AR-1184

MERRIMACK RIVER
THERMAL DILUTION STUDY
1978

Prepared for

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Manchester, New Hampshire

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April 1978

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I. INTRODUCTION

The Public Service Company of New Hampshire (PSCO) currently operates power spray modules in the discharge canal of the Merrimack generating station in Bow. These modules spray heated water from the discharge canal into the air to increase evaporative cooling and thus lower the temperature of the discharge prior to its entrance into the Merrimack River.

There may be periods, however, when the power spray modules are not necessary, and the power they consume could be available for other purposes. This case would most likely occur during periods of high river flow when turbulent mixing of the thermal plume with the river water may reduce plume temperatures to within guidelines specified in the NPDES permit. PSCO, therefore, at the request of the New Hampshire Water Supply and Pollution Control Commission, is developing guidelines based on river flows and temperatures to determine when operation of the power spray modules is necessary.

This study was designed to specify those guidelines by using a series of simple, theoretical calculations that would provide a reasonably accurate estimate of thermal dilution by mixing. The desired end-product of this study is an estimate of the minimum river discharge necessary to maintain river temperatures within 5°F of ambient when the ambient temperature is <68°F, and within 1°F when ambient >68°F.

II. ASSUMPTIONS AND CALCULATIONS

For purposes of this study, temperature is considered to be a conservative constituent. Neumann and Pierson (1966) define conservative constituents as "physical, chemical, or biological properties of sea water that are not altered by external or internal processes which may either create or destroy the amount or concentration of such constituents or properties in a given volume of water. The concentration of a conservative property may vary locally and with time as a result of transport or currents and diffusion properties." The salt content of sea water is a typical example of a conservative constituent. By assuming that temperature will act conservatively, we are ignoring the atmospheric effects; all heat being discharged from the generation station is considered to enter the Merrimack River. This provides a worst-case condition and allows a conservative estimate of river flows needed to dilute the thermal effluent.

Two other worst-case conditions are also assumed. First, the Merrimack Station's output is assigned a value of 200,000 GPM (445.6 cfs), which represents the maximum circulating capacity of Unit I (60,000 GPM) and Unit II (140,000 GPM). Second, the maximum Δt induced in the generating station's cooling water is assigned a value of 23°F (12.8°C); this figure was obtained from PSCoNH engineers (Wayne Nelson, PSCoNH, personal comm.). Both assumptions are worst-case conditions, and lead to conservative estimates of minimum required dilution flows.

The distribution of a conservative property in a mixture is dependent on: 1) its concentration in the original volumes to be combined, and 2) the magnitude of the volumes to be mixed. This can be expressed for temperature as:

$$T_R(D_R - D_P) + T_P D_P = T_{mix} D_R \qquad (1)$$

Where: D_R = River discharge (cfs)

D_P = Plant discharge

T_R = River temperature

T_P = Plant discharge temperature

T_{mix} = Temperature of the river below the mixing zone

Algebraic rearrangement of equation 1 to solve for D_R yields equation 2:

$$D_R = \frac{D_P(T_R - T_P)}{(T_R - T_{mix})} \qquad (2)$$

Equation 2 holds true only when there is complete mixing of the thermal discharge (D_P) throughout the river's water column. To estimate the minimum river discharge that would provide total mixing of the heated effluent, thermal profiles measured from 1968 through 1977 were selected according to river discharge levels on the profiling date (Normandeau, 1969; NAI, 1969; 1971; 1972; 1973; 1974; 1975; 1976; 1977). Only profiles measured while both Units I and II were operating were chosen. Using an electronic planimeter, the area of the river cross-sectional profile at Station S-4 (mixing zone) and the area of the thermal plume were calculated. In this case, the thermal plume is defined as all water warmer than ambient river water. The ratio of the plume area to the total river cross-sectional area was plotted as a function of river discharge (Figure 1). At discharges greater than 2500 cfs, the entire water column was utilized for mixing.

By applying the worst-case Δt ($T_P - T_R = 23°F$) and plant discharge ($D_P = 445.6$ cfs), the solution to equation 2 is not influenced by ambient temperature. Under the conditions that $\Delta t = T_{mix} - T_R \leq 1°F$ when ambient river temperature is >68°F, the discharge required is 10248 cfs. When ambient river temperature <68°F, the permit specifies a maximum $\Delta t = T_{mix} - T_R = 5°F$. Solving equation 2 under these conditions yields a minimum discharge of 2050 cfs which is less than the 2500 cfs required to maintain total mixing of the effluent. Because our data do not allow us to predict the final water temperature under conditions of non-

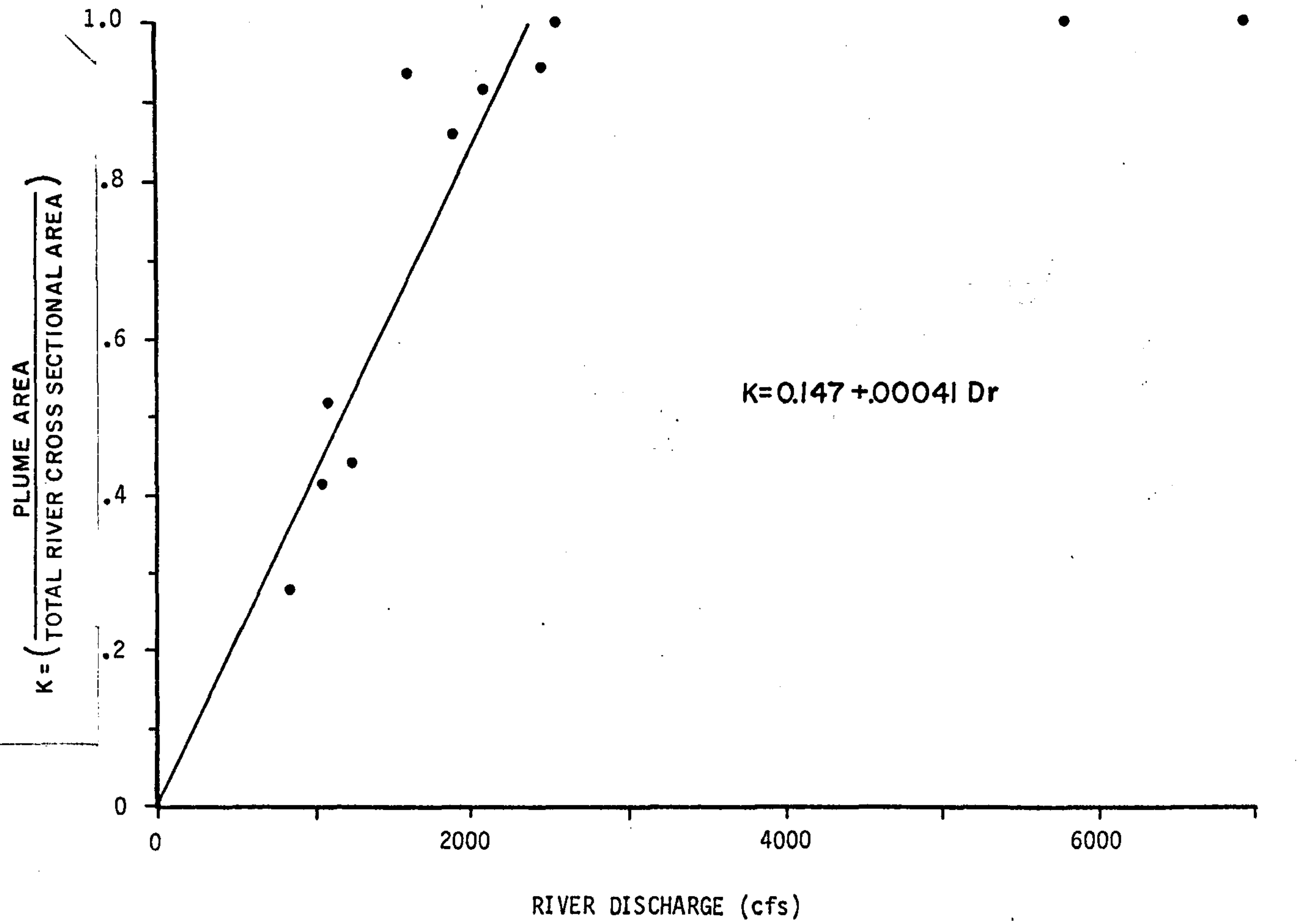

Figure 1. The ratio of thermal plume cross-sectional area to total river cross-sectional area (k) at Station S-4 as a function of river discharge (D_R). Merrimack River Thermal Dilution Study, 1978.

complete mixing, we have assigned 2500 cfs as a minimum river discharge necessary to maintain $\Delta t = 5°F$.

By solving Equation 2 for $(T_R - T_{mix})$ when the river discharge is 2500 cfs, we obtain an anticipated $\Delta t = 4.1°F$. This is 0.9°F lower than the permit standards. Therefore, the use of 2500 cfs as a minimum river discharge provides a conservative guideline for maintaining $\Delta t \leq 5°F$.

III. DISCUSSION AND APPLICATION

In practical terms, these figures can be used to determine, based on ambient water temperature and river discharge stage, when the power spray modules need to be operated. Figure 2 (based on the above calculations) shows the conditions of temperature and flow requiring operation of the power spray modules.

Figure 3 summarizes the mean monthly Merrimack River discharges and ambient temperatures from 1968 through 1977. These data were taken from the Merrimack River Monitoring Studies conducted by Normandeau Associates, Inc. From this figure, it is apparent that river temperatures normally exceed 68°F from June through September. In addition, river discharge is consistently less than the 10,248 cfs required to meet the permit conditions of $\Delta t \leq 1°F$ unless the power spray modules are used for cooling the thermal discharge. Therefore, during the summer, power spray modules will be required. However, in April, May, October and November, ambient river temperatures are generally <68°F, and flows are normally >2500 cfs. Under these conditions, the power spray modules may not be needed to provide supplemental cooling. This should hold true consistently during April and May when the flows are much higher than 2500 cfs, but depending on precipitation, river discharge in the fall may not exceed the $\Delta t = 5°F$ critical flow minimum of 2500 cfs. If this occurs, the power spray modules would be needed to cool the Merrimack Station's thermal effluent to within permit standards.

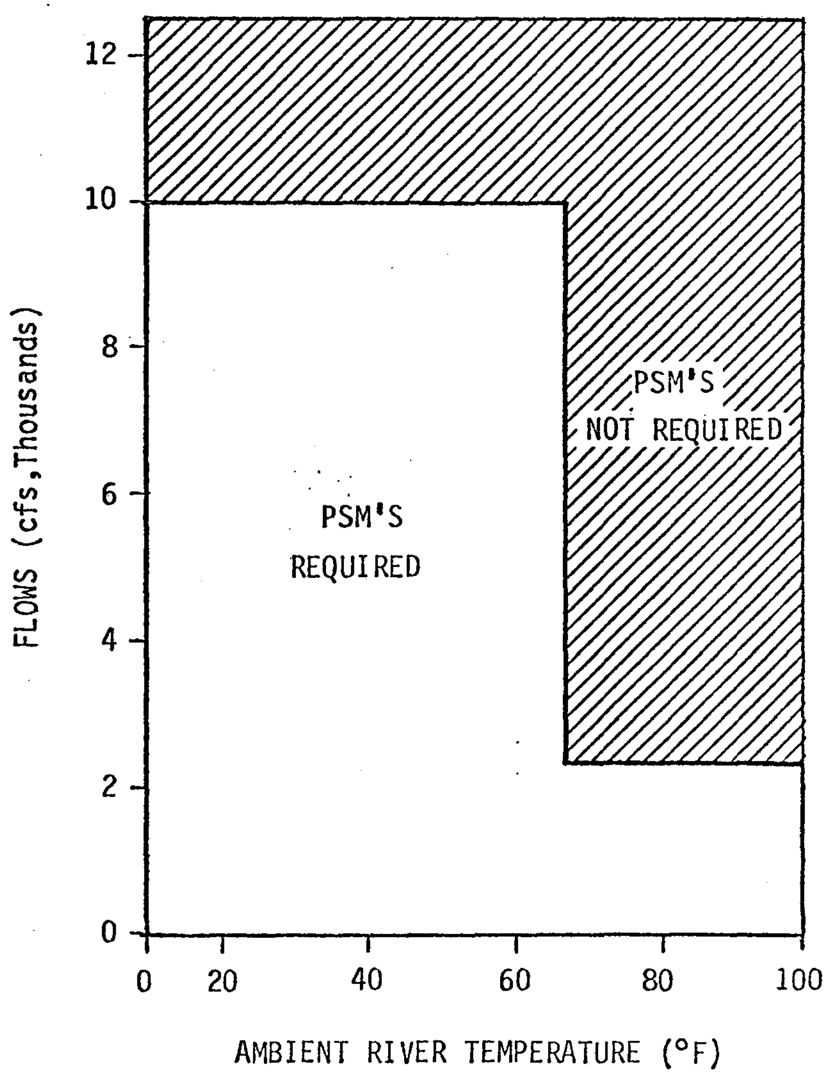

Figure 2. Power spray module (PSM) operation as related ambient temperature and river discharge conditions. Merrimack River Thermal Dilution Study, 1978.

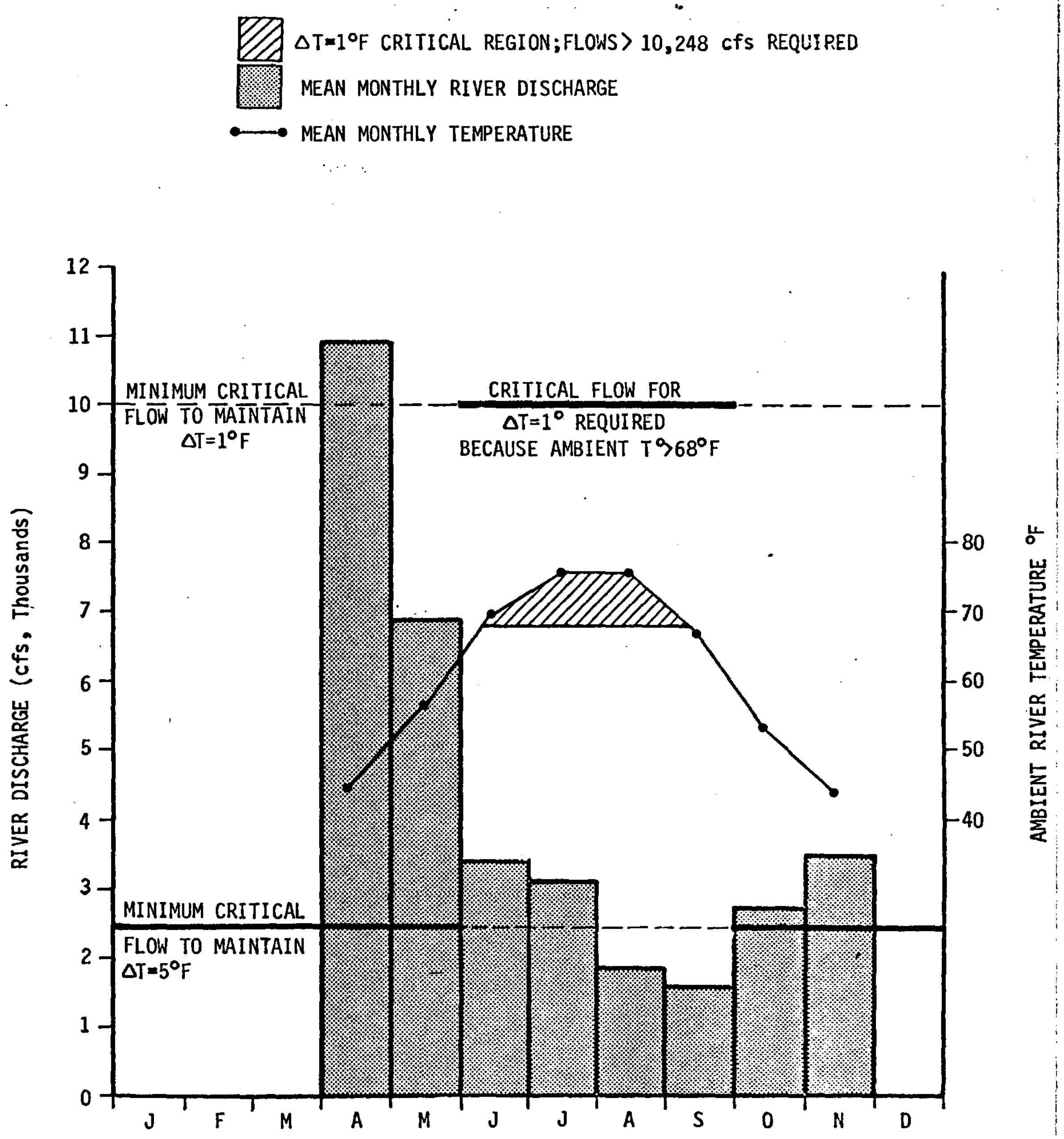

Figure 3. Mean monthly river discharge and ambient water temperature from 1968 to 1977. Merrimack River Thermal Dilution Study, 1978.

IV. SUMMARY

By assuming a worst-case Merrimack Station output and Δt, the volume of river water required to dilute the heated effluent to a Δt specified within the station's NPDES permit was calculated. To maintain a Δt $\leq$ 5°F from ambient to the downstream boundary of the mixing zone (Station S-4), a minimum river discharge of 2500 cfs is required. When ambient temperature exceeds 68°F a Δt = 1°F is stipulated in the permit; this requires a minimum river discharge of 10,248 cfs.

Based on mean monthly temperatures and flows from 1968 to 1977, it appears that temperature/flow conditions require the operation of the power spray modules from June through September. During April, May, October, and November, the temperature/flow conditions would provide dilution of the thermal effluent, and operation of the power spray modules may not be necessary. If the modules are not used, however, the river discharge as well as ambient and mixing zone temperatures should be monitored to insure that baseline conditions are being maintained.

V. LITERATURE CITED

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