increase above the velocity of the ambient water at the centerline of the jet

B = half width of jet, $B = \sigma_n \sqrt{2}$

σ_n = standard deviation of transverse temperature and excess-velocity distribution

It was further assumed that the jet behavior could be described by the following two-dimensional conservation equations:

Volume conservation:

$$\frac{d}{dx} \int_A \Delta U dA = 2E_o H \Delta U_c \tag{4}$$

Momentum conservation:

$$\frac{d}{dx} \int_A \rho (\Delta U)^2 \, dA = 0 \tag{5}$$

Heat conservation:

$$\frac{d}{dx} \int_A c\rho \, (\Delta U)(\Delta T) \, dA = 0 \tag{6}$$

where

E_o = entrainment coefficient

A = cross-sectional area of jet; $dA = Hdn$

x = coordinate in downstream direction

n = coordinate normal to x

H = depth of water

c = specific heat

Eq. (4) implies that the temperature reduction is brought about by inflow of ambient water across the jet boundary at a rate proportional to the centerline velocity, ΔU_c. Eq. (5) says that the momentum flux remains constant, which is true only when shear and drag forces on the jet can be neglected. Eq. (6) expresses that the rate of change of excess heat flux is zero, which implies that the rate of heat transfer to the atmosphere can be neglected.

By substituting Eq. 3 into Eqs. 4 and 5 it is seen that

$$\frac{dB}{dx} = \frac{4}{\sqrt{\pi}} E_o \tag{7}$$

or

$$B = B_o + B_1 x \tag{8}$$

where $B_1 = 4E_o/\sqrt{\pi}$. In the model studies of the cooling water discharge from the Quad-Cities Nuclear Power Station, Parr and Sayre (Ref. 2) found that the standard deviation of the transverse temperature distributions could be described by

$$\sigma \; [illegible] + 0.086 \, x$$

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or

$$B = \sigma_n \sqrt{2} = 0.? \, B + 0.12 \, x \tag{9}$$

That is, $B_o = 0.7\ D$ and $B_1 = 0.12$. This result was used in the present study.

Eq. (6) may be written

$$\int_A (\Delta U)(\Delta T)\, dA = \text{constant} = Q_o \Delta T_o \qquad (10)$$

where Q_o = rate of discharge

ΔT_o = initial temperature difference between the discharge and the ambient water (=ΔT at x=0)

Substituting Eqs. 2 and 3 into Eq. 10 yields

$$(\Delta T_c/\Delta T_o)^2 = \sqrt{2\pi}\ D^2/(4HB) \qquad (11)$$

This equation, together with Eqs. 2 and 9, was used to predict the temperature distribution downstream from the discharge structure.

IV. RESULTS

The results are presented in Figure 2 and 3 and in Table 1. Figure 2 shows four contour lines of $\Delta T/\Delta T_o$; Table 1 lists the area within each contour line. The area within any contour line may be estimated from Figure 3. Example: If the initial temperature rise, ΔT_o, is 20°F (which is the projected maximum value of ΔT_o), the area surrounded by the contour line $\Delta T/\Delta T_o = 0.1$ is the area in which the temperature is expected to exceed the ambient water temperature by more than 2°F. The area covers approximately 5000 ft^2. Outside this area the excess temperatures are expected to be lower than 2°F.

REFERENCES

1. Jirka, G.H., and Harleman, D.R.F., "The Mechanics of Submerged Multiport Diffusers for Buoyant Discharges in Shallow Water", MIT Parsons Laboratory for Water Resources and Hydrodynamics, Technical Report No. 169, March 1973.

2. Parr, A.D., and Sayre, W.W., "Prototype and Model Studies of the Diffuser-Pipe System for Discharging Condenser Cooling Water at the Quad-Cities Nuclear Power Station," IIHR Report No. 204, The University of Iowa, June 1977.

Table 1 Area within contour lines for excess temperatures

Contour Line of $\Delta T/\Delta T_o$	Area Within Contour Line in Ft^2	Area Within Contour Line in Acres
0.20	200	0.005
0.15	1200	0.028
0.10	5000	0.115

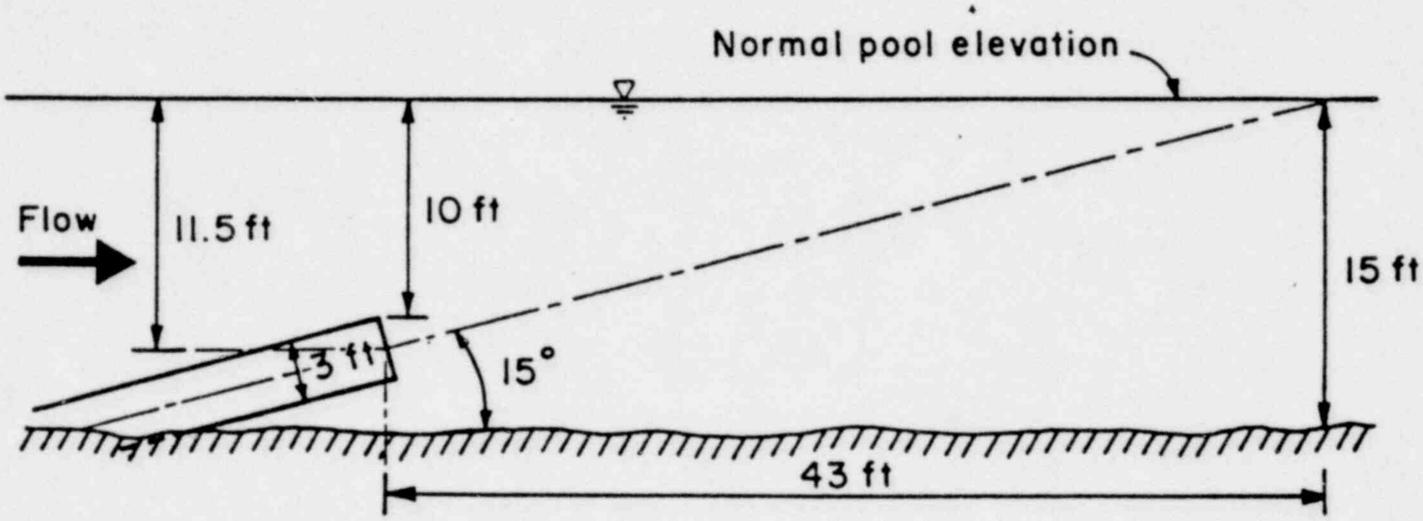

Figure 1. Schematic of discharge situation

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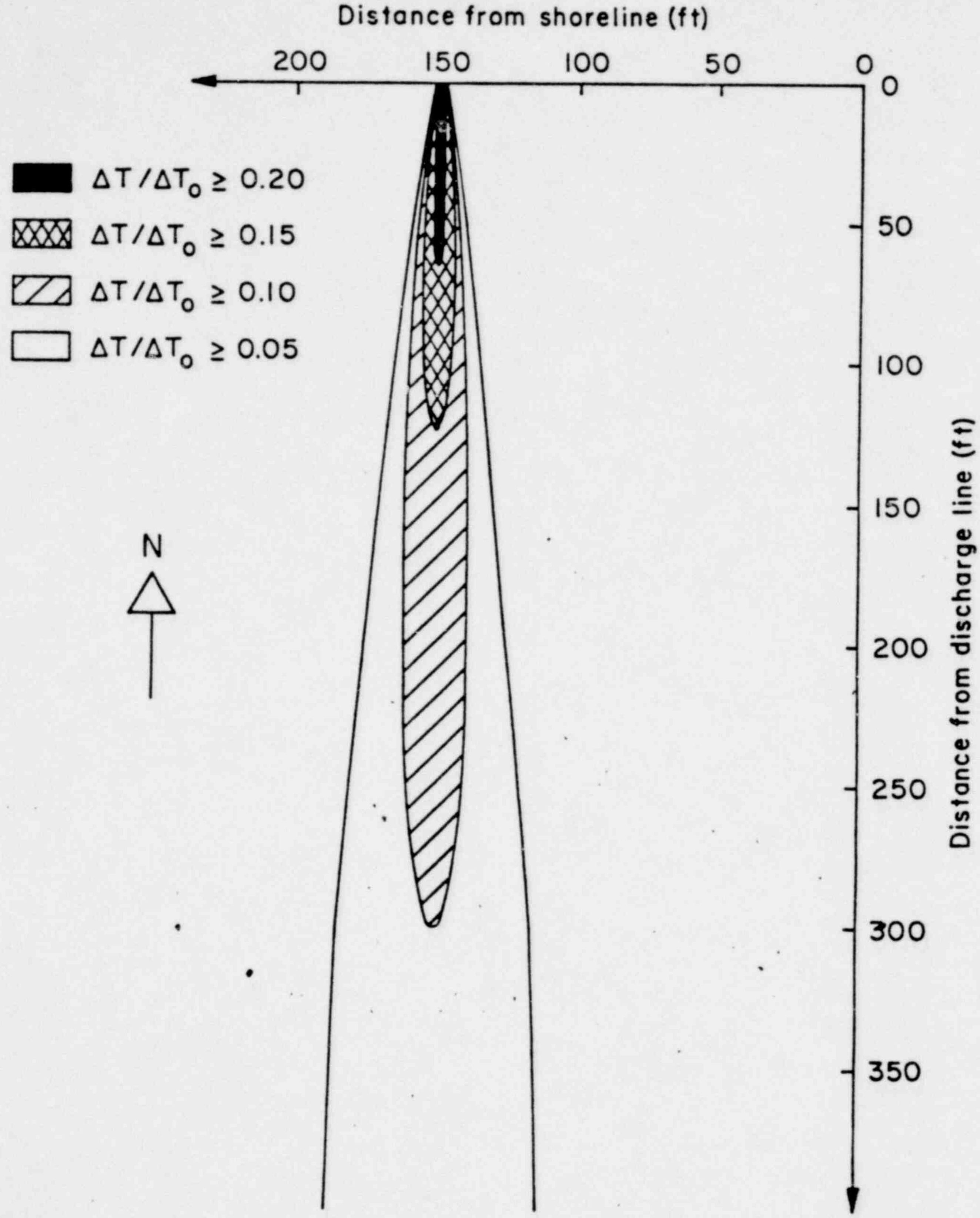

Figure 2. Contour lines for excess temperatures

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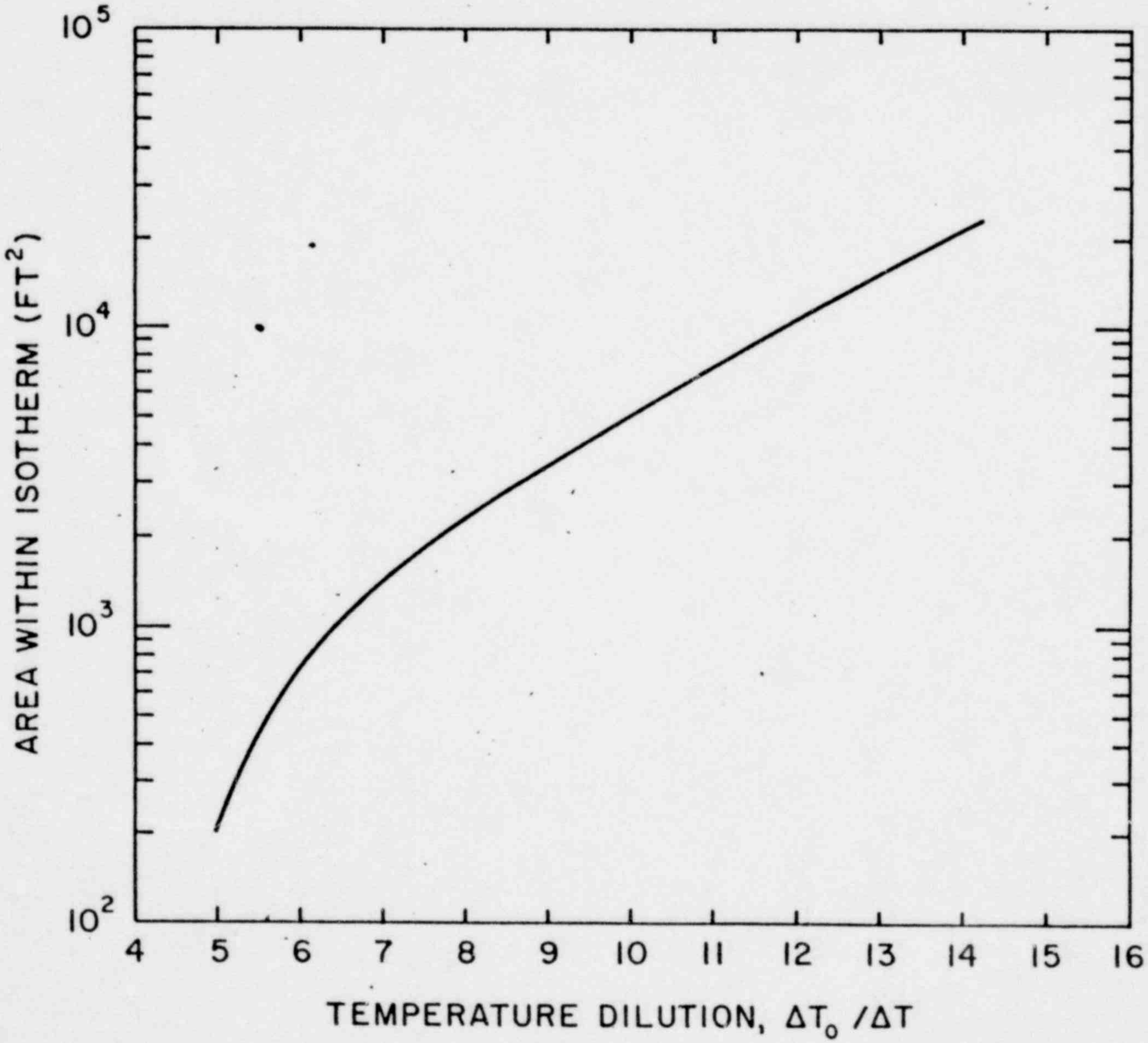

Figure 3. Area within contour lines for excess temperatures

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